The Industrial LASER USER

association of industrial AILU laser users

Issue 13 November 1998

AILU honours Jim Wright, entrepreneur

The AILU 1998 award for outstanding contributions to the industrial use of lasers in the UK was presented to Dr Jim Wright MBE, who started one of the most successful Nd: YAG laser companies in the world and pioneered many industrial applications arising from those machines. Professor Bill Steen, AILU President, made the presentation at the members' meeting at the Rutherford Appleton Laboratory on 20 October 1998.

The award, a trophy sponsored by British Aerospace, was designed and built by Annie Hall, a London silversmith. The trophy is a pen with a Nd: YAG rod for a body, a gold nib and silver grip, mounted on a stand with a decorative laser engraved back plate made by Anne-Marie Carey of Liverpool University.

Presenting the award, Professor Steen reviewed Jim's extensive background in the laser business. 'Jim Wright is one of the leading pioneers of laser technology in the UK. His link with lasers began soon after the laser had been invented. At that time he was completing his PhD at Nottingham University in a group working on masers, the forerunner of lasers. On leaving the University in 1962 he was awarded a Civil Service research fellowship to work on lasers at the Signals Research and Development Establishment (SRDE) in Christchurch. Here he developed the first frequency multiplied lasers in the UK, which included the first Q-switching of Nd:glass lasers. Realising that his interests lay more with developing the technology and its applications than the pure research, he left the security of the Civil Service to join AEI Research Laboratories, a brave move. Whilst there he developed the first Nd:YAG lasers for military guidance applications. It was here that he met Ron Burbeck who ran the electronics group that provided the power source for Jim's YAG laser. In 1968, when GEC bought AEI and wanted to move the laser work to Wembley, Jim, Ron and several colleagues decided against the move and formed a branch of Laser Associates to manufacture the first commercial YAG lasers in the UK. However, concerns about the management at Laser Associates led Jim and Ron to resign and form JK Lasers Ltd at the beginning of 1972. Initially they made a high powered stroboscope, using a laser style water cooled flashtube and its associated power supply. Jim says this was because they couldn't afford laser rods. However, they soon developed and marketed their System 2000 range of pulsed lasers using ruby, YAG and glass laser rods.'

'Jim and Ron Burbeck built up their business in scientific and industrial lasers slowly and with much personal sacrifice. It is the story of many a successful business that success is related to energy and enthusiasm. By 1975 there were 11 people on the payroll producing one laser per month, by July 1982 there were 100 when the company merged with Lumonics of Canada to form one of the largest laser companies in the world. Within Lumonics Jim championed the development of the industrial laser business until his resignation from the company in 1988. He was awarded the MBE for his services to laser technology in the same year.'

Jim Wright is a designer and physicist, a man of outstanding intellect and leadership. He was also a greatly loved leader and few staff left his company. Although now retired, many of his protégés from JK Lasers continue to exert a major influence on the development of the industrial laser activity in the UK."'

Presentation of the 1998 AILU award by the President, Prof Bill Steen (left) to Dr Jim Wright MBE, for his outstanding contributions to the industrial use of lasers in the UK

In accepting the award Jim commented that the excellent review by Clive Ireland on the history of the development of YAG lasers, which had preceded the presentation, had evoked many memories from his career. In particular he noted that the first lasers he worked on were made with what was available and not with laser components as we know them today. Ruby laser rods were cut from crystals grown to produce watch bearings; mirrors were silver coatings on the ends of the rod; flashtubes were made by the local glass blower and the power supply was borrowed from the photographic studio. Such lasers could only be fired once every few minutes and frequently it was either the mirror, flashtube or power supply that went off rather than the laser! It was the frustration of trying to use such lasers for scientific measurements at SRDE, that made Jim realise that lasers would never be really useful unless they could be made to operate at higher repetition

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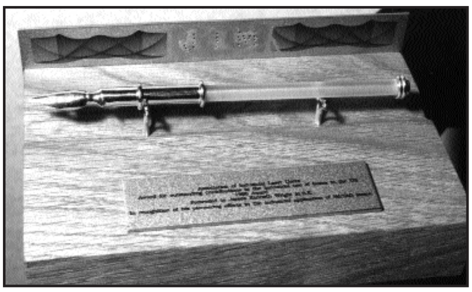


The trophy, sponsored by British Aerospace. The 'pen' has a Nd: YAG rod for a body, a gold nib and silver grip. It is mounted on a stand with a laser engraved back plate.

Letters to the editor

I would like to make a plea for a greater degree of balance in the presentation of laser materials processing applications to potential industrial users. More should be said about the safety aspects of laser use, and too much is often assumed about the reader's knowledge of the practical implications of a laser installation such as heat exchanger and extraction requirements, gas consumption and storage considerations, as well as issues of operator and personnel training.

When discussing these practical issues with potential clients I often hear words to the effect of 'well the man from (laser manufacturer) never mentioned this, and he must know what he is talking about – so you must be making a meal of it to get some work'.

Ignorance and confusion over the safety use of lasers owes much to the poor example set by some laser manufacturers and suppliers. For example, I came across a Nd:YAG laser marking system at a public exhibition where the rear guarding had been completely removed 'so that customers can see better', and when challenged the company representative said that 'the danger of YAG lasers was exaggerated'. He had worked with CO_2 lasers and 'they didn't need guarding, and a laser is a laser so what's the problem?'

Steve Ainsworth
Ainsworth Consultants

INDUSTRIAL RESEARCH

After working for almost ten years in applied research at different places in universities and industry, I was astonished how research leaders were defending blue sky research funding in the panel discussion at the end of the Tech-Focus II meeting at CLEO/Europe at Glasgow in September this year. Especially in a session aiming at exchanging ideas for industrial applications of lasers.

What is blue sky research? We could define blue sky research as basic research without any imaginable application but heading for better understanding and better knowledge. This is in contradiction with the industrial manufacturing objective of the Tech-Focus II session.

Most of the key innovations in industrial manufacturing have been carried out by industrial funded research groups or by industrial research labs in the last decades. Times have changed in the sense that industry is less motivated to finance long term high risk projects, and a strong decrease in basic research projects carried out in industry is obvious.

To circumvent the resulting decrease of technological innovations the governments of many countries created and finance international/european research pools, tackling problems over periods of several years. Many results from these studies are more or less far away from the main stream idea and still scientifically interesting. This means that some academic research liberty is intrinsic in these projects (light blue sky research).

Real blue sky research is still possible, using installations built for funded projects and run by (unpaid) students supervised by Ph. D. students, combining teaching, education and research. As for these projects there is less time pressure compared to applied and industrially funded research it should satisfy the blue sky researchers.

Dr. Patrik Hoffmann
Département de Microtechnique
Swiss Federal Institute of Technology, Lausanne

Seeking to make distinctions - particularly relating to perceptions of importance or quality - between basic, strategic and applied research is such an old fashioned and sterile argument, where people on both sides tend to take up rather entrenched positions. It seems to me that in practice, effective research does not usually occur as distinct activities which can be clearly delineated with labels such as fundamental or applied, but rather it exists as a near-continuous broad spectrum with feedback loops.

The process of generating new products and new processes which contribute to the delivery of industrial competitive advantage depends both on careful iterative R&D - but also (and sometimes much more significantly) on step-function changes where whole new technologies are introduced based on new concepts. Both types of research are important. Without a measure of basic (even curiosity-driven) research, might it not be that the world would now now be stuck with incredibly well-developed candles, rather that electrically-driven lighting and . . . . lasers?

A balance is needed - but companies and universities necessarily have different though hopefully not entirely conflicting agendas.

Denis R Hall
Professor of Optoelectronics

..... continued on p3

A note from the editor

This month AILU entered it's fourth year and our membership recently topped 200. Fortuitously, these milestones coincide with an issue devoted to papers reviewing industrial applications of lasers. Thanks to the generosity of speakers at the recent AILU Tech-Focus meeting *Lasers in Modern Manufacturing* in Glasgow, this issue becomes in effect the Proceedings of the event and we are pleased to be sending complimentary copies to all the delegates who attended the meeting.

The review papers in this issue paint an exciting picture of the challenges and successes of the industrial laser industry. Perhaps the best illustration of this is the evolution of the diode laser, where the recent availability of kW-class diode laser stacks is challenging applications engineers to 'think diode' and find new ways to work around the low beam quality of these 'building block' sources and benefit from their flexibility and relatively low cost per Watt.

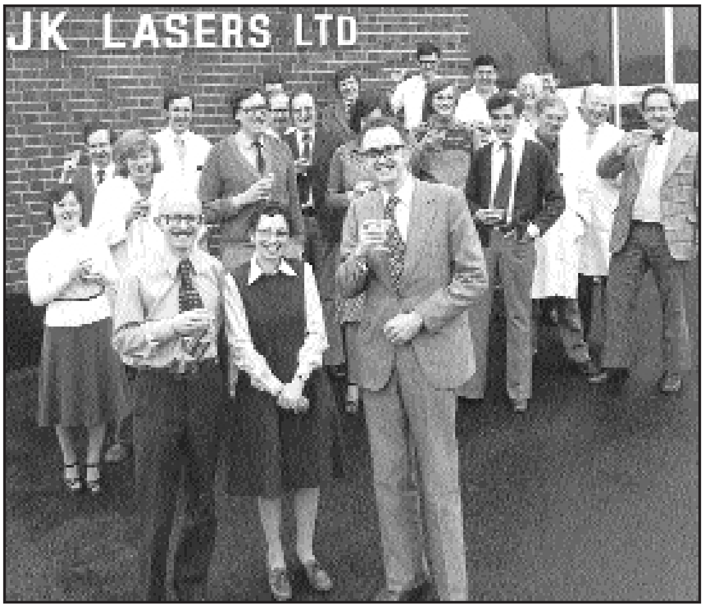
Looking further ahead, how much scope for improvement is there in the output beam quality of diode laser stacks? Will diodes threaten the traditional application areas of the CO_2 laser? Watch this space.

1998 AILU award (continued from page 1)

rates and with high reliability.

This was the principle which had driven most of Jim's subsequent technical developments, culminating with the industrial products at JK Lasers.

Jim also pointed out that he had been fortunate in many respects



The entire staff at UK Lasers in 1978 celebrating the first Queens Award In the front row with Jim Wright is his wife, Tina and Ron Burbeck.

throughout his career. First of all he seemed to have benefited from being in the right place at the right time both with regard to the early development of lasers in the UK and the subsequent development of a commercial market. An apposite example he quoted was that JK Lasers had been fortunate to lose the major contract to supply lasers for Vulcan, the high energy laser facility at the Rutherford Laboratory. Although disappointed at the time, it had forced JK Lasers to pursue Nd:YAG lasers for industry rather than research, which proved to be a good move. Secondly he wanted to acknowledge the tremendous support he had received from others. In particular Ron Burbeck had, as the co-founder of JK Lasers, shared the principles and determination to succeed on which the company was based. During the development phase they had been supported by the work of Roy Noon and Jim Higgins in the boardroom and, of course, all the employees who had given both practical and emotional support. Jim said "The continued growth and success of the business since I left is clear testament to the part they played and are still playing." He further acknowledged the part that customers had played and in particular noted the courage of their first customers who placed orders for expensive equipment from two guys working in a shed. Finally Jim wanted to thank his wife, Tina, who was not at the presentation ('not one for the limelight') for her tremendous support throughout his career.

In closing he said "Thanks again for this award. It really does mean more than I can say."

At the committee meeting following the technical meeting at RAL, the committee voted unanimously to give life membership to Jim Wright and last year's winner Peter Houldcroft *Ed.*

Letters (continued)

CLEO EUROPE

Department of Physics, Heriot-Watt University

For many years the Optical Society of America (OSA) has run an annual conference on Lasers and Electro-Optics (CLEO), part of which is a major scientific laser and electro-optics exhibition. This very successful format has been replicated in Europe at Amsterdam (1994), Hamburg (1996) and Glasgow (1998).

From the perspective of an exhibitor CLEO-Europe is a strongly 'scientific' show which attracts a very international audience. It cannot match the 'Munich' laser shows for breadth of audience interest or size of exhibition. Against that, when was the last time any of us had the opportunity to attend a major international laser exhibition in the UK?

Having many interests in the scientific field we took a major part in the show, exhibiting our range of lasers, diodes, optics and laser accessories. In return we received a good throughput of interested visitors from a wide geographical base. The exhibition was generally well run and its location (the SECC) worked well. One slight grouse was the unwillingness of the OSA to allow local organisation and operation of the exhibition. When paying out a considerable sum to exhibit I do not take kindly to begging letters from the local committee who are unable to fund refreshments etc because the Americans have run off with all the money. Worse still is the difficulty of dealing with the OSA when they are 3,500 miles and 5 time zones away in Washington DC. It is now mid-November and I still have not resolved a payment issue with them!

Overall a good international scientific show. (Do not expect to sell multi-kW CO_2 lasers at CLEO-Europe). The next one is in two years time in Nice. Hopefully by then the OSA will have found a way to run the exhibition locally, which would greatly benefit exhibitors.

Roger Beaman
UK Country Manager
Coherent Laser Group

The days I spent at CLEO-Europe (the industrial day + 1) was very well worthwhile. Speakers at the AILU Tech-Focus session were on the whole very interesting and I did learn some things.

Costs were a little weird however, with speakers and session organisers paying the "entrance fee". I have not come across this before. Many people were commenting on this fact. Perhaps the conference organisers should look at this in the future.

The exhibition seemed to be well attended on the day I was there. However, as this is very much a 'networking' event, there was not sufficient space to sit down and talk to colleagues and others about this and that. A bigger seating area for future meetings!

Tim Holt
UK Sales Manager
Rofin-Sinar Laser

A full programme of events for 1999

At a recent committee meeting the programme for 1999 was approved, kicking of with a workshop on rapid production with lasers at PERA in February.

The four 1998 AILU workshops, beginning with a laser cutting workshop at Warwick University in May and recently concluding with a laser welding workshop at TWI in November, have proven great successes. The Association is committed to providing at least two meetings a year for members only, but by making a modest charge to members and considerably more to non-members, AILU is able to provide additional meetings which concentrate on specific topics.

The provisional AILU 1999 meetings programme:

24 Feb *'Laser-based Rapid Production Technologies'*
Workshop at PERA, Melton Mowbray

April *Members-only meeting and AGM*
Theme: 'What's new in ….' (short presentations on new products and services). Venue TBA

4 May *'Laser Job Shop Practice'*
Workshop at NG Bailey, Leeds

9 June *'Microengineering with Lasers'*
Rutherford Appleton Laboratory

Oct *Members-only meeting*
Theme: 'Monitoring, Maintaining and Servicing Laser Equipment'. Venue TBA

Nov *'Tricks and Secrets of Designing for Manufacture by Laser'*
Venue TBA

CLEO Europe success

Having canvassed the AILU members who attended CLEO Europe (Glasgow, 13-18 Sept) as delegates or exhibitors, it is clear that the event was a great success. The emphasis of CLEO remains very much with the physics rather than the engineering aspects of lasers and applications. There is, of course, an increasingly grey area where physics and engineering meets, as was illustrated by the conference sessions devoted to surface processing, laser ablative deposition and microstructuring with lasers. All the more reason for the Association to be grateful to Prof. Denis Hall of Heriot-Watt University for organising the AILU Tech-Focus day on 'Lasers in Modern Manufacturing'.

AILU's Tech-Focus session was attended by over one hundred delegates from around Europe. There are no formal proceedings for this event but the speakers have generously provided copies of their presentations for inclusion in this issue of the magazine. The session concluded with a lively panel discussion on 'thinking laser at the product design stage'.

The SECC in Glasgow provided an excellent venue for the event. Exhibitors and visitors alike were delighted at the size of the exhibition and the high level of attendance, thanks in part to the promotional efforts of the Scottish Development Agency. Exhibitors found that many of their sales leads came from non-UK organisations, somewhat to the disappointment of UK suppliers who deal only with the home market.

AILU's first laser welding workshop

Fifty delegates attended Laser Welding in Practice on 11 November at the TWI Conference Centre. This meeting, the last of the AILU workshops of 1998, was chaired by Paul Hilton, Technology Manager of The Laser Centre. The day included a lunchtime exhibition, and ended with a lively welding clinic and a tour of the laser facilities at TWI.

Derek Russell (TWI) opened the presentations with a review of laser welding including the different types of welds available, the laser and gas requirements and head design, some important areas of application and the relevent welding standards. He noted in particular the role of the new high power Nd:YAGs in thick section welding and highlighted applications in the shipbuilding industry, where correcting the distortions of arc welding typically accounts for 20 - 25% of labour hours.

Trudy Auty, European Market Manager with VIL of Chicago, presented the practical considerations of laser welded tailored blank production. Her talk included a cost comparison of CO_2 and Nd:YAG. VIL use both types of laser and find that to match the Nd:YAG benefits for welding of a more uniform intensity distribution, better absorption and low plasma absorption, an 8 kW CO_2 laser is needed to weld as fast as a 4 kW Nd:YAG. The capital cost and process costs are about the same for each: in other words, for tailored blanks a draw!

Ray Duhamel (Convergent Energy, USA) addressed thick section welding with multi-kW CO_2, illustrated with a wide range of welds with lasers up to 45 kW. His rule of thumb: a 25 kW CO_2 welds 25 mm low C steel at 1 m/min.

Delegates at the laser welding workshop exhibition

Chris Williams (Howden Laser) concentrated on welding very large structures using a multi kW laser and fixed beam delivery mounted on a gantry motion system.

Michael Rabuser (Kuka Schweissanlagen GmbH in Germany) described the challenges of robotic control of the welding process, including flexible beam delivery for CO_2 lasers and the use of a contact wheel on the welding head to maintain stand-off distance.

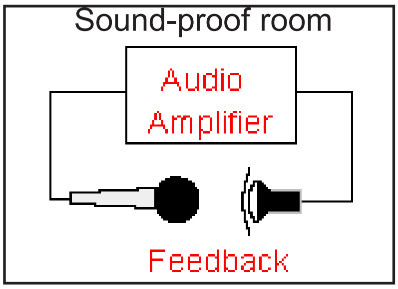
Peter Vincent (Electron Beam Processes) explained their success with laser welding and its potential for enhancing their EB welding sub-contract service.

Tim Holt (Rofin-Sinar) described opportunities for diode laser welding and stressed how these are largely complementary to other laser welding applications. *(See feature on p 30)*

In the final presentation, Chris Peters (Lumonics) reviewed the plethora of welding parameters and diagnostic opportunities, in particular how changes in the time signature of spectral emission can be used as an effective on-line monitor and diagnostic tool.

We hope to publish issues raised at the welding clinic in Issue 14.

Back to Beam Basics



How a laser works, by analogy with how positive feedback of noise in an electronic amplifier, leads to a 'whistle'. A good start by Denis Hall to an explanation of how laser beams are produced and the challenge of extracting a good quality high power beam.

Prior to the meeting 'Laser Beams and Optics for Engineers' at the National Physical Laboratory on 8 October, the topic might be considered not to be a popular one for an AILU workshop; yet it attracted nearly 50 delegates from all sectors of the user community. Aimed primarily at engineers with little or no background in optics and laser beams, the meeting attracted a surprisingly large number of delegates from laser equipment supplier organisations and universities but had little appeal to the laser job shop community. The principal challenge of such a broad based meeting, in terms of subject and audience, was to define a common knowledge base.

The technical session opened with Prof. Denis Hall of Heriot-Watt University providing an introduction to laser sources and the why's and wherefores of resonator design and beam modes.

Brooke Ward (Europtics), who chaired the meeting, went on to consider laser beam optics and propagation. Starting with basic lens formulae for plane waves, he explained how these basic formulae have to be modified for the real waves encountered in laser beams and how focussing produces a beam waist, not a point. A number of important features of beam waists, their size and location, were explained including how two settings of a telescope can give a beam waist at a required position. (Service engineers beware you don't set your telescope to give a beam with a small waist and high divergence down your beamline!)

The practicalities of free space laser beam delivery, including such topics as contamination, beam clipping and other causes of power loss in the beamline, were covered by David Greening (V&S). David also addressed the optical elements of fixed and moving path beamlines and the related issues of polarisation effects and laser beam damage. He stressed how damage thresholds of optics for cw laser beam exposure should be expressed in 'Wm^{-1}' and not, as is still commonly the case, 'Wm^{-2}'.

The three overview presentations were followed by a series of shorter presentations by Tim Weedon (Lumonics) on power delivery through optical fibres and the practical limits on focusing the fibre output; Simon Hall (NPL) on power and energy measurement and the challenges of achieving reproducibility and high accuracy; Eddie Judd (Davin) on laser optics and the confusions of optics definitions, Mark Wilkinson (Laser Beam Products) on metal mirrors and how to clean them (tip: don't talk over your optics); and Cedric Knox (General Scanning) on scanning power beams and the evolution of moving optics.

The meeting finished with a lively discussion at the optics clinic, ranging from elliptical beams and adaptive optics to safety issues for Beryllium mirrors, and was followed by a tour of the laser measurement laboratory at NPL.

Our thanks to Simon Hall of NPL for hosting this event and providing such excellent facilities at Bushy House.

High-tech meeting at RAL

The General Technical Meeting at the Rutherford Appleton Laboratory (RAL) in Didcot, Oxon, on 20 October attracted 35 members. The main theme of the morning session was 'Making the Most of Your Computer' and began with a presentation and discussion of CAD-CAM software packages by Mario Grandinetti and John Turner of RADAN. Dave Pepler of RAL then gave us an on-line demonstration of browsing web sites of interest to laser users including a review of the new AILU web site. The session on computer topics ended with a light-hearted look at the beta version of an interactive CD by ILT Aachen on CO_2 laser welding, in which Paul Hilton took the audience through a virtual laser lab, carrying out all the tasks from turning on the gas supply to the laser through to making trial welds and plotting the results, all from the keyboard of his lap top PC.

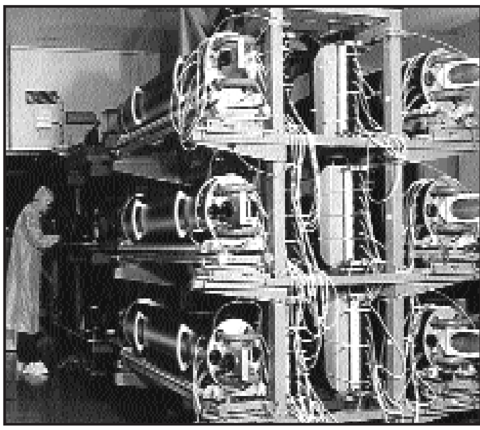
Topics covered in the RADAN presentation included data transfer and news of STEP, the first international standard for data transfer, and how nesting can make more efficient use material and reduce production times. RADAN has 700 users of their software in the UK, operating on a wide range of machines, and many generic aspects of the software were illustrated at the meeting in real time.

The on-line tour of the internet included a first look by members at the closed area of the AILU web site at *www.ailu.org.uk*. With some of the closed site still under development, members can already access up-to-date contact information on members, the database of our consultants providing free advice, some frequently asked questions, news items, links to other laser sites and a product and services directory. Future developments include back issues of the magazine, a well illustrated laser applications database and technical information on cutting, welding and other laser processes. Key elements of some of the presentations given at AILU workshops will also be included.

The presentation of the AILU award for 1998 to Dr Jim Wright (see front page) was preceded by a fascinating brief history of the development of the Nd:YAG laser by Clive Ireland, from the early days to the new high power lamp and diode pumped varieties. This was followed, after the presentation and lunch, by a review by Colin Danson of how short pulsed lasers for target compression experiments have evolved. Those in the audience more familiar with industrial pulsed lasers found the idea of a laser filling a large building and providing only a few pulses per hour a little difficult to grasp!

Colin then introduced the Central Laser Facility at RAL as a prelude to what was unanimously regarded as a fascinating laboratory tour.

Our thanks to Colin Danson, Dave Pepler and all at RAL for helping make this members-only meeting so enjoyable.



Courtesy of CLRC

The output stages of Vulcan, the high power Nd:glass laser facility at RAL, capable of delivering up to 2.6 kJ in nanosecond pulses.

Make it with Lasers in the Automotive Industry

The Make it with Lasers™ programme held a workshop on Lasers in the Automotive Industry at Nissan Motor (UK) in Sunderland on 22nd October 1998. Over 80 delegates attended the event, many from outside the UK. The highlight of the meeting was a tour of the body assembly and trim and final assembly halls at Nissan. The tour highlighted techniques, including team working, minimum lineside storage and the sequencing of sub assemblies to the main assembly line, by which Nissan achieve an output of 90 cars per direct man per year

Presenters included Steve Riches (TWI) on the various applications of seam and spot laser welding, including component assemblies, tailored blanks and body assembly applications; Mike Osborne (AEAT) on laser surface engineering and benefits including localised wear resistance, friction control, hardening, corrosion resistance and preparing surfaces for adhesive bonding. Mohammed Naeem (Lumonics) outlined the work being done in laser welded aluminium tailored blanks and its potential in high performance vehicles with aluminium skinned bodies (Audi A8, Landrover Discovery etc); Johann Hornig (BMW) described the application of laser welding in the body assembly process of the BMW 5 series vehicle, and the structural strength advantages of laser welding over more conventional methods. Martin Cooke (NG Bailey) reviewed the way that lasers can help minimise work in progress in the automotive component supply chain, both due to their flexibility and low economic batch quantity. Finally, Stephen Ainsworth outlined some novel or unconventional applications of laser techniques and non contact measurement, finishing with a review of laser system installation considerations (hardware through to training) and stressing the importance of continuously exploring the parameters used for the laser process to improve overall performance.

Once again, MIWL achieved its objective of introducing laser technology to engineers. Next year is the 10th anniversary of the programme, a tribute to the sponsors and to TWI who manage the programme.

Meeting report by ***Stephen Ainsworth***

MIWL Innovation Award

The first of what is planned to be an annual award was presented to Vosper Thornycroft (UK) Ltd during a Make It With Lasers™ workshop held at Nissan in Sunderland on 22 October 1998.

This award has been established to recognise companies who have applied laser technology in an innovative and profitable manner thereby furthering the industrial use of lasers.

Vosper Thornycroft was awarded the trophy for the introduction of laser cutting into the shipbuilding industry. The resulting benefits are a 20% man-hour saving on building the hull and superstructure of a military ship and an improved quality product.

Three other companies were highly commended and received certificates. They are Johnston Engineering Ltd in the heavy transport sector, KeyMed Ltd who use lasers for marking, cutting and welding in medical applications and The Real Gold Card Company who manufacture a solid gold credit card which carries laser-marked details.

New products & services

BTEC for laser system operators

Funded through the European Social Fund, Loughborough College has submitted a course in Laser Material Processing to BTEC for approval. The college claim that the course will provide the first ever nationally recognised qualification for laser operators. The first units begin in early 1999.

The Laser Centre at Loughborough College

The BTEC Award, especially devised for industry-specific applications, is a short, flexible and competence (i.e. vocational) based qualification. The emphasis is very much on relevant, practical training.

A survey of the Industrial Laser Community to identify training needs, topics and methods is ongoing. It is an opportunity for the whole industry to influence a training course developed ‘by the Industry for the Industry’.

Info:
Sharron Waring
The Laser Centre,
Loughborough College
T: 01509 618249
E: warings@loucoll.ac.uk

Controllers for Coherent Lasers

Anglia Laser Products model LC-597 laser controller has proved an outstanding success in controlling Coherent Diamond series 62/64/84 lasers in a wide range of industrial applications. Anglia is now pleased to announce a new model range, specifically designed to control the Coherent Diamond and G series lasers and able to operate at output frequencies up to 100 kHz.

LC-597 laser controller

The new controller, the LC-597CD has the same appearance as the LC-597 but houses different electronics and is equally suitable for Diamond 64/84, G and K series lasers. The inputs/outputs are constructed and labelled to suit current Coherent practices. The controller will be available from January 1999. A wave shaping version, the LC-597DCWS, will be available in May 1999.

The new controllers feature full programmability, automatic shutter control and direct interfacing with CNC or robotic controllers.

Info:
Kevin or Brian
Anglia Laser Products
T: 01603 721822
F: 01603 721815
E: info@anglialaser.co.uk

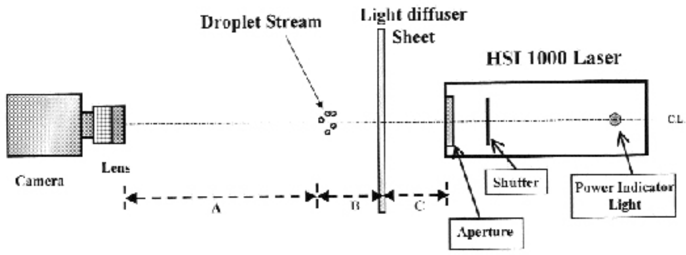
New VisiSizer for the measurement of droplet size and velocity

Oxford Lasers VisiSizer is a rugged, portable and integrated instrument suitable for droplet analysis in harsh industrial or laboratory environments.

With the Visisizer it is not only possible to measure droplet size and velocity simultaneously but, for the first time, it is possible to visualise images of the droplets. In a sequence of frames, the way the droplets change in shape and size can now be clearly seen. Visualisation provides an increasingly important insight into a wide range of complex industrial, chemical and engineering processes from food product drying and paint spraying to powder coating and drug delivery.

The system comprises a stroboscopic solid state laser light source, camera and display unit. For flow visualisation, blur free images are obtained by exposure times of only 1 μs at frame grabbing rates up to 1000 per second. The quality of the images enables accurate analysis of jet break up, ligament growth, droplet size distribution and droplet shape, crucial in studies aimed at development of more efficient spray systems. VisiSizer represents a vast improvement on point anemometry systems that supply only processed numerical data which can in some cases be misleading.

Capable of capturing up to 256 particle images per frame and ready for immediate playback or later frame by frame analysis, VisiSizer also allows visualisation as a slow motion movie of the captured event.



Schematic arrangement of the Visisizer®. The short pulsed output from a pulsed solid state laser is scattered by a diffusing screen to provide an illuminated background for the droplet stream under investigation. The camera is focused on the droplets and synchronised to the laser pulses.

Front, rear sheet lighting techniques can be selected for best possible results in a wide variety of applications. Such flexible illumination also allows imaging of very small test areas, difficult angles of vision or test areas with restricted optical access.

Info:
John Boaler
Oxford lasers
T: 01235 554211
F: 01235 554311
E: oxford.ltd@oxfordlasers.com

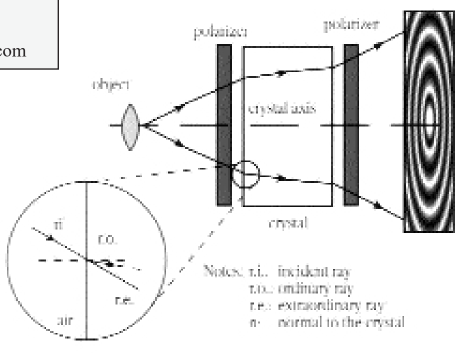
Non-contact surface profilers

BFi-Optilas now offer a new range of 3-dimensional non-contact measurement systems developed by Optimet. Based upon a patented application of conoscopic holography these systems permit users to perform absolute distance measurements and to create precise 3-dimensional digital images of a wide range of surfaces, at high speeds and at relatively large stand-off distances.

At the heart of Optimet's range is a single light beam measurement head (the Conoprobe) with interchangeable optics. Conoprobes may be purchased separately or as part of complete Conoscan systems, which also incorporate computer controlled translation stage(s) and a graphical user interface.

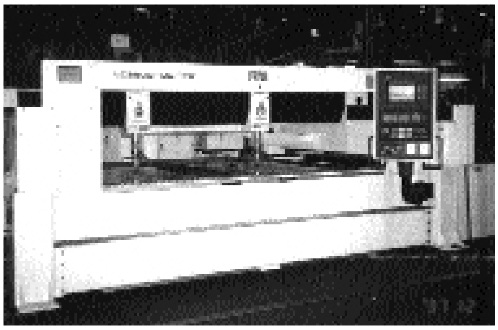
Info:
Mike Dockney
Optilas
T: 01908 326326
F: 01908 221110
E: Mike_Dockney@uk.optilas.com

The Conoscope offers 4000:1 precision regardless of stand-off distance chosen by means of lens selection e.g. 8 μm precision over 25 mm.



A conoprobe comprises a uniaxial crystal sandwiched between two polarisers. The crystal splits light from a quasi-monochromatic light source (not necessarily a laser) into an ordinary and extraordinary component. These form the object and reference beam of a hologram, the fringes of which are measured by a CCD camera to produce a 3D map of the illuminated surface. By changing the objective lens the range and precision of the Conoprobe can be set from microns to metres.

New dual head machining centres



The NVL Balliu MTC LC OG Twin CO_2 laser system provides high throughput and accurate profiling of sheet materials.

In one installation a 3.0 x 2.5 m machine was integrated with dual pallets and two Rofin-Sinar RS1700 lasers. Continuous processing was achieved with dual automatic reciprocating pallet tables each constructed to provide a full 3.0 x 2.0 m working area. Integrating 2 lasers into the system, capable of working in tandem or independently, the machine can still be fully utilised over the 3.0 x 2.0 metre area if one laser was down or not required. The variable pitch centre spacing (450 – 1550 mm) between the process heads allowed for full utilisation of material blanks with minimal wastage and contributes towards efficient nesting.

The machine was evaluated over a 9 month period in a production environment cutting carbon steels in the range of 2 to 8 mm thick. Compared to a competitive single laser system used in the same area, the detailed results showed that an overall 70% increase in productivity and throughput. It was also proven that by employing the NVL Balliu MTC Rapid Piercing Facility the system averaged a 1 second peck-through time, thereby reducing individual piercing times by up to 35%.

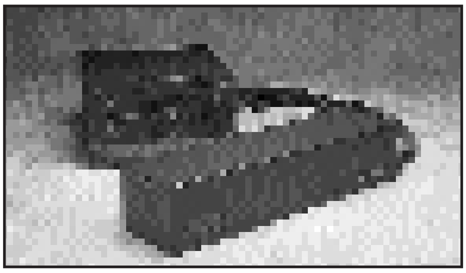
Info:
John Barker
Balliu UK
T: 01733 703591
F: 01733 703592
E:

New Pulsed UV Solid-State Laser for Industrial Micromachining Applications

Coherent has recently unveiled a new UV laser which will bring many micromachining applications to industrial reality. The Avia 355-1500 is an all-solid-state, diode-pumped, Q-switched design that produces greater than 1.5W of 355nm output at 15KHz and can operate at any repetition rate up to 60KHz.

Coherent have incorporated into the Avia design a number of important features, all of which contribute to Avia's ability to work reliably in industrial situations. The head is sealed and requires no realignment following cleanroom assembly at Coherent. Operator control is via the display panel on the power supply front face. The laser head is designed for over 10,000 hours of operation between maintenance periods and is interchangeable with other Avia heads in order to minimize downtime.

Degradation of the 355nm harmonic generator is a well known problem in pulsed solid-state UV lasers. Coherent have incorporated a multi-point crystal mount, allowing upto 30 operating sites per crystal, with automated changes between sites, thereby eliminating the need for operator intervention within the laser head.


The AVIA laser: UV power for micromachining

UV micromachining is a rapidly growing area, but the lack of compact, solid-state industrial lasers has hampered a number of potential applications. Not only does Avia address the need for a rugged industrial lasers, but its ability to operate at any repetition rate up to 60KHz allows it to tackle a wide range of materials efficiently.

Applications for Avia include micro-via drilling in multi-level circuit boards, a $500M per year market and growing, micromachining medical devices and marking plastics.

Info:
Coherent (UK) Ltd
http://www.cohr.com
T: 01223 228833
E: Cohr_UK_CLG@cohr.com

Lasertube 651 flexibility cuts corners

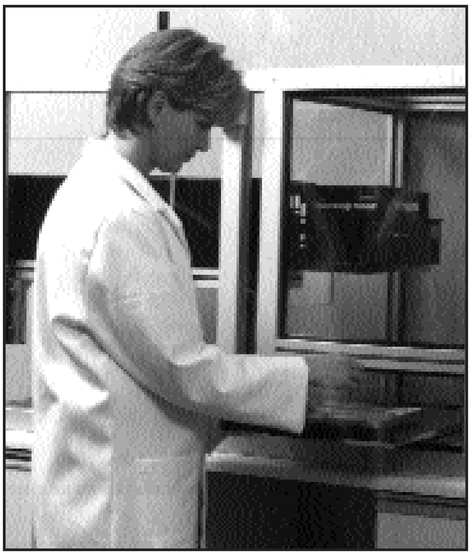
The Lasertube 651 is Adige's latest solution for processing round, square, rectangular and oval tube. Virtually every conceivable shape can be cut into the tube along its entire length including holes, slots, notches or mitres and in any material including stainless steels, copper, aluminium and exotics such as titanium. Equipped with a 'tube holding chuck' the Lasertube is able to effect simultaneous 4th axes movement permitting the fullest possible access to the tube being processed, and allowing the entire tube including both ends to be worked upon.

CAD CAM programs are simply downloaded to the Siemens 840D controller. Prototypes or special components can be developed rapidly without incurring tooling or fixturing costs making short runs and even one off's economical. A major benefit of the Lasertube 651 is it's ability to effect crisp clean cuts, a kerf of just 0.1mm results in the minimum of material loss, while the ability to process thin wall tubes without the need for shell jaws or special tooling has obvious advantages.

A bundle loading system which can handle up to 4000 kgs of tubes offers production over extended periods without the need for operator intervention.

Info:
Paul Lake
BLM Adige
T: 01525 402555
F: 01525 402312

Laser marking kit from Synrad



Synrad's new laser marking system kit is fully self-contained. With some minor integration, the user can have a system operating on a production line in just a few hours.

The laser source, a highly reliable sealed off CO_2 laser, is delivered to the new Synrad DH Series Marking Head (included in the kit) which has a fibre optic link to the control unit, thereby providing electrical noise immunity in the industrial environment.

The user interface is the critical element of every system, and defines its ease of use. Synrad's WinMark Pro system control software is designed to make laser marking a simple task. Created in the familiar Windows® environment, it's pull down menus, toolbars, and dialog boxes intuitively guide the user through the set up and execution of any laser marking applications.

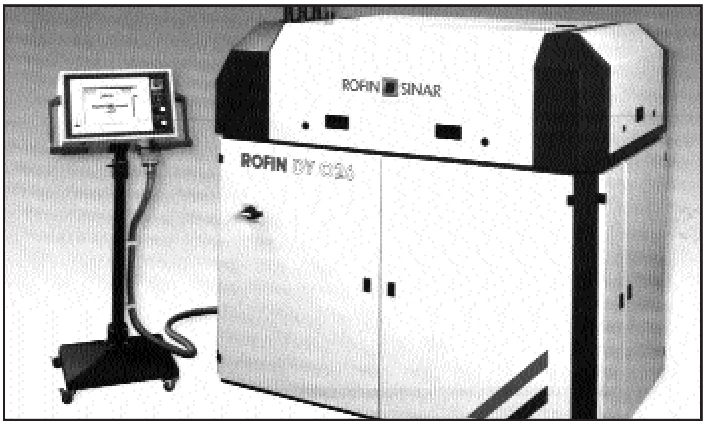
To supply the beam to its intended target the DH Series High Power Marking Head combines beam delivery components and a motion system, capable of handling up to 125 Watts. Offering a comprehensive choice of focal lengths, the DH Series incorporates lightweight (beryllium) mirrors. With the laser vertically mounted, the factory footprint of the compact DH Series head is only one square foot, an important consideration when space is at a premium.

Info:
Steve Knight
Laser Lines Ltd
T: 01295 267755
F: 01295 269651
E: corp@laserlines.co.uk

Rofin to introduce new range of high power diode pumped Nd:YAG lasers

Tim Holt
Rofin-Sinar Laser

During 1999 Rofin-Sinar Laser will be introducing a range of high power diode pumped Nd:YAG lasers at 1.3 kW, 2.6 kW and 5 kW output. These lasers have been developed in collaboration with Dilas, the Rofin-Sinar company specialising in high power diodes. Demonstrator diode pumped Nd:YAG lasers, at 1.3 kW and 2.6 kW output power, have been built to confirm the advantages of these lasers over the lamp pumped laser, the three major advantages are described below.



Rofin's 2.6 kW diode pumped Nd:YAG laser, the DY026

Advantage 1: Efficiency

The lamp pumped Nd:YAG laser has an efficiency of about 2-3%. One of the main reasons why they are so inefficient lies with the lamps, which produce a broad spectrum of light, only a fraction of which couples into the YAG rod. The rest is wasted heat. The diodes which replace lamps have a much smaller wavelength spread, tuned to match the Nd:YAG absorption (pump) band. This leads to more efficient coupling and less heat generated. Diode pumped YAG lasers have efficiencies of greater than 10% meaning less electrical power consumed and a smaller chiller.

Advantage 2: Maintenance Intervals

Lamps for a lamp pumped Nd:YAG laser require frequent replacement. The typical life of the lamps depend on the laser duty cycles and is typically between 300 hours (for very severe duty cycles) to 1,000 hours (for more relaxed duty cycles). At the end of life, the lamp must be exchanged. This should take approximately 10 minutes per cavity, assuming that the laser manufacturer has designed the cavity for easy replacement.

The diode packs used in a diode pumped Nd:YAG laser have an expected lifetime of typically greater than 15,000 hours. The diodes are not affected by 'heavy' duty cycles to the same extent as the lamps. The figure of 15,000 hours implies several years between diode pack replacements.

Advantage 3: Beam Quality

With diode pumped lasers there is less heat generated than in lamps and therefore a better quality beam is produced. A typical beam quality for a high power lamp pumped Nd:YAG laser is 25 mm.mrad; further improvements in beam quality are usually at the expense of efficiency e.g. a 15 mm.mrad lamp pumped laser might have an efficiency of less than 2% compared to 3% for 25 mm.mrad beam quality output. The limitation to beam quality is thermal distortion in the YAG rod caused by the heat generated by the lamps. Some companies shape their rods to compensate for this but the technique is only effectively at a specific pump power.

Less than 15 mm.mrad, typically 10 mm.mrad, is easily achievable by a diode pumped laser, even at very high powers. This means that the beam can be launched down a smaller diameter fibre, which has advantages in terms of final power density and size and robustness of the final focusing unit. The 1.3 kW beam can be launched down a 300 µm fibre. It also means that cutting, as well as welding, with a diode pumped laser can be considered.

Cost analysis

The current disadvantage of the diode pumping over lamps is unit price, although this is expected to drop swiftly as diode production increase to meet the demand of a wide range of applications, not just pumping Nd:YAG lasers.

Trials done by Rofin indicate that a diode pumped Nd:YAG laser matches the processing power of a lamp pumped laser of approximately 60% greater output power. The 60% figure is a direct reflection of the better beam quality (15 vs 25 mm.mrad); taking this into account, it can be shown that there is a significant cost saving to be gained by choosing a diode pumped laser.

COMMENT: Laser lamps still have a future ……

Over the last few years diode lasers have made slow progress in their attempt to replace the lamp as the primary pump source for high power solid state lasers. During this time, lamp manufacturers have been improving the cathode, gas fill and envelope technology, resulting in a product which is far superior to that against which the diodes were originally conceived to compete.

Advances in cathode design have produced continuous lamps that are guaranteed for 1200 hours under the heavy loading of a marking application. Cavity designs now make changing lamps a simple procedure for the operator. Diode stack replacement, whilst being more infrequent, is a specialist and skilled operation.

Advances in the manufacture of laser rods and the design of lamps and cavities mean that laser conversion efficiencies of 3 – 6% are now possible. The 8 – 10% efficiencies claimed by diode pumped laser manufacturers are therefore not vastly superior. Moreover, diodes cannot compete with lamps for pumping high energy pulsed laser systems.

I believe that for the foreseeable future, the vast majority of high power solid state lasers being manufactured will be pumped with lamps. Most end-users will find it difficult to justify the higher initial capital outlay and the cost of replacement diode sacks.

Paul Walker
Laser Lamp Product Manager
Heraeus Noblelight Ltd

Members' News

Record sales year for Electrox

Electrox results for the last financial year, as part of the annual reporting of their parent organisation, the 600 Group, revealed another record year of sales despite the global economic downturn. All business areas moved forward – Markers, CO_2 lasers, and Nd:YAG welders. A 12% increase in Marker sales was particularly noteworthy in view of the economic problems in the Far East, where a number of their major customers are located.

The 600 Group has entered the laser profiling market this year with the introduction of a low cost, no frills CO_2 cutting system, the Lazerblade, developed by a newly formed company, Profile 600. At the heart of the Lazerblade is an Electrox 1500 W fast axial flow CO_2 laser derived from the successful Nova range.

University's £1.5 M to develop industrial laser technology

Coventry University's Centre for Advanced Joining has been awarded a £1.5 million European Regional Development Fund (ERDF) grant to assist in the development of industrial laser welding across the West Midlands. The key aim of the four-year project is to assist manufacturing-based small and medium size enterprises (SMEs) to modernise and innovate through the practical application of the latest advances in advanced joining and laser technology.

The programme comprises four main elements: (i) a series of technology demonstrator projects; (ii) a series of technology application projects customised to suit individual SMEs in specific manufacturing sectors; (iii) awareness raising and technology dissemination events; and (iv) a feasibility study to establish the sub-contract laser processing requirements of SMEs in the West Midlands through a regional 'Laser Job Shop'

'This programme will stimulate the take-up of the latest welding technologies and associated innovative manufacturing methodologies', commented John Biffin. 'The resulting improvement to manufacturing efficiency will help safeguard existing employment and support the creation of new jobs in the area,' he added.

Houston, Texas USA hosted the annual meeting of the international committee dealing with laser safety standards, IEC/TC76 in October. Two of the U.K.s delegates representing AILU interests (Mike Barrett, Lumonics (left) and Steve Walker, H.S.E) were ready to fly should John Glenn have backed out of his Space Shuttle flight.
(see p 11 for more news on safety meetings)

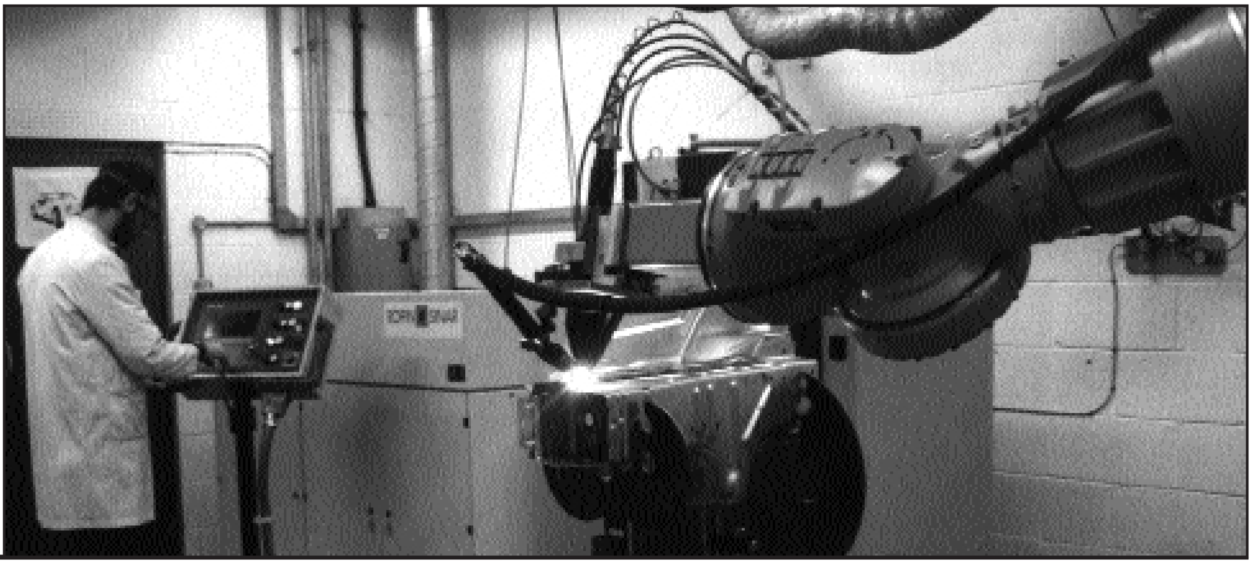
Rugby College appointment

Brian Sandford is the new Laser Technician in the Laser Centre at Rugby College. Brian's experience is ideal for his role in keeping the lasers up and running and he is keen to develop the Applications and Research work at the Centre. He brings to the college extensive experience in the laser sub-contracting world, starting with the first laser installation at Lasercut Products in Bishops Stortford in the late 1970's. His most recent work was with Convergent Energy and a Nd:YAG laser based sub-contractor in Rugby.

Brian Sandford

Brian specialises in developing programming and processing techniques and has experience in building laser systems and in service management.

A new 2 kW cw Nd:YAG laser from Rofin-Sinar is one of the laser facilities at the Centre for Advanced Joining at Coventry University



Safety and Standards

TC76 meeting overview

The generic laser safety standard in the UK is BS EN 60825-1 'Safety of laser products Part 1. Equipment classification, requirements and user's guide', part of a series that includes BS EN 60825-4 'Laser guards'. The origin and source of revision of the 60825 series is the IEC Technical Committee TC76 which at the last annual meeting split up into nine active working groups.

Houston, Texas USA hosted the 62nd IEC General Meeting in the middle two weeks of October this year. The occasion drew 57 Technical Committees comprising approximately 200 Working Groups or Committees covering all aspects of the electro-technical field of Standards. Delegates attended from 47 countries from around the world with the U.K. being well supported.

A first for the IEC was the provision of a web site for the benefit of delegates. This facility provided electronic mail and internet access together with a FTP capability for the exchange of electronic documents. This major development was limited by too few available PC access points to cater for the needs of the delegates. All documents produced at the meeting were distributed by electronic means and are available on the internet for a limited period at the IEC's web site *http://www.iec98.com*.

Representatives from eight countries participated in the IEC TC76 meeting. Nevertheless, many of the Working Groups, including WG7 that deals with the aspects of high power laser safety, were poorly attended. The standard IEC 60825-4 Laser Guards was developed in WG7 with significant U.K. input. This Working Group is now working on informative documents to support 60825-4, in particular the design and application of laser guards.

As with all standards-making bodies there are a variety of influences within the Working Groups. The agendas of Test Houses, Manufacturers, Enforcement Agencies, etc. must be balanced with the needs of users to produce solid workable standards that are of benefit to the laser industry as a whole. The British delegation at this TC76 meeting provided a good balance of all these aspects.

Mike Barrett Lumonics

Performance standards for materials processing machines

There is an agreement between CEN, the European standards body, and ISO, the international standards body, to share workloads and Working Groups. Usually the international aspect is satisfied first in an ISO committee and then CEN adapts it to their requirements. In this example a CEN committee has drafted a standard that is unlikely to get international recognition.

prEN ISO 15616-1 to 3.'Acceptance tests for CO_2 laser beam machines for cutting and welding'

The purpose of the draft standard prEN ISO 15616 is to provide requirements for acceptance testing of CO_2 laser machines, prior to or during installation at the user's premises. The tests address the ability of the machine to produce cuts or welds of consistent quality.

The standard can be criticised on many fronts. AILU members may first of all be amazed that the draft can apply to both cutting and welding machines, since the process and speed parameters, accuracy targets and gas requirements of the two processes can be widely different. A quick glance would indicate that the writers of the standard have in mind a fixed optical path and moving workpiece, since no guidance over the consequences of variation in beam diameter in flying optic beamlines, nor are beam expanding telescopes considered.

Tolerances to deviations in performance (Part 1, Tables 2 and 3) appear to be erratic and arbitrary. Medium term power stability is advised to be within ±5% but the long term stability and repeatability is required to be ±2%. The repeatability of positioning along one "path" (presumably "axis") is limited to a maximum deviation of 20 µm performing adequate processing with considerably less demanding accuracy. In contrast to the more demanding tolerances, there is an allowable limit of deviation of the "free-running beam diameter" of ±15% and a method of measuring beam diameter (acrylic "burn-ins") is offered that is admitted to have an uncertainty of measurement approaching ±30%!

Inadequacies arising in Parts 2 & 3 of the draft include an emphasis on mechanical methods (e.g. dial gauge and straight-edge) of measuring worktable or gantry movement accuracy. The measurement of mechanical accuracy *and* laser beam performance *and* gas supply adequacy would be most easily performed by production and inspection of test pieces. This technique seems to appear as an afterthought in Part 2 (5.5).

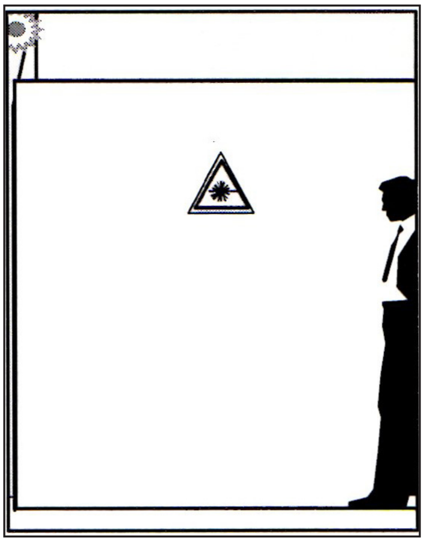
The optical aspects of laser beam propagation, manipulation and focusing don't appear to be understood. Beam alignment, mirror adjustment tests and the performance of focus height controllers .receive no attention.

Part 3 of the draft standard is a very brief description of verification of the process gas flow and pressure measurements and calibration procedures. The need to locate pressure measurement gauges at the nozzle is not discussed. Tests and the consequences of nozzle damage are ignored. The whole area of this sensitive and complex aspect of laser cutting and welding is given a superfluous treatment by the draft standard.

In summary, most of the critical factors affecting process performance have been disregarded and the standard should be withdrawn and completely rewritten from the viewpoint of the industrial process that is to be performed by the laser system. CEN TC121 has done all the drafting work, a prEN/ISO draft has been produced for a two-month parallel vote in both CEN and ISO. The voting deadline has just passed (30 November) and it is likely that CEN will vote positive but ISO negative.

Brooke Ward Europtics

Laser safety screens



It is likely that there will soon be a European standard for laser safety screens. The draft standard prEN 12254 'Screens for laser working places' has com voted on by the European national standards committees; the voting result is still to be given, and although the UK voted against it is likely that the document will be approved.

So what is the status of this standard, why did the UK vote 'No' and where do we go from here? Firstly, despite the similarity in test procedures in prEN 12254 to the laser safety eyewear standard EN 207, there the similarity ends. Unlike eyewear, screens are not subject to the Personal Protective Equipment Regulations so there is no requirement for users to buy screens that comply with 12254, nor must the testing of screens be performed by a certified test house. EN 12254 is simply a convenient product standard that users and manufacturers can quote to.

Why did the UK vote 'No' to prEN 12254? The main concern of the UK committee is the 'stability to laser radiation' test requirement, which allows the freedom to test for suitability for high power laser use by focusing a relatively low power laser beam to produce a spot of the same Wm^{-2}. As readers of this magazine will know (see, for example, Brooke Ward's article 'Intensely damaging' in Issue 10, p24) the damage threshold for cw beams exposure scales better as power divided by spot diameter rather than divided by area and is better expressed in Wm^{-1}. e.g. a curtain that doesn't melt when exposed to a specified Wm^{-2} in a small focussed beam may yet do so when exposed to a larger area beam of the same intensity.

There are other factors of suitability that need also to be considered, including laser rep rate, intensity distribution, condition of surface etc. and whether 100s protection stipulated in prEN 12254 is long enough for the intended application. However, one needs also to see things from the screen manufacturers viewpoint; it is impractical to provide screens tested for each individual user's requirements; the tests are there primarily to reject inappropriate materials.

Where do we go from here? The UK committee has agreed that if and when EN 12254 is published, there will be a foreword in BS EN 12254 stating:

'Caution for users of laser safety screens:

The tests for stability to laser radiation stipulated in this standard provide only an indication of suitability. The protection afforded by a screen depends on several factors, including laser power, beam area, repetition rate, intensity distribution, exposure duration and condition of surface. Users should satisfy themselves that the screen material provides adequate protection under the worst reasonably foreseeable conditions of exposure.'

The basic testing by the manufacturer should guarantee the necessary level of attenuation, it is the laser damage threshold that needs to be tested by the user. One solution would be for potential purchasers of screens to ask for a sample piece and then to make a test under worst reasonably foreseeable conditions of exposure.

Some Frequently Asked Questions about the Machinery Directive

Mike Barrett
Lumonics

Translations

Q: *When a manufacturer sells a sub-assembly (a laser, say) to a contractor, he does not know the country of final destination, what language should be used for the instructions?*

A: A sub-assembly to be incorporated into a more complex installation is not usually considered a "Machine". It usually does not satisfy the two criteria:

- that it should be "for a specific application"

- that it should be able to "function independently" as a machine.

Thus it is not necessary to comply with the procedures for evaluation conformity. The instruction manual will be written (in theory) by the person who supplies the installation to the end user. The information provided to this person by the manufacturer of the sub-assembly can be in any language chosen by mutual consent. Clearly, commercial pressures come into this and in practice it is common for the sub-assembly supplier to provide manuals that can be directly supplied to the end-user in the correct language.

Q*: Before a machine is placed onto the market, must the translation of the instructions into all Community languages be available,. even if the manufacturer has decided not to sell in certain countries?*

A: The Machinery Directive allows for a machine to be placed on the market, it is sufficient for the instructions to have been drawn up in a single Community language.

The translation may be made by the authorised representative or even the person importing the machine. This means that when a machine is out of stock, say, in one country, a machine may be brought from a neighbouring Member State, the only obligation being to translate the instructions if they have not already been translated.

Declarations

Q: *When a machine is imported:; (a) who must sign the Declaration of Conformity, and (b) where must the technical file be kept?*

A: Only the manufacturer or the authorised representative established in the Community must sign the Declaration of Conformity. Recall that this Directive is part of EU legislation and thus only manufacturers or others resident within the EU can be held accountable. The Declaration of Conformity must be sufficiently detailed to give a satisfactory prima facie indication that the machinery complies with the Directive.

The Directive requires a technical file to exist but does not specify where it is to be kept. There are many cases where it is difficult to imagine the file being kept anywhere other than on the premises of the manufacturer, even if that is located outside the EU.

Q: *In the case of series manufacture, must each Declaration of Conformity be signed by hand?*

A: The Declaration does not require a hand-written signature, but specifies only that the Declaration of Conformity must be signed by a person empowered to sign on behalf of the manufacturer or his authorised representative established in the Community. The Declaration of Conformity is a very important document because by signing it the manufacturer, or his authorised representative, assumes liability for the machinery.

It is therefore in his interest that the Declaration should not be easy to reproduce. The use of photocopies could be argued as inadvisable because it is for the manufacturer to establish that fraud has been committed, and this could be difficult if he himself uses photocopies.

Demonstration Machinery

Q: *If a manufacturer installs machinery on the promises of a potential customer for him to evaluate it but the machinery is not sold and remains the property of the manufacturer, does the machinery have to bear the CE marking and meet the other requirements applicable to it?*

A: In this particular case, as long as the machinery remains under the manufacturers control and as long as the operators are the manufacturers employees, it is considered that the machinery has not bee placed on the market. As soon as the satisfied customer takes delivery, the machinery has to comply with the Machinery Directive (and any others applicable) and bear the CE mark, etc.

The manufacturer has to make sure that a notice is affixed in the vicinity of the machinery saying that the machinery is not in conformity with the Directive.

If there manufacturer has supplied the machinery for evaluation by the potential customer and the machinery is to be operated by the future customers staff, the machinery has been considered as placed on the market (handed over provisionally but handed over all the same) and put into service in accordance with the Directive and must be entirely in conformity with the Directive.

Article 8(6) also applies the same conditions on those who assemble machinery or parts from various origins or constructing

Continued on page 23

CO_2 Laser Cutting – Notes for Jobshops

an occasional series edited by John Powell

No 1

Finding the focal position of the lens in a CO_2 laser cutting machine.

Abridged (with the authors consent) from John Powell's book *CO_2 laser Cutting**

Lens manufacturers generally accept a 1 or 2% variation about the nominal focal length. This may be sufficient for the cutting of some polymers, but in general the focal position will need to be determined whenever a lens is replaced if optimum cutting performance is to be achieved.

A number of different techniques exist for establishing the focus position of a lens and two of the simplest and quickest will be described here: the blue flash test and the drilling test.

The blue flash test

The blue flash test relies upon the fact that near the focus of a high power CO_2 laser it is possible to vaporise metal and ionise that vapour, giving rise to a blue flash above the surface. This blue flash will only take place with the metal at, or near, the focal point of a CO_2 laser beam.

The basic technique involves exposing a metal sample (usually stainless steel) and, with the laser set in short pulse mode, changing the lens-material distance. For low power or very short pulse laser operation, the focus position may be accurately identified as the point at which the brightest blue flash and loudest noise is achieved. For machines where the production of such low power pulses is impractical or unreliable, a blue flash may be observed over a substantial range around the focal point, in which case identifying the brightest flash may be too inaccurate. In this case, the best approach is to identify the threshold points either side of focus where the blue flash is only just visible. The focus can then be assumed to lie halfway between these two positions.

The technique

1. The best approach is to set the laser to generate a single short pulse on demand. Alternatively, control the shutter to open and close quickly, but beware that shutter operation can be unreliable and the blue flash is very sensitive to pulse-to-pulse variation. If reproducible short pulses cannot be created by either method, use the drilling method below, which is not so dependent on the reproducibility of pulses.
2. After fitting the lens to the cutting head in the usual way assemble the head but remove the cutting nozzle (to avoid beam 'clipping', since the nozzle will not have been aligned to the beam at this stage). If there is a nozzle-lens distance adjustment, set it as close to the lens as possible to allow the beam to be focused below the plane of the metal sheet without the cutting head touching the sheet.
3. Use an air supply to the cutting head to protect the lens from spatter. Any of the usual assist gases can be used except oxygen. A high flow rate with low pressure will result because the nozzle has been removed. To avoid producing an excessive pressure which will artificially suppress the blue flash, set the exit pressure flow of the gas jet at approximately the same level as the highest value you can achieve by blowing hard through pursed lips. A large diameter short nozzle can be specially made for this test if the hole left by the removal of the cutting nozzle is too large.
4. Position a sheet of stainless steel beneath the cutting head at a distance which is known to be beyond the focal point of the lens (eg for a supposedly 100 mm focal length lens, make the lens-target distance 110 mm or more).
5. Wearing suitable laser safety goggles, expose the sheet to a single pulse from the laser and incrementally lower the cutting head (or raise the metal sheet) and move the sheet laterally before pulsing again to avoid exposing the same area of the sheet. Continue lowering the head and firing the beam until the first blue flash is seen. Make a note of the reading on the micrometer adjuster on the cutting head.
6. Continue lowering the lens and firing the beam on new areas of the stainless steel target until the blue flash event rises to a maximum and subsequently dies away – note the micrometer reading of the laser position at which a final blue flash is observed.
7. Position the micrometer adjustment between the first and final blue flash positions. For most practical applications this can be considered to be the focal point. Checks can be made by repeating the test at a different pulse power to get a smaller spread between the blue flash start and end points. Alternatively, use a different target material, for example aluminium should give a much narrower range than stainless steel. Do not use anodised aluminium as the aluminium oxide coating absorbs the beam too readily and obscures the result. Some materials give a white rather than a blue flash but this does not affect the results.

The Drilling Test

This test works on the assumption that the smallest diameter beam (ie at the focus) will drill the smallest hole in thin sheet material. Use a sheet of thickness between 0.5 and 1 mm in either wood, a wood based product or acrylic. Such materials have low thermal conductivity, thereby minimising thermal 'spreading' of the hole if a pulse is held on for too long; also, these materials are readily ablated and are highly absorptive of the beam, so holes are rapidly created.

The set up is the same as for the blue flash test with the nozzle removed from the cutting head and a substantial flow or assist gas. Fire the beam onto the sheet (use a laser power similar to the intended cutting power for half a second or so), then change the lens-material distance and fire again on a new area of the sheet. The position of the focus is the one that gives the smallest hole. It is important to make measurements both sides of the focus in order to establish the mid point accurately. One method of speeding up the test is to mount the sheet of material at an angle to the horizontal; as the sheet is translated horizontally the lens-material distance changes automatically. □

**'CO_2 Laser Cutting' by Dr John Powell is now available in paperback at £37.50 from major booksellers or the publishers; phone 0148 411880 (Published by Springer, 270 pages, ISBN 1 85233 047 3)*

Future Perspectives of Laser Manufacturing Technology and Applications

Reinhart Poprawe, Peter Loosen, Dirk Petring, Andreas Ehrhardt
Fraunhofer-Institut für Lasertechnik
Steinbachstr. 15 Aachen D-52074 Germany. email: poprawe@ilt.fhg.de

Over the past decade lasers have evolved to important standard tools for industrial manufacturing technology due to their advantages such as high processing speed, accuracy and flexibility. This is clearly reflected in the development of the market for laser beam sources and laser systems (beam sources plus handling systems), which grew with an average rate of approximately 20% p.a. over the last years and has reached 1997 a volume of 1,4 and 4,1 billion DM resp. (Figure. 1).

This remarkable size and growth is constantly driven by new market needs and customer requirements, which are initiating the evolution of laser beam sources towards higher output power, higher beam quality and lower costs. Recent investigations of this kind for 'classical' CO_2- and lamp-pumped solid-state lasers are discussed in section 2 as well as results and trends at more advanced systems such as diode-pumped solid-state lasers and diode lasers for direct applications.

With these new laser beam sources becoming available now, the spectrum of economical relevant laser applications can be broadened considerably. Thicker materials can be cut with high quality and laser cutting systems have the perspective to compete with punching presses in the future as discussed in section 3. Diode-pumped solid-state lasers in the kW-range are tested in first applications as discussed in section 3 along with recent results in the field of high-power welding of aluminum with high-power lasers and related process control. A completely new type of laser, the high-power diode laser, is presently in the state of qualification for different applications, some examples will be discussed in section 4.

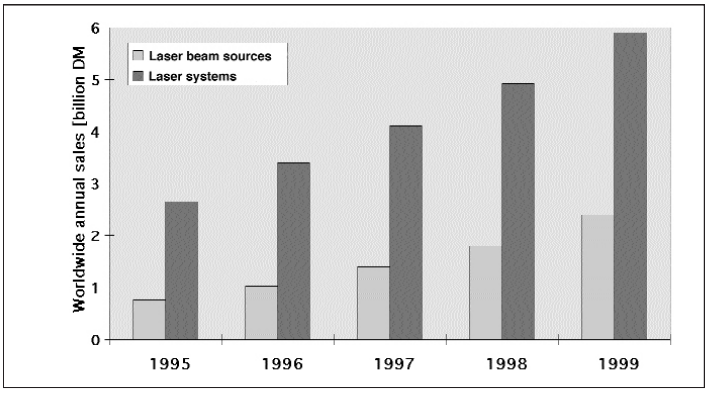


__Figure 1.__ Development of the market for lasers and laser systems (1998 and 1999 estimated) [7]

2 Lasers for industrial materials processing

The dominant beam sources for materials processing presently are CO_2- and lamp-pumped Nd:YAG-lasers. In Table 1 typical data for such lasers are compared to the predicted output of diode-pumped solid-state lasers and high-power diode lasers for direct applications. The most important parameters, defining the application range of a laser, are average output laser power and intensity at the workpiece. For aberration-free optics of a given numerical aperture, the latter is proportional to the laser beam quality expressed as the Beam Parameter Product (BPP) of half beam width and half beam angle. (*Editors note: See Brooke Ward's comments in Issue 11, p22 for the relationship between M^2 and BPP in mm.mrad. The latter is particularly useful for comparing laser beams of different wavelengths.*)

The laser parameters 'average output power' and 'beam quality' are displayed in Fig. 2 for the most common processes used in production technology. The dominant applications to date are cutting and welding of metals. These applications require lasers with high average powers in the kW-range and intensities at the workpiece which can only be achieved if the BPP is well below 100 mm.mrad. Apart from these high-intensity applications a large variety of laser applications have been demonstrated, covering the laser power spectrum from some 10 Watt to several kW, but requiring only low or medium beam quality. Examples include transformation hardening and the soldering of electric and electronic parts. However, due to the fact that such lasers are generally still too expensive, bulky and inefficient, many such applications have not found the way into a mass-market.

__Table 1.__ The first two columns shows typical data for existing commercial systems. These can be compared with the predicted data for diode-pumped solid-state lasers and high-power diode lasers (third and fourth column).

Property	CO_2-laser	Nd:YAG laser lamp-pumped	Nd:YAG laser diode-pumped	High-power diode laser
Wavelength [µm]	10,6	1,06	1,06	0,8 - 1,0
Efficiency [%]	5 - 10	1 - 3	10 - 15	30 - 50
Average output power	up to 40 kW	up to 4 kW	up to 5 kW	up to 6 kW
Intensity in focus [W/cm^2]	$10^{6...8}$	$10^{5...7}$	$10^{6...9}$	$10^{3...5}$
Fibre delivery	no	yes	yes	yes
Maintenance period	1.000 - 2.000	500 (lamps)	5.000 - 10.000 (diode lasers)	5.000 - 10.000 (diode lasers)

Figure 3 has the same axes as Figure 2, and a direct comparison of the two indicates that all processes shown in Figure 2 can be performed with currently available CO_2 and lamp-pumped solid-state lasers. The decision between the two is usually made according to process, materials properties, beam handling and economics.

A typical example of an industrial CO_2-laser is given in Figure 4. The laser employs diffusion cooling technology, where the waste heat is removed by heat conduction to the water-cooled electrodes of the rf-gas discharge which excites the laser medium. Other high-power lasers use a fast axial gas flow to cool the laser medium. This technology has been scaled in commercial lasers up to approximately 30 kW. The system in Figure 5 utilises a fast axial gas flow, driven by 4 turbo-blowers. By careful matching of the gas flow to the rf-excited discharge the active medium can be made very uniform, thereby producing a high-quality beam near the theoretical limit for the unstable resonator it uses[8].

Whilst CO_2-lasers have achieved a high level of sophistication in terms of output power, beam quality and reliability, their use in applications where the beam has to be moved in three dimensions, car body welding for example, is limited by the lack of optical fibres at the far infrared (10,6 μm) CO_2 laser wavelength. In contrast, beams from solid-state lasers can be transported via fibres and such lasers are presently available up to approx. 4 kW cw lasers (Figure 6). However, in comparison with CO_2-lasers their efficiency is small, a high degree of maintenance is required, due to limited lamp-lifetime, and beam quality is considerably lower.

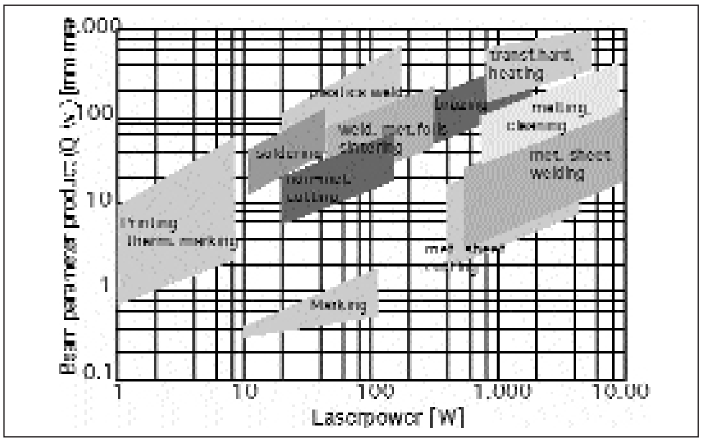


Figure 2: *Laser parameters for the most common processes. The beam quality, measured as beam-parameter product (BPP), was calculated on the basis of a F4 focusing optic.*

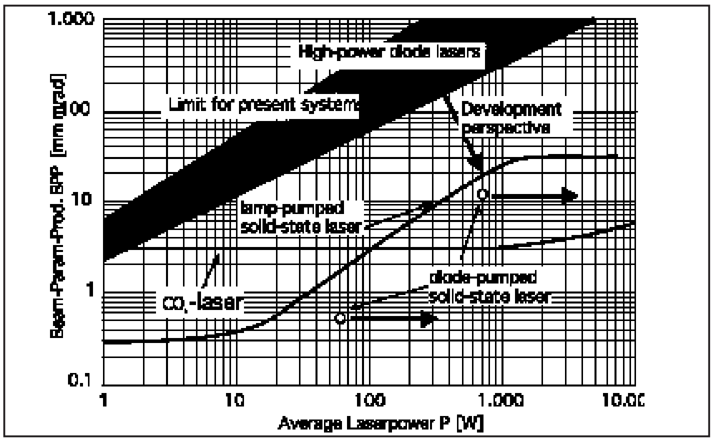
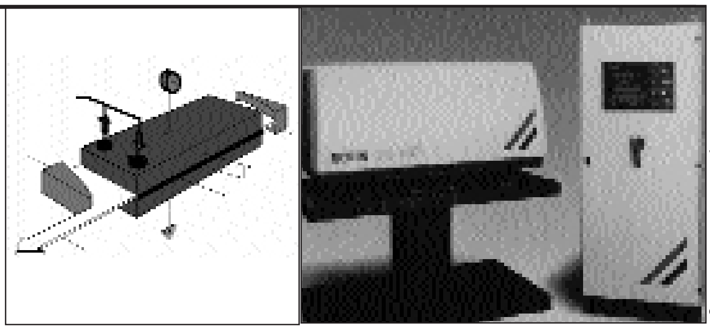
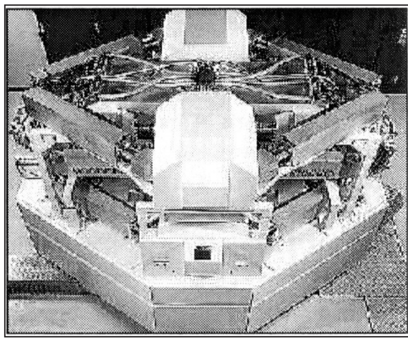


Figure 3: *Average laser power and beam quality for the lasers listed in Table 1, using the same axes as in Figure 2. The curves plot the best beam quality (i.e. minimum BPP) quoted for currently available systems .*



Courtesy Rofin-Sinar, Hamburg

High power CO_2 laser technology

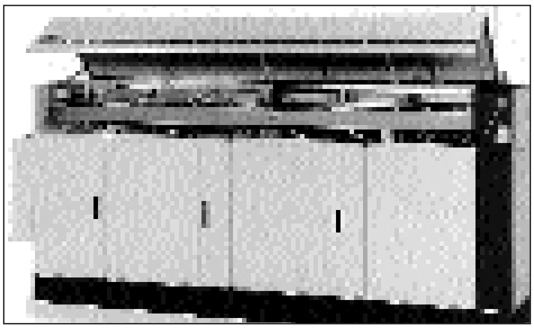


Courtesy Trumpf, Ditzingen

Figure 4: *(above) Commercial CO_2-laser with diffusion cooling, output power range up to 2,5 kW.*

Figure 5: *(right) Commercial CO_2-laser with fast axial flow, output power 20 - 30 kW.*

High power YAG laser technology



Courtesy Haas, Schramberg

Figure 6: *Commercial lamp-pumped solid-state laser, output power up to 4 kW.*

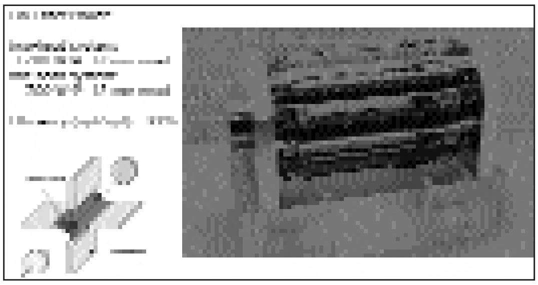
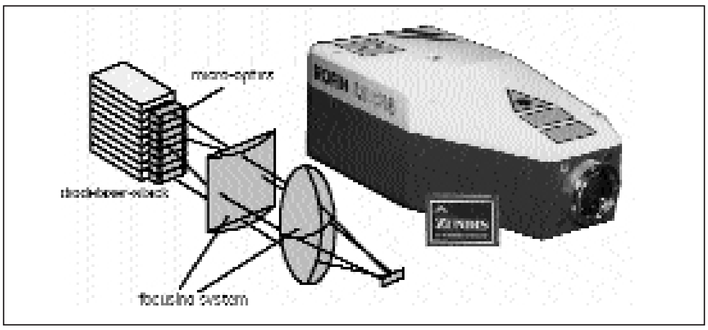


Figure 7: *Laboratory type diode-pumped solid-state laser. The active medium, a Nd:YAG rod, is transversely pumped by high-power diode lasers.*



Courtesy Rofin-Sinar/DILAS

Figure 8: *Schematic and industrial system of a diode laser for direct application, output power up to 2 kW.*

High-power diode lasers, for pumping solid-state lasers as well as for direct applications, will contribute to overcome these problems in the future (see Table 1). In diode-pumped solid state (DPSS) lasers the lamps used for laser excitation are replaced by highly efficient and long-life diode lasers. The laboratory set-up of such a system with a maximum output power in the range of 700 - 1.200 W is shown in Figure 7 and demonstrates the large potential of this new technology. Such lasers have a higher beam quality and a considerably higher efficiency than lamp-pumped systems and can thus be made 2 - 3 times more compact. A commercial system, based on this technology will be available within the next few months and will be scaled up to 5 kW.

A further large step towards even more efficient and compact laser sources is the use of diode lasers, not for pumping a laser crystal but directly for materials processing. Present sources combine the diode lasers in stacks as shown in Figure 8, and provide maximum output powers of approximately 3 kW and intensities at the workpiece of approximately 10^4 W/cm^2. This relatively low intensity is due to the relatively poor beam quality of these lasers (see Figure 3) and presently limits uses to such applications as plastics welding and transformation hardening. Current investigations are aimed at increasing output power and beam quality to match those achieved by lamp-pumped solid-state lasers.

3 High-power CO_2 and solid-state laser applications

Cutting of metal sheets with CO_2-lasers is a well established industrial process. Steel sheets are cut commercially up to thicknesses of approx. 20 mm and speeds up to approx. 15 m/min (at a thickness of 1 mm). Current developments are aimed at higher material thickness and cutting speeds. In order to achieve this, process simulation and advanced system components, such as cutting heads and sensors, are needed. Laser cutting is a complex multi-parameter process that cannot be scaled up efficiently by a simple variation of parameters, which is why process simulation is key to opening up new cutting applications.

Figure 9 shows examples of high quality fusion cutting of stainless steels. The cutting parameters (laser beam size, F-number of the focusing system, position of the focal spot etc.) have been carefully optimised on the basis of detailed computer-simulations of the process[1]. These calculations show, for example, that stainless steel with a thickness of 40 mm can be cut with a 10 kW-laser at a speed between 150 and 200 mm/min and high quality (average roughness Rz between 150 and 200 mm, tolerance in rectangularity below 300 µm) and that even higher cutting speeds and thickness are achievable with higher laser powers, Experiments currently under investigation based on the 20 kW CO_2 laser shown in Figure 5.

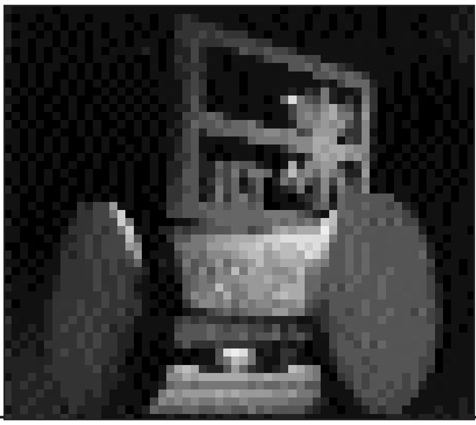


***Figure 9:** Examples for laser fusion cutting of thick stainless steel with thickness between 6 and 40 mm. The cut edges are free of oxides.*

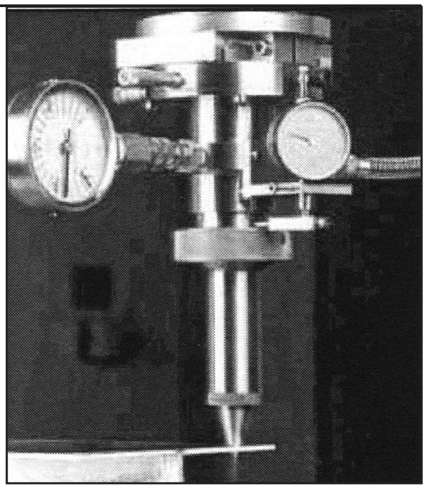


***Figure 10:** 'Autonomous' nozzle for laser cutting without transmissive optics: the component uses solely reflecting optics thus enabling high gas pressure and laser power.*

Schlieren-diagnostics as well as practical experience indicate that cutting gas flow has to be increased considerably for thicker material. Regular transmissive focussing lenses would fail at the required gas pressures and laser powers due to the high mechanical and thermal stresses. This problem has been solved by the focusing optics shown in a special version in Figure 10. The technology is already well-proven in industrial cutting machines and commercially available[2]. It consists of a focusing mirror and a nozzle system which sets up the required gas pressure and gas flow conditions without the need to seal the gas chamber, as it is the case in ordinary cutting heads with lens focussing. This technology was used to cut the samples in Figure 9.

The second development trend in laser cutting is aiming at increasing cutting speed. Due to recent improvements in the technology of CNC and linear drives, handling systems for laser cutting are able to operate at speeds which in principle would make

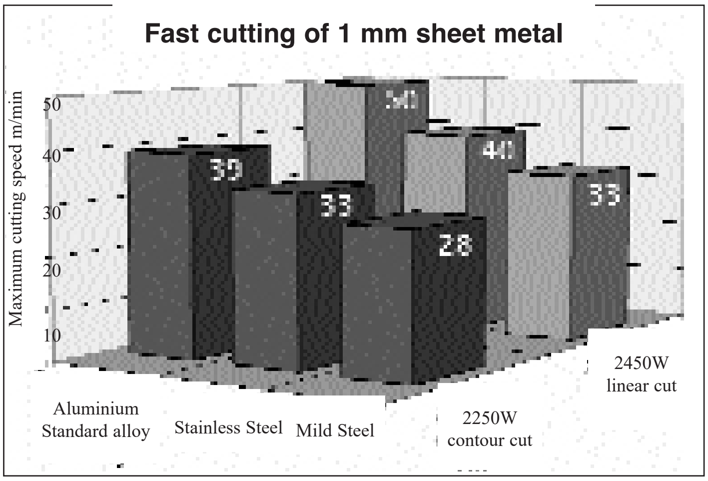


***Figure 11.** high-speed cutting results with flat sheet metals (cut with a fast axial-flow CO_2-laser of approx. 2,5 kW output power)*

***Figure 12** View on the edge of a fast cut sheet (CO_2-laser, 3,4 kW, s = 1 mm, Aluminum, 75 m/min cutting, tool rotationally symmetrical)*

laser cutting systems as productive as punch presses, but much more flexible. However, the most important target is to achieve a significant increase in the laser cutting speed over present limits.

For thin metal sheets of thickness of some 0.1 mm a cutting speed of up to 300 m/min was demonstrated some years ago and has recently been commercialised for laser slitting lines[3]. Based on this experience and using lasers with excellent beam quality, the cutting speed of 1 mm thick metal sheet has been raised to values currently between 30 and 75 m/min (Figures 11 and 12). Even higher cutting speeds appear achievable in the future, but the development of an appropriate system technology for fast contour cuts has still to be completed. An important key for these results have been the use of computer simulations to identify the real process limits.

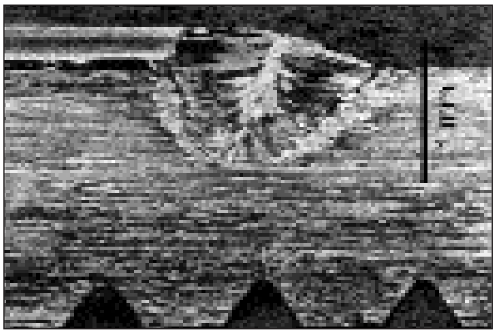
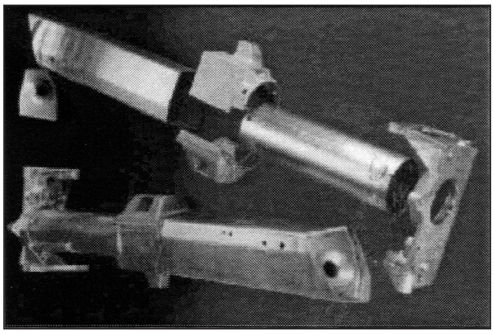


Figure 13. *Welding of stainless steel with a diode-pumped solid-state laser. (laser power 650 W, beam quality of 12 mm mrad). The beam was delivered via a fibre of 300 µm core diameter, NA 0,22.*



Courtesy of Audi AG

Figure 14. *Laser welded aluminum space-frame components.*

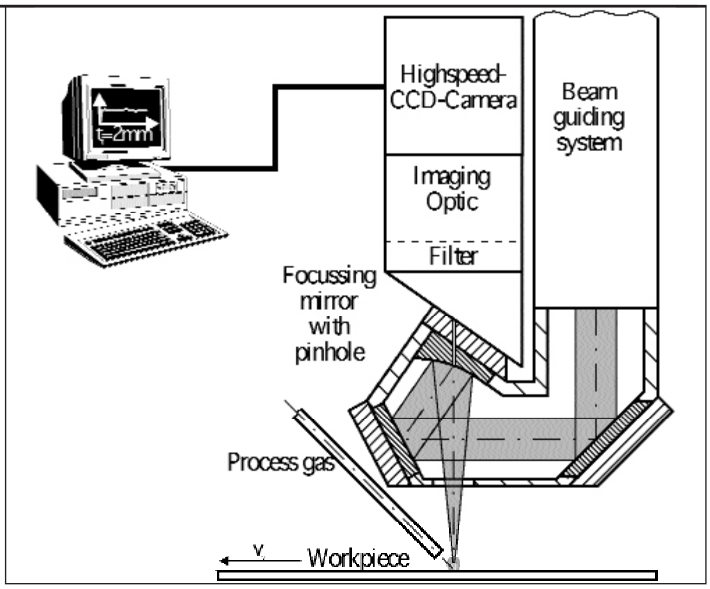


Figure 16. *(above) Principle of the sensor for on-line measurement of the keyhole geometry (CO_2-laser version)*

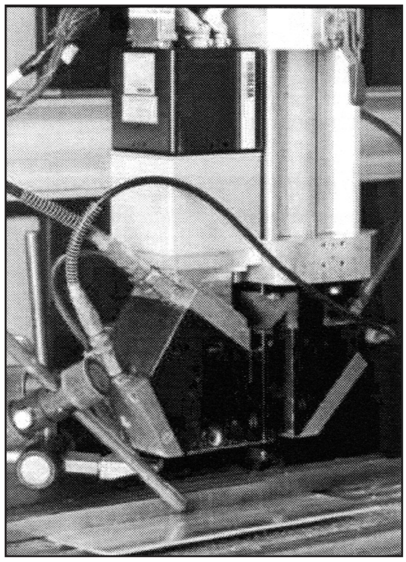


Figure 17. *Experimental set-up of the keyhole sensor*

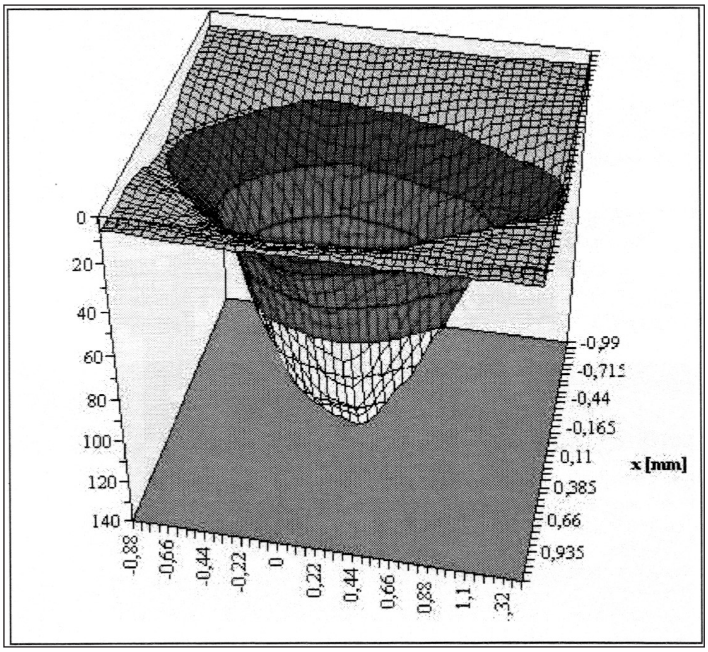


Figure 15. *Geometry of the keyhole, produced by an elliptically shaped CO_2-laser beam for high-quality welding of aluminum without blow-out weld defects*

High speed in combination with high flexibility thanks to fibre delivery characterises the welding application in Figure 13, which was carried out with the DPSS laser such as is shown in Figure 7. The experience gained so far with the practical use of this system revealed not only technical advantages such as small focal spot size, but also that such diode-pumped systems can be integrated easily into existing production lines due to their small foot-print, low energy consumption and low electrical power supply and cooling requirements.

Considerably higher output powers are needed for the welding application illustrated in Figure 14 which shows components of the space-frame of an Audi A8 body. Audi has proposed and jointly investigated the technique of laser welding the extruded aluminum profiles to the cast connection elements. In corresponding studies, it has been proven that CO_2 lasers, Nd:YAG lasers as well as hybrid processes, combining laser and arc welding, can be employed. However, one of the main problems in aluminium welding is that the welding process suffers from instabilities in the melt flowing around the keyhole. These instabilities give rise to the blow-out of melt, leaving back holes in the weld seam. Following detailed process analysed using the keyhole sensor discussed below, the process stability was increased considerably by changing the beam spot from a circular to an elliptical geometry, thus producing an elliptical keyhole (Figure 15) without any blow-out in the resulting welding seam. This is in agreement with other investigations and approaches[4], but in comparison to these solutions the elliptical beam used in our investigations can be easily produced by the simple and low-cost replacement of a mirror in the focusing head.

The experimental basis for these investigations has been a sensor for time-resolved monitoring of the keyhole depth. It has been shown that under conditions usually found in laser welding the local intensity of the plasma glow is a measure of the depth of the keyhole[5]. This can be used either for simple sensors, monitoring the maximum depth of the weld seam for quality control in production, or for more sophisticated set-ups as shown in Figures 16 and 17 for the measurement of the complete geometry of the keyhole. The later has been used to design the optimum shape for the elliptical focus for stable aluminum welding.

(with courtesy of Marquardt GmbH)

Figure 18. Electronic car-key: the cover plate has been welded on the case by diode lasers

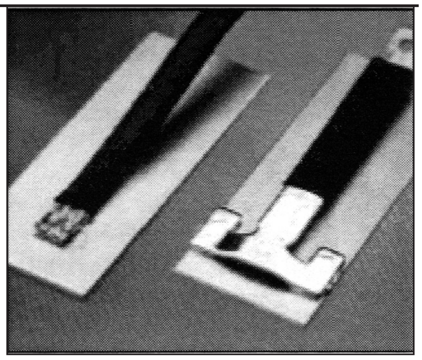


Figure 19. Soldering of electrical connecting braids by diode lasers

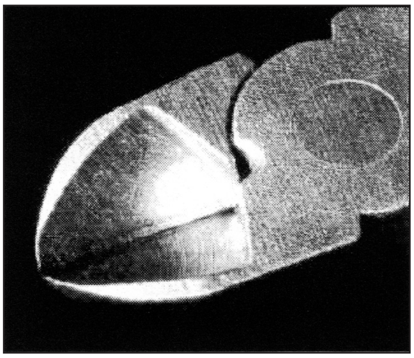


Figure 20. Transformation hardening of the knife-edges of a side-cutter

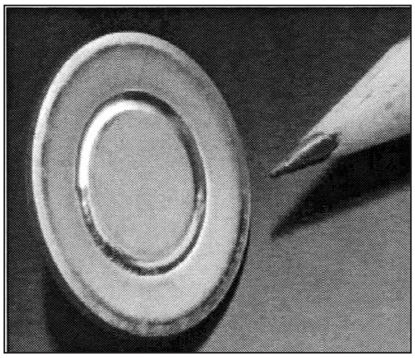


Figure 21. Heat-conduction welding of a stainless steel coin (600 W, 1,5 mm thick, 200 mm/min)

4 Applications of high-power diode laser systems

Despite the fact that the direct application of diode lasers is quite a new technology, a couple of processes are already used industrially or are tested at a pre-production stage. Medium and high power applications as illustrated below were performed with stacked diode lasers as shown in Figure 8 at powers in the range of 100 W - 3.000 W.

In applications requiring lower laser power, such as the welding of plastics cases in Figure 18, fibre coupled diode lasers in the power range of 10 - 100 W are usually employed[6], being focused to a spot diameter of about 1 mm. This can easily be achieved with diode lasers and facilitates a highly flexible design of weld geometry. In addition, diode laser welding of plastics offers several advantages including high accuracy, direct process and quality control (via temperature monitoring), and suitability for less accessible parts and to thermoplastic elastomers, which cannot be welded by conventional processes.

Another industrially emerging application is the soldering of electronic and electrical components (Figure 19). Again, only moderate laser power and beam quality is needed: 10 - 100 W focused to a spot diameter from 0.1 mm up to several millimetres.

Transformation hardening with lasers has been intensively studied and tested in the past, but has only seldom been applied in production lines so far. It has proved excellent from the technical point of view, but was in most cases too expensive and too complicated to be integrated into existing production environments. In both respects the industrial process will benefit from the lower costs and the compactness of diode lasers. In addition, illustrated in Figure 20, diode lasers have the advantage of emitting a beam which is already rectangularly shaped and thus matched to the geometry of the workpiece.

The last example in Figure 21 illustrates that metal welding with diode lasers is possible in principle. However, the relatively slow heat conduction welding process as shown is fundamentally different from the deep penetration welding usually performed with lasers. Focussed diode laser intensities at the workpiece are currently too low to create a keyhole, which is a prerequisite for high processing speeds. Nevertheless, if current investigations are successful and the predicted performance indicated in Figure 3 is realised, then diode lasers will find a place even in the classical laser applications of cutting and welding of metals.

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Lasers in Marking and Coding

Clive Ireland

Technical Consultant

88 Hillmorton Road Rugby Warwickshire CV22 5AH email: clm.ireland@zetnet.co.uk

Laser marking has a long history. In the 1950s and early 1960s scanned e-beams were being used for surface modification processes, and it was a natural development to use laser beams when they became available. US Patent 3,112,850, 'Dicing of Micro-Semiconductors' (1963) and an article 'Electron and Laser Beam Processing' by Namba & Kim in Jap J Appl Phys (1964) disclose use of a scanned focused e-beam or laser beam to scribe patterns on the surface of materials eg stainless steel parts, or silicon for dicing wafers

US Patent 3,256,524, 'Laser Recording Apparatus' (1966) discloses use of a galvanometer scanned CW or pulsed (1-3kHz) focused laser beam to write information onto a material by forming a visually contrasting or perforated surface eg for recording data. Although not referred to as marking in the patent, this clearly is the process that it describes. In, 'Laser Application to Part Number Printing & Reading' by Holzinger et al in Opt Comm (1972) laser marking through a mask/stencil that is imaged for generating very durable part identification via engraving is described. That is, by the beginning of the 1970s, the concept of laser illumination of stencils for etching characters, and the importance of machine readability were noted.

Since the Nd:YAG and CO_2 lasers were first operated in 1964, and the TEA CO_2 laser first in 1970, the above publications show that laser marking as an application developed simultaneously with the sources ie surface marking is one of the earliest industrial applications of lasers.

Technology

The principles of laser markers are straightforward. In vector marking a focused beam is scanned over the part surface by a pair of orthogonal galvanometer mirrors and changes the surface to make a visible marked track. The beam is usually pulsed, but can be CW. Large characters, bar-codes, etc can be built-up by arrays of marks. Products are largely differentiated by the type of laser source (eg wavelength, beam quality) and the drives and software for controlling the galvanometers. The fastest commercial systems can write 200-300 small characters/s.

The mask marking method uses a stencil that is laser illuminated and imaged to the workpiece. The mark rate is the laser pulse rate. The technology was developed first with TEA pulsed CO_2 lasers, which typically run at 10s of Hz, but is now also used for some specialist applications with UV excimer laser pulses. With stencil marking, the mark shows the WEB from the metal mask.

Much more recently, a third type of marker has been developed for applications where high speed and low cost are key, and mark quality and versatility are lower priorities. These are based on kHz type pulsed or modulated lasers, particularly CO_2 waveguide lasers. Again the concept is straightforward. For example, in the

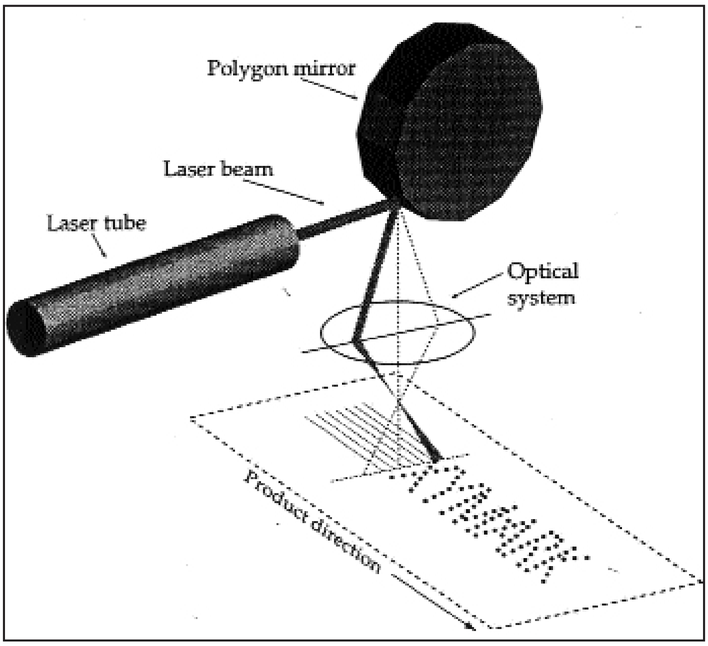


Figure 1 High Speed Dot-Matrix Marker (From 'Marking, Coding and Labelling' published by PERA (1997))

Lumonics XymarkTM system, a polygon deflector scans at high speed and the high rep rate laser is modulated on and off to put down linear rows of dots. Combined with the constant movement of the part on the marking line, this results in a dot-matrix pattern, as shown schematically in Figure(1). Table (1) shows the print speed of these type of markers ie 1kHz to 2.5kHz, an order of magnitude higher than vector markers and mask markers (assuming a mask marker puts down 5-10 characters/code).

Marking Market

A recent article which included Table (2) compared the merits of laser marking with more traditional methods. It can be seen that vector marking is the only technology assessed as 'Good' under all four headings. However, the choice of marking technology is very much, 'horses for courses' with the buyer getting what he/

Table 1 Comparison of laser printer specifications
From 'Marking, Coding and Labelling' published by PIRA (1997)

Manufacturer	Type	Format	Print speed	Character Height mm
Willet	dot matrix	1-3 lines	2500 cps	1-15
Linx	dot matrix	1-4 lines	2400 cps	1.5-9
Domino	dot matrix	1-2 lines	1000 cps	1-11
Lumonics	dot matrix	1-4 lines	2000 cps	
Imaje	mask	250mm^2	25*	0.4-15
Lumonics	mask	18 x 75 mm	30*	

* codes per second

Table 2 *Comparison of marking methods (Adapted from article in Injection Moulding, March 1998)*

COMPARISON OF MARKING METHODS
(Adapted from article in Injection Moulding, March 1998)

Marking Process	Speed	Permanence	Quality	Flexibility
Laser Vector Marking	Good	Good	Good	Good
Laser Mask Marker	Good	Moderate	Moderate	Poor
Chemical Etch	Good	Good	Good	Poor
Photo Etch	Good	Good	Good	Poor
Inkjet	Good	Poor	Moderate	Good
Mech Stamp	Good	Good	Poor	Poor
Nameplates	N/A	Moderate	Good	Poor
Casting/Moulding	Good	Good	Poor	Poor
Pneumatic Pin	Moderate	Good	Moderate	Moderate
Vibratory Pencil	Poor	Good	Moderate	Good

she pays for. Laser vector markers score well but are the most expensive – typically $50-100k for a system. In comparison laser mask markers don’t score so well, but are typically $25-40k, whereas a small character inkjet system might be $10k – at least half the price of the nearest laser marker.

In the case of laser markers, the result of sales and market analysis by Optech Consulting is summarised in Table (3) for 1993, with a forecast for the year 2000 also shown. These numbers suggest that marking is the biggest laser application (excluding laser diodes) in terms of global unit sales.

The market study shows that marking electronic components and semiconductor chips has been (and will remain) a big application for Nd:YAG vector markers. In 1993, many TEA CO_2 lasers were used for coding in the food and beverage industries. (NB coding is a sub-set of marking referring to applying date stamps, lot numbers, bar codes, etc in packaging type industries). Contemporary market research shows that dot-matrix marking sales have grown more strongly than Optech Consulting forecast in 1994. Now such sales exceeds TEA CO_2 laser marker sales, with the latter probably declining relative to the 1993 data due to the lack of flexibility and low speed of the technology. The Optech Consulting forecast shows overall sales heading towards 5,000 units/yr with revenues moving from ~ $100m to ~ $200m over the 1993-2000 period. The biggest segments were forecast to remain electronics marking and food & beverage coding. (NB: for comparison, small character inkjet marker sales are estimated as ~ 20,000/yr).

Table 3 *Optech consulting market data (January 1994). World Market for marking lasers 1993 & 2000. Units.*

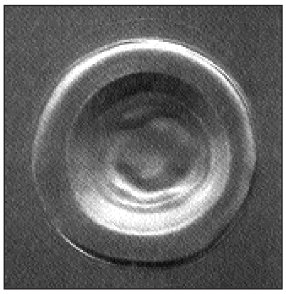
Industry	1993				2000			
	YAG	CO2 TEA	CO2 Dot Matrix	CO2 Vector	YAG	CO2 TEA	CO2 Dot Matrix	CO2 Vector
Auto	168				422			
Machine & Tool	178				259			
Elec, Electron & Office	502	148	120		961	204	224	
Medical	60				123			
Fine Mech & Measure	28				53			
Job Shops	31				56			
Food & Beveridge	1	607	78		660	887	904	
Misc	65	20		216	161	32	72	375
Total	1033	775	198	216	2695	1123	1200	375
Forecast Annual Growth%					14.7	5.4	29.4	8.2

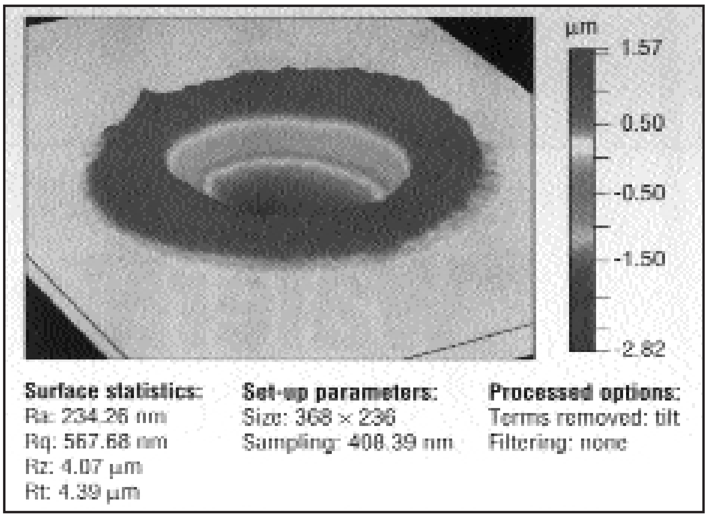
Applications Examples

Semiconductor Wafer Marking

Early important marking applications were in the semiconductor/electronics sector. A good example is marking silicon wafers with Nd:YAG vector pulses for tracking purposes. A magnified inspection of a ~ 100µm dot mark on silicon made in the 1970s shows it looks something like a moon crater with debris all around the rim. Today debris generation can’t be tolerated as adjacent circuit feature sizes are sub-micron. Now there are very tight industry specifications on the debris generated and all marking is in a Class 1 environment. However, the need remains for marks to be of a sufficient depth (2-3µm) such that they are readable after all the wafer process steps, and they also must not put stress in the wafer surface.

Figure 2 *Debris Free Mark in Silicon. SEM record of Debris free mark in Si (right), and WYKO surface profile measurement showing depth of mark (below).. Parameters can be controlled to give marks of 70 µm ± 10 µm and depth 2.5 µm ± 0.4 µm, and particle count of < 0.02/cm² for particle of 0.17 µm size of larger*





The main difficulty in marking silicon is the very rapid change in its absorption with laser wavelength and with temperature. For Nd:YAG laser pulses, a ~ 250 µm absorption depth at 20˚C becomes ~ 35 µm at 300˚C, and in the micron range at 1410˚C - the silicon melting temperature. However, by use of new very stable lasers (eg diode pumped YAG), the pulses can be controlled in peak power and duration to ~ 1% so that the surface melts but with very little evaporation and next to no particles. Under such control, the vapour pressure generates a shallow depression which solidifies as a frozen wave without splash generation at the end of the pulse. Figure 2 shows the typical result.

Plastics Marking

Plastics marking is a big application (eg in the electrical and packaging industries), but a number don’t mark well – they tend to have narrow absorption lines and bands that don’t correspond to laser wavelengths. There are as many poor as excellent materials in this respect. Fortunately, there are some additives (see Table 4) that are known to enhance marking of polymers without changing

Table 4

ADDITIVES KNOWN TO ENHANCE LASER MARKING OF POLYMERS
Pigments
Mica
Titanium Dioxide
Alumina Silicates
Iron Oxide
Aluminium

key physical characteristics eg strength, or electrical properties. Unfortunately, marking is often not an essential requirement and chemical companies have been reluctant to use laser markable additives in such cases, particularly if they significantly increase costs.

However, there are a growing number of applications where improved product marking has been the result of additives. Wire marking for aerospace applications is an important case. The PTFE insulation is very thin and must not be damaged. By good fortune, TiO_2 is already used in the insulation to give it desirable physical properties. Pulses from an excimer laser produce a surface mark without affecting the integrity of the insulation. The colour change is chemical, oxygen deficient TiO_2 is formed under irradiation resulting in permanent colour centres.

Besides simple marking, it is possible to make a 'grey scale' by using various laser patterning techniques, and by changing pulse energy – so long as mark width or spot size changes with pulse energy (unfortunately in many plastic there is little or no dynamic range). An example of grey scale on white high density polyethylene is for black & white photographs on bank or security cards marked by Nd:YAG vector markers. Some European banks are using lasers for this application, but the results are modest compared with more conventional printing techniques (eg dye diffusion) which give full colour and are therefore more popular, particularly in the USA.

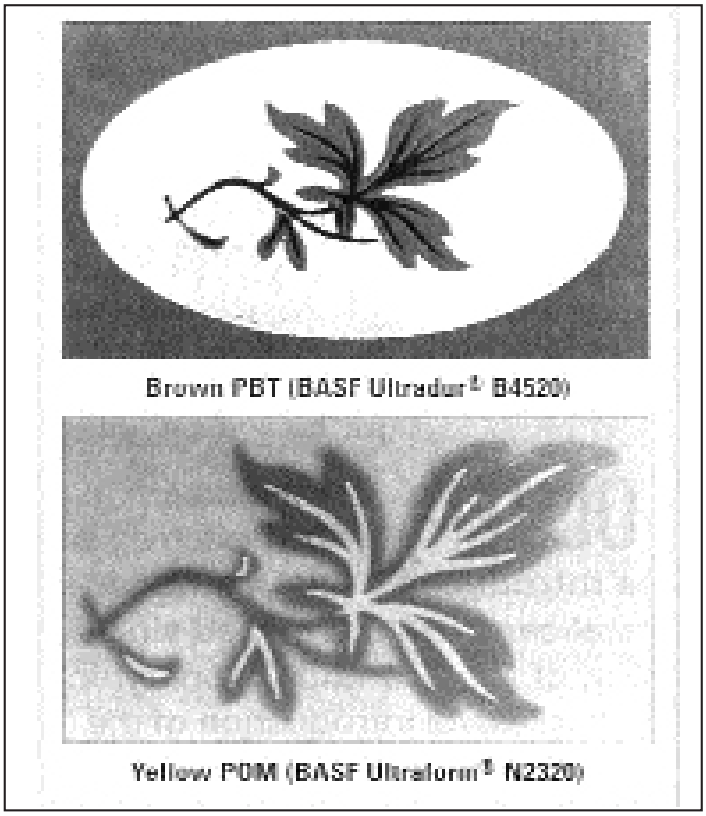


Figure 3 *two marks are shown in materials where low pulse power tends to bleach the plastic, but carbonise it at higher power. As a result, the coloured plastic can be changed in a controlled way to white or black.*

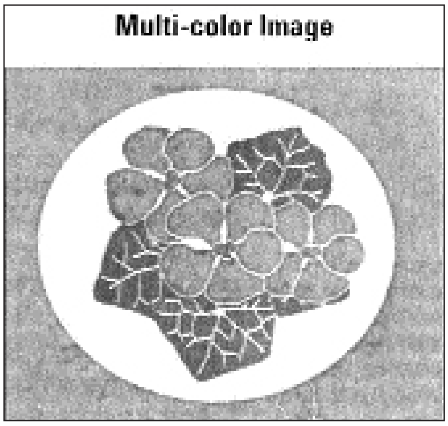


Figure 4 *The colour change is to white then green with increasing pulse energy, giving three colours.*

Colour Marking

Interestingly, there are some materials and additives that change colour when marked, so decorative colour marking is becoming possible. In Figure 3 two marks are shown in materials where low pulse power tends to bleach the plastic, but carbonise it at higher power. As a result, the coloured plastic can be changed in a controlled way to white or black. In Figure 4, the colour change is to white then green with increasing pulse energy, giving three colours.

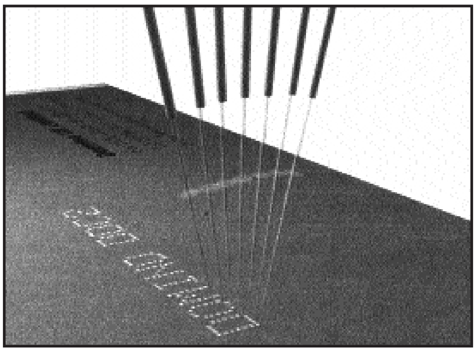
Also, in specific cases, colour marking on metals has been achieved. Titanium develops an oxide film when laser marked. The thickness of the film can be controlled by the laser parameters. Under white light illumination, interference in the film generates a colour pattern. In Japan, a scanned pulsed Nd:YAG laser beam has recently been used to vector mark stainless steel in such a way that 1 μm scale ripples (generating a diffraction grating in the surface) normal to the motion direction result. Again, careful control of the laser pulses has been found to control the period of the ripples and the colour generation in white light. In both cases, remarkable coloured patters have been generated.

Future Prospects

With regards the future, the main development trends in laser marking and coding are believed to be:

- The availability of lower price systems for coding to further compete with inkjet markers, and to increase sales volume
- Higher speed for all types of marking products. Improved speed means improved productivity and a higher economic return for users
- More products tailored to 'niche' applications eg markers with wavelength tunable to material absorption peaks. Like the wafer marker and UV wire marker, such niche products are likely to be high added value.
- Marking with improved quality, including colour marking. There is a growing interest in decorative marking to compete with traditional printing but allowing easy product customisation very late in the manufacturing cycle, and
- The continued market growth and product innovation is expected to keep marking and coding as the No 1 industrial laser application, in terms of unit sales.

COMMENT
Some suppliers views on laser marking



The Domino range of laser coders is able to print 1-3 lines at 2000 characters/s. This increase in speed was made possible with the introduction of high speed tubes about a year ago. The patented multi-tube head uses seven low power lasers to mark the substrate, rather than using one tube to mark all positions in the vertical axis, this allows the coder to mark at very high speeds (two lines of code at 5 m/s is not unusual), also due to the way the multi-line optics work, this high speed is also available on multi-line applications. Domino manufactures its own laser tubes and as such has been able to develop systems for niche markets like flow wrap, glass and plastics coding.

Robert Squires
Domino UK

Laser markers are having a good time at the moment. People want faster marking, better marking and cheaper marking. Rofin make what look at first sight to be expensive markers, but cost of ownership and running costs of our lasers are low and reliability and performance are very high. So we are selling into those areas where these are important, for example car manufacturers, on-line production systems, etc. i.e. applications where down time is rated as a cost. With a well designed laser marker, downtime is designed to be minimal. Not all customers think about the cost of ownership when they are buying a product. A few pounds more spent on the equipment in the first place often is paid back many fold in lower running costs.

Tim Holt
Rofin- Sinar Laser

It's good to see the importance of laser marking and coding as the highest volume application of industrial lasers being stated. A simple vector system using a low powered air cooled sealed CO_2 laser now costs only $25k and the price trend is definitely downwards. A vector marking system typically only requires 10-25 W of laser power compared to the 60-100 W required by dot matrix systems hence the laser can be directly air cooled without heat exchangers or refrigerated coolers.

It is true that vector CO_2 marking cannot match the 2,500 cps print speed quoted for dot matrix systems, however 130 cps is more than adequate for applications away from the packaging industry. With exception of bare metal CO_2 vector markers can mark most materials including anodised Al, oxidised steel, plastic, acrylic, glass, packaging etc. As well as simple text vector CO_2 systems can also be used to mark logo's, barcodes and 2D matrix codes.

I would also like to comment on the volume of sealed CO_2 lasers being used in marking and coding. The latest figures I have access to show about 1400 sealed CO_2 lasers being supplied world-wide for marking and coding. The number of these that were supplied for vector applications is certainly far higher than Dr Ireland's projection for two years hence.

Both CO_2 marking technologies have bright a bright future with dot matrix systems predominating for high speed alpha numeric coding in the packaging industries and vector CO_2 being used as a general purpose, flexible, lower speed and lower cost for other applications.

Steve Knight
Laser Lines

FAQ's about the Machinery Directive *(continued from page 13)*

machinery for their own use. Once installation and evaluation is complete, the machinery is effectively put into service and thus requires to be CE marked, etc.

Second-Hand Machinery

Q: *Does the Machinery Directive apply to second-hand machinery?*

A: The Machinery Directive 89/392/EEC applies only from the time a product is first placed on the market or put into service in the European Economic Area. As a result, it applies if the second hand machine enters the EEA from a country outside the EEA.

Thus machines which were on the market BEFORE the implementation of the Machinery Directive are not covered. Machines placed on the market after this date will comply and thus if they are subsequently sold as second-hand after initial supply, need to conform. They will generally conform with their original specification and thus the original Declarations of Conformity are appropriate. However if the machines have been significantly modified then they will almost certainly require re-assessment for conformity and a new Declaration issued by the manufacturer doing the modifications. Note that Switzerland, while a member of EFTA, is not a contracting party to the EEA agreement and, as a result, second hand machines originating in Switzerland are considered as originating outside the EEA. □

Economics of Industrial Laser Use

Gordon Freeman
Howden Laser
Charles Bowman Ave Claverhouse Ind Park Dundee DD4 9UB email: laser@howden.com

Anyone contemplating the use of lasers for industrial use for the first time may be interested to know what size the club is that they are likely to be joining. Here are some figures taken from market data published in *Industrial Laser Review*:

- World sales of all laser types (sources only) in 1997 were estimated at $3.2 billion and were forecast to grow 18% in 1998*.
- World sales of industrial laser systems (laser source plus workpiece manipulation etc.) in 1997 were estimated at $2.1 billion and were forecast to grow by 15% in 1998*.
- World sales of CO_2 laser systems in 1997 were estimated at $1.5 billion and were forecast to rise by 16% in 1998*.
- World sales of solid state laser systems in 1997 were estimated at $0.5 billion and were forecast to rise by 13% in 1998*.
- World sales of excimer laser systems in 1997 were estimated at $45 million and were forecast to rise by 11% in 1998*.
- In 1997 the geographical split of new laser installations worldwide was North America 51%, Europe 26% and Japan 23% by number and 36%, 36% and 28%, respectively, by value.
- In 1997 of all the laser installations 37% were in cutting, 16% in welding, 21% in marking , 18% in microprocessing, 2% in drilling and the remaining 6% in a variety of applications.
- In 1997 the geographical split of new solid state laser installations world-wide was North America 43%, Europe 26% and Japan 31% by value whereas CO_2 laser installations divided North America 32%, Europe 39% and Japan 29%.

**Forecasts were based upon data collected in late 1997 and should probably be revised downwards in the light of the present economic uncertainty.*

Laser system sales for industrial applications are significant in value but it is worth putting this into context in world economic terms by comparing this to the global electronics market which in 1997 was estimated at about $950 billion.

Why Use Laser?

There are a number of potential advantages in the use of lasers in industry, including:

- low noise and fumes.
- non-contact process so no tool wear.
- high quality edge, dross free, low heat effected zone.
- no appreciable distortion - cutting, welding and drilling.
- many secondary operations eliminated.
- rapid processing.
- flexible and easily integrated with computer controlled system.
- in case of Nd:YAG lasers, availability of optical fibres enables simple integration with standard robots.
- fit up sufficiently good such that laser cut parts can be 'self-jigging'.
- can be used either in on line production or in stand alone cell.
- same source can be used to cut, drill, weld and heat treat.
- narrow kerf.
- good utilisation of material

Obviously, not all the above will apply in each case. All of the advantages listed above have quantifiable economic benefits to help justify the investment in laser processing equipment; in some cases the technical benefits using the laser make it the only realistic option.

Many of the points above have been discussed in previous published articles but some provide significant cost benefits and are worth highlighting. Examples include the elimination of secondary operations, fibre delivery systems and self-jigging, where parts for welding can be laser cut to dovetail together and thus be assembled and held together without the need to build special jigs and fixtures.

Cost Considerations

The purchase of a laser system for material processing is, in economic terms, similar to any other equipment purchase in manufacturing industry in that costs can be categorised into the initial capital cost and the ongoing running cost as shown below.

1. Equipment Acquisition Costs

- Purchase Price of Equipment (this may be funded by lease finance or purchased outright)
- Installation Costs
  - Site civil work
  - Service supplies
  - Training costs

It is difficult to give anything other than a very general estimate of the likely purchase price of a laser system. It may vary from a simple system at perhaps £30-£50k up to a high power multi-axis installation costing £400k -£500k. Site installation costs are unlikely to be more that about 1-2% of the equipment costs. The financing of the purchase of the equipment can be done a number of ways with many companies using lease financing.

2. Running Costs

- Electricity (laser, machine motion system, laser chiller)
- Laser gas costs (for flowing gas lasers)
- Flash lamps (for some Nd:YAG lasers).
- Process gas costs
- Consumables (lenses, cutting gas nozzle tips)
- Spares and service costs

Table 1: Example of Running Costs of 3 kW CO_2 Laser System

Item	Consumption	Cost per hr of running	% of running cost
Electrical costs Laser Machine system Laser chiller **Total**	 33kVA 20kVA 15kVA **68kVA**	 £2.50 £1.60 £1.20 **£5.30**	 **38 to 61%**
Laser Gas (where appropriate) Hourly consumption	50 STP L/hr	£0.25	1.5 to 2.0%
Process gas Cutting • Low pressure oxygen • High pressure nitrogen Welding • Helium • Argon	 2000 STP L/hr 10000 STP L/hr 1000 STP L/hr 1000 STP L/hr	 £0.93 £4.00 £6.10/hr £2.00/hr	 11% 34% 44% 21%
Consumables	1 lens per ˜3000hr	£0.12	0.8 to 1.4%
Spares and service (system)		£2.02	15 to 23%
Total running cost cutting:-low pressure oxygen		£8.62	
Total running cost cutting:-high pressure nitrogen		£11.69	
Total running cost welding:-helium		£13.79	
Total running cost welding:-argon		£9.69	

Table 2: Running costs of 2 kW Nd:YAG Laser Welding System

Item	Consumption	Cost per hr of running	% of running cost
Electrical costs Laser Machine system Laser chiller **Total**	 65kVA 15kVA 30kVA **110kVA**	 £5.20 £1.20 £2.40 **£8.80**	 **38 to 61%**
Process gas Welding	 0	 0	 0
Consumables	Fibre, Slider Flashlamp	£3.18	21%
Spares and service (system)		£3.04	20%
Total running cost welding:-		£15.02	

The running cost data for a 2kW Nd:YAG Welding System presented in table 2 is based upon information kindly provided by Lumonics Limited whose assistance is gratefully acknowledged. Any inaccuracies in this table are the sole responsibility of the author.

The size and complexity of the laser system is the determining factor when assessing running costs. In order to give some indication of running costs two examples of laser systems have been prepared. The first (Table 1) is for a CO_2 laser system and the second (Table 2) is for a Nd:YAG laser system. In both cases running costs are expressed as the cost per operational hour.

In the case of the CO_2 laser the cost of laser gas does not apply to sealed-off laser types but, as the example shows, this is not a significant element of the cost. Indeed, running costs presently work out to be about the same whether the laser is of the sealed or flowing gas type, since the electrical efficiency of RF driven lasers (the form of excitation used for sealed-off lasers) tends to be less than that of the DC inverter type used on many fast flow lasers. The cost of process gas can vary by a factor of 6 depending upon the process. For some materials, such as wood, the process gas may simply be compressed air (supplied from a dry oil free supply) and is therefore an insignificant cost.

Other Laser Types

There are other types of laser used in material processing in industry such as excimer and diode lasers but they are not used to the same extent as the examples above. Diode lasers are relatively new and their purchase prices and running costs are significantly lower than other laser types. Presently their beam quality is such that their application is limited. However, the cost of the devices makes them a serious alternative to a number of other processes (e.g. soldering) where previously lasers would have been discounted on the grounds of cost.

The Bottom Line

The purpose of all investments is to show a financial return. In the case of laser systems this means that the process must show a financial benefit which initially pays off the cost of the investment and then provides a return.

To pay off the cost of investment:

$$\begin{array}{c}\text{Monthly Cost Savings}\\ \text{or Process Sales Value}\end{array} \geq \frac{\text{Monthly Depreciation or Leasing Cost + Monthly Running Cost}}{\text{Pay Back Period (in months)}}$$

The pay back period is a matter of individual company policy but in the larger UK companies it is likely to be 24 to 36 months.

The considerable benefits of using the laser in industrial material processing often provide the necessary cost benefits to justify their use. In the end, however, financial assessments must be made on a case by case basis. Applications are diverse and range over many industrial sectors and involve both large and small companies. New applications continue to emerge and are likely to continue doing so.

Lasers in the Automobile Industry

Tim Weedon
Lumonics
Cosford Lane Swift Valley Rugby Warwickshire CV21 1QN. weedont@lumonics.co.uk

As a laser user, the automotive industry has many features in common with the rest of the industrial laser user-base. It also has a distinct character and special needs. The huge diversity of applications and large volume of individual applications make it a fascinating sector of the laser market.

The processes applied to the manufacture of components and their assembly into the vehicle include:

- Spot and seam welding
- Drilling
- Cutting
- Surface treatment
- Soldering
- Marking
- Resistor trimming, memory repair, substrate processing
- Measurement and inspection.

In the development process lasers are also used for:

- Rapid prototyping
- Destructive and non-destructive testing.

This paper is concerned mainly with manufacture of mechanical and electromechanical components and assembly of the complete vehicle. The most important laser processes, in terms of investment, are welding, cutting, marking and drilling. The dominant lasers in these applications are CO_2 gas lasers and solid state Nd:YAG lasers. They range in power from a few Watts to several kiloWatts.

Welding

One of the earliest laser welding applications, established in the early 1970s, was spot welding the dipped-beam shield and the lead-out conductors of quartz-halogen headlamp bulbs. Each laser machine had a modest output of 2000 units per hour using a 30 W mean power laser. The high repeatability laser process enabled automation of the lamp manufacture and so reduced the manufacturing cost by 50% whilst raising product quality. Automation was not practical with the previous, maintenance intensive, resistance brazing technology.

Spot welding applications include switches, relays and small electrical components as well as bigger spot welds terminating the windings of inductors, motors and alternators.

Welding fuel injectors is one of the biggest applications by number of units. Each injector contains a number of spot and seam welds, almost all produced on automatic machines incorporating Nd:YAG lasers of 30 to 1000 W. Very similar processes are applied to oxygen sensors, air bag gas generators and brake (ABS) components.

Higher power Nd:YAG laser applications, 2.5 to 4.5 kW, are in welding body components and assembling car bodies. These tasks include tailored-blank welding. Blanks, from which components are subsequently pressed, are made by joining pieces of different materials or different thickness prior to forming. The main reason

Comparison of lasers for welding applications

	CO_2	Nd:YAG
Maximum power available in a commercial product for welding	45 kW	4.5 kW
Capital cost, laser only	About half that of Nd:YAG per output Watt	
Capital cost, complete system	Lower than Nd:YAG for simple 1-D and 2-D systems, much higher for 3-D (5 axis) systems.	Inexpensive when robots are used
Operating cost	Very high helium cost for shielding and aero dynamic windows. needed for much	If shield gas is need ed it is likely to be cheaper argon. Not
mild-steel body weld for aluminium alloys.		ing, essential
Fibre optic beam delivery	No	Yes
Process speed range	Minimum speed is re stricted by coupling pro blems at low mean	Go as slowly as you need in tough places because good
power chopped mode	coupling is maintained	in
Final Optics	Vulnerable and very expensive	Inexpensive and ea sily protected

for doing this is to reduce the weight of the vehicle by optimising the material used in each region. Whilst the majority of tailored blanks are steel, aluminium is under intensive study.

Other laser body-welding tasks include:

- Framing (mainly spot welds)
- Single-sided spot welding where access is limited
- Roof to side panel seam welds
- Side panel to wheel housing seam welds
- Panel to hydro-formed section welds
- Aluminium panel welds
- Hemming or coach joints.

Cutting

Both CO_2 and Nd:YAG lasers are used widely in the production of body components and adding detail or customisation to complete bodies. The two technologies are complementary and, whilst it is not the place of this paper to discuss the physics or design of the lasers, it is worth mentioning some of their distinguishing features.

It follows from the table above that when flat sheets of car body steel are to be cut, CO_2 lasers are usually used; if articulated arm robots are needed, Nd:YAG is the usual choice. For other cases the correct solution is determined by cost of ownership (COO). The COO can be affected very much by access problems, competencies of the plant, environmental factors and so on.

Comparison of lasers for cutting applications

	CO_2	Nd:YAG
Minimum kerf, mm for practical use and high speed	0.1 mm	0.3 mm
Maximum power available in a commercial product for cutting	6 kW	4.5 kW
Capital cost, laser only	About half that of Nd:YAG	
Capital cost, complete system	Lower than YAG for flat sheet cutters but can be much higher for 3-D systems.	Inexpensive when robots are used
Operating cost	Similar	Similar
Fibre optic beam delivery	No	Yes
Capacity in carbon steels	excellent	good
Capacity in stainless steels	good	excellent
Capacity in Aluminium alloys	fair	good

The most common applications of laser cutting are:

- Trimming pressed parts (CO_2 and Nd:YAG)
- Cutting variation holes in pressed parts and complete bodies (CO_2 and Nd:YAG)
- Trimming hydro-formed parts (CO_2 and Nd:YAG)
- Cutting high precision features in complete bodies (CO_2 where access is easy, Nd:YAG otherwise)
- Cutting exhaust system components (Nd:YAG)
- Cutting clutch components in metals (usually Nd:YAG) and friction materials (usually CO_2).
- Cutting upholstery materials (CO_2)
- Cutting timber-based materials (CO_2)

Drilling

The majority of drilling is done to compensate for shortcomings in design, for example to deliver oil to a bearing that is inadequately lubricated. From a supplier viewpoint these are not very satisfying applications because the laser system becomes redundant when the design is corrected.

There are some notable 'standard applications', which include the drilling of oil spit holes in connecting rods and of flow control apertures in brake or transmission components.

Virtually all the metal drilling is with Nd:YAG lasers and almost all the plastic drilling is by CO_2 laser.

Marking

There are several reasons for marking components:

- Part numbers
- Grading
- Serial numbering critical components
- Vehicle Identification Numbers (VIN)
- User information

A wide range of laser devices is used to make marks depending on the material to be marked, character size, production rate, accessibility, cosmetic quality, permanence and so on. For non-metal parts, pulsed CO_2 lasers are used most commonly. However for the highest quality marks on, say, dashboard components, it is common to find high precision Nd:YAG vector markers doing the work. For metal parts the mark is usually engraved using Nd:YAG laser. For very deep marks, such as used on engine blocks or for chassis numbers, a laser very similar to a cutter may be used.

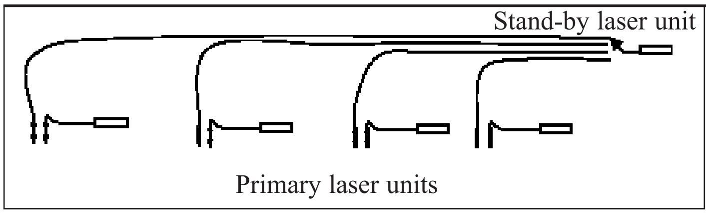
User Requirements

In other industries, many laser processes take place in areas where it is normal for operators to maintain complex equipment and to be involved in fine tuning the process. In the automotive industry it is more common for maintenance to be performed by specialist technicians. The expectation is that equipment will require no maintenance during the working shift; all service and preventative maintenance is done in the 30-minute shift changeover and in one maintenance shift per week. In North America, specific tradesmen commonly do maintenance so a laser system may need attention from a plumber, an electrician and an electronics technician. This leads to a requirement for the working areas of the respective trades to be separated into different cubicles.

A detailed study identified the following user requirements:

- Operation & maintenance by shop floor people
  - minimum operator actions
  - simple, unambiguous controls
- Minimise service
  - maximise service interval
  - minimise service time
- Optimise preventative maintenance
  - early indication of potential problems
  - excellent diagnostics to module level
- Viable life-cycle cost
  - optimise all aspects that contribute to life-cycle cost
  - (can be tough because of the spread of methods of evaluating LCC)
- Easy installation & integration
  - flexible footprint
  - plug-in modules
  - self-diagnostics and calibration
  - minimum service connections
- Compatible with local environment
  - temperature, humidity
  - working practices
    - 30 minute break between shifts
    - training to 'module-exchange' level
    - customer self-sufficiency
    - (Asia, South America) 40 ºC , 90% relative humidity, factory cooling water above 40 ºC.
    - (North America) segregate enclosures by trade (electrics, water, electronics)

The auto industry has little or no buffer of material at any stage. Whilst this is clearly the right approach from economic and space considerations, it puts huge pressure on equipment and process reliability. If an assembly line is producing cars at 80 per hour there is a severe penalty for an equipment breakdown or for taking it out of service for routine maintenance. This can make it economically attractive to incorporate redundant equipment to raise the up-time of the facility (If the up-time on one unit is 99%, the up-time on a station with two such units is 99.99% providing the switch-over is instantaneous). Optical fibre beam-delivery is a great support to such redundant arrangements because it allows the switch-over to be fast and it permits the standby unit to be located a considerable distance from the working point. This



Schematic illustration of the use of optical fibre beam-delivery for rapid switch-over to a remote standby unit in the event of a failure of a primary laser unit on an assembly line.

allows one stand-by unit to support a number of primary units, as illustrated above.

Many of the early laser tasks were in applications running alongside the track and where a failure was not so critical to continued production. These included customisation of components or vehicles, serial numbering components and so on. Whilst reliability is still very important, a breakdown lasting a few minutes was tolerable. Applications of this type continue and benefit from the constantly improving reliability and serviceability of available equipment. There is an on-going mutual benefit between these and the on-line applications.

Most of the cost drivers for all laser types continue to move downwards while capability improves. As progress is not the same in each of the technologies, the best solution can vary with time. This is complicated by the requirements of safety and environmental legislation. These sometimes increase the cost of the laser solution but they frequently make the competitive techniques less attractive so that the overall advantage tends to move in the laser's favour. This dynamic means that it is necessary to examine each new project afresh to determine the most appropriate solution for the user.

System Engineering

The nature of automotive applications and their working environment mean that the overall system engineering is even more important than in other industries. Frequently this may be done by the user company, the laser system supplier or by a third party company. In order to have the best appreciation of the user's requirements and to interpret these into solutions, Lumonics has found it necessary to form a team devoted to this market sector. This team works with the customer, the systems engineering groups, the customer support organisation and the laser engineering groups to define future product direction as well as a response to the immediate needs of customers.

The user requirements have implications which reach at least as far into the support organisation as they do into the design of laser processing systems.

Acknowledgments

I am grateful for help in the preparation of this paper from Keith Withnall, Mo Naeem and Simon Wheatley. Lumonics gave permission for publication though the opinions are my own.

COMMENT on lasers in the automobile industry

I was delighted to read Tim Weedon's article. I would like to add late model customisation to the list of important laser cutting process in the auto industry and to take the opportunity of adding some general points concerning the planning and forethought involved in installing a laser cell.

a. High gas consumption. Gas use, typically 70 litres of O_2 per cutting minute or 30 litres of inert gas per welding minute, means that the most economical means of gas storage and supply is to use liquid gas, with all the associated demands of tank siting to for safety and tanker access, and the need to minimise the length of pipe run between the tanks and the point of use.

b. The extraction/filtration system. For safety reasons, the extraction unit must have sufficient capacity to prevent a build up of assist gases and that the fumes produced are properly controlled and filtered before venting to atmosphere. Fumes from cutting plastics and some coated metals and alloys need particular attention. A typical request might be 60 air changes per hour within a laser cutting cell.

c. Heat exchanger. The heat required to be removed from the laser source may be sufficient to make waste heat recovery a practical proposition. The warm air can be used for preheating process equipment, of for space heating.

d. Housekeeping. Laser cutting in particular can produce large quantities of particulate fume in the form of a fine dust. The heavier particles which are not extracted will sink to the floor, creating a health hazard and in some cases a fire risk. The laser cell therefore needs frequent vacuuming and, depending on the materials cut, the dust bag needs to be handled as hazardous dust.

e. The environment. Dust and vibration are two of the more important environmental considerations to address in the location of a laser cell. Particular issues include dust on beam steering mirrors, leading to excessive laser heating of the optics resulting in beam distortion, and vibration-induces misalignment.

f. Fixture design. To minimise the cycle time of the cell, it is essential to facilitate to removal of the finished component so as to avoid operators having, for example, to fish around inside a tube to remove a cut slug wedged inside.

Finally a few points on safety:

g. Relative safety of CO_2 lasers. One of the benefits of using CO_2 lasers in vehicle body assembly applications is that safety precautions are less stringent, thereby making them easier to integrate into an automated welding line than a Nd:YAG lasers. Although optical fibres are an advantage, there are robots which have mirror systems integrated into their arms and wrists allowing CO_2 lasers to be used with a conventional 7 axis robot (KUKA, Fanuc etc), for example, the KUKA beam delivery system is used at BMW and other German installations.

h. General safety awareness. Training should include all personnel from Directors downwards. While addressing the hazards and special requirements of the laser it is also important to dispel the myths and legends about laser injury before they give rise to restrictive work practices.

i. Check list. At a Nd:YAG laser cell installation I was involved with a few years ago we instigated a system similar to that used for power presses, where the cell was checked at each shift handover before it was accepted for use including a detailed check of the seals and other key safety equipment – something that ensures the prompt repair of any faults, or replacement of worn seals.

Stephen Ainsworth
Ainsworth Consultants

Applications of High Power Diode Lasers

Friedrich Bachmann
Rofin-Sinar Laser GmbH
Galileo-Galilei-Str. 10, D-55129 Mainz Germany email: f_bachmann@compuserve.com

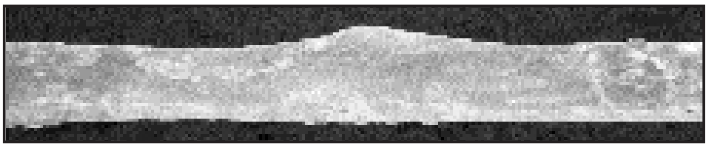
Diode lasers are widely used in communication, computer and consumer electronics technology. These applications are based on low power lasers. However, over the last few years, high power diode lasers have become available, with powers up to several kilowatts. Classical laser materials processing becomes possible with such lasers; moreover, the special features of high power diode lasers open up applications which have previously not been attractive or even not possible for lasers.

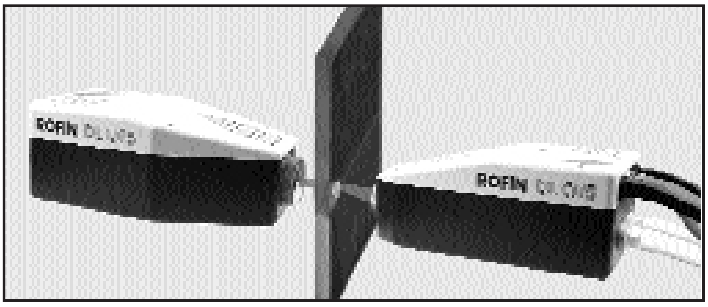
Applications of high power diode lasers

Since diode lasers in the kW range consist of a large number of single lasers incoherently coupled together to deliver laser power, the quality of the beam is poor compared to other laser beams. Today, a beam parameter product between 100 and 1000 mm.m-rad is typical for these lasers, for the moment excluding these lasers from traditional high power laser applications such as cutting or deep penetration welding. As illustrated in the paper by Poprawe *et. al.* in this issue (Figure 2 and 3), the output of diode lasers in the high power range is sufficient for heat conduction welding, brazing and surface treatment and cladding.

For most of the results that follow, the laser head was mounted on a gantry type positioning system; the maximum laser power was approximately of 1.5 kW and the working distance was about 35 mm. A focal area of ca. 3.8 × 1.8 mm could be illuminated, corresponding to a maximum intensity at the workpiece of about $2{\times}10^4$ Wcm^{-2}. Despite the relatively low intensity the high power diode laser offers advantages over other lasers. In particular, its high efficiency (up to 50%) leads to economic use and its small size allows easy integration into existing production systems; even portable systems can be easily realised.

Examples of thin and thick sheet welding are shown in Figure 2. The attractive shape of high power diode laser weld seams gives rise to the term 'cosmetic weld'. Such welds have smooth edges





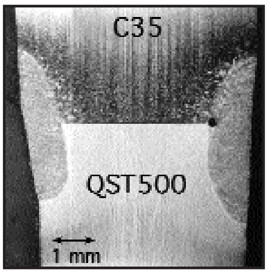
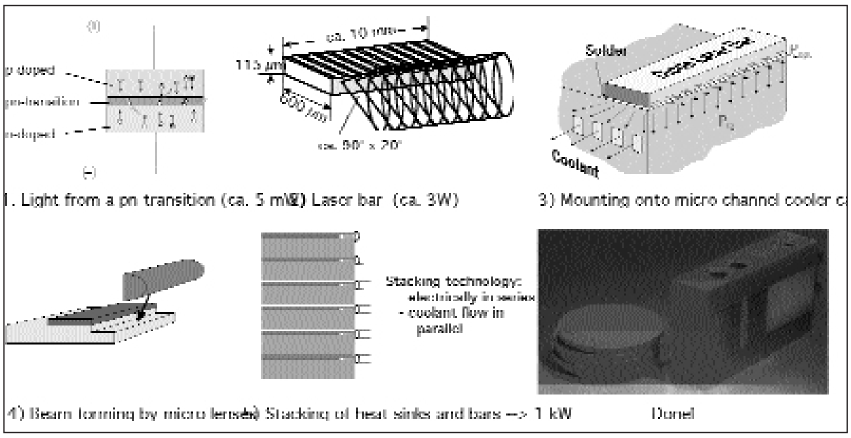


Fig 2: (above, top) An example of thin sheet welding, a 150 µm thick stainless steel plate welded with only 500 W diode laser power at 6 m/min (ref 2). Care must be taken to avoid oxidizing, even downstream of the laser welding spot, and good clamping tool become essential since the large heat load in the thin material tends to tends to cause bending.
(above, bottom) A sketch.of simultaneous welding using two high power diode lasers for thick sheet welding. A seam between a hardenable steel and a high strength structural steel, with rather poor edge preparation (i.e. a gap in the range of several tenths of a millimeter between the two parts) can be produced with good mechanical stability and without distortion and cracks.
(left) Cross section of a two sided laser weld..

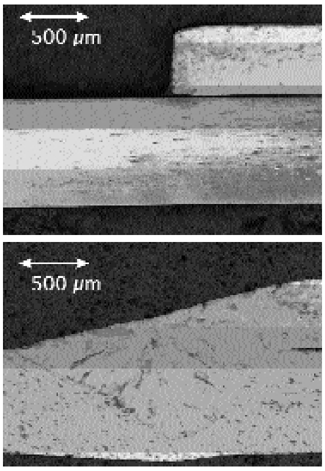
and are generally gas tight. One application is to seal the gap after a first (conventional laser) weld to avoid crevice corrosion. An example can be seen in Figure 3. Aluminium based materials can also be welded vacuum tight, as can be seen in Figure 4.

Because of its rectangular shape, with a top hat profile in one direction ('slow axis') and a Gaussian like in the other ('fast axis'), the high power diode laser beam is especially well suited

Construction of a high power diode laser source



A traditional diode laser element typically provides only a few milliwatts from a pn-transition (fig.1/1); to increase the power, several single elements are integrated into a 'laser bar' with a size of about 10000 x 600 x 115 µm (fig. 1/2). The shape of the light generation area leads to light emitting with a high divergence in the direction of the pn-transition (the 'fast axis'), and a lower divergence, but a wide emitting 'stripe' in the other (the 'slow axis'). By mounting the laser bar on a heat sink, currents up to 50 A can be applied without overheating the diodes and laser power up to and exceeding 40W can be generated (fig. 1/3). The fast axis is collimated by cylindrical micro-lenses (fig. 1/4) and the units stacked on top of one another, so that total powers up to 1 kW can be achieved (fig. 1/5 & 1/6). Two or three such stacks can be combined by strip mirrors or polarization or wavelength coupling, to provide multi- kW laser power can be delivered from a laser head no larger than a shoe box.



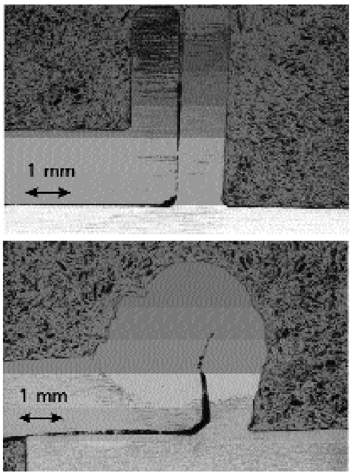
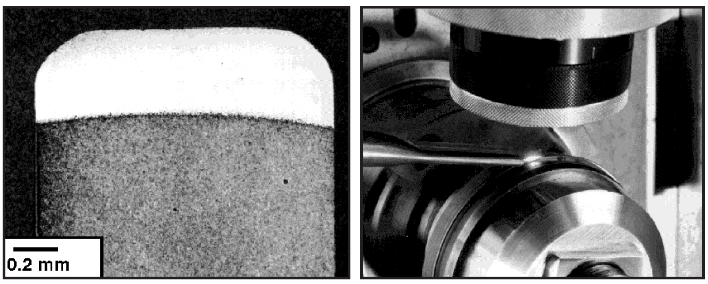


***Fig.3:** Cosmetic weld to avoid crevice corrosion (ref 2)*
A 1.5 kW diode laser welds at a speed of 2 m/min. Top: before bottom: after laser welding.

***Fig.4:** Gas tight welding of an aluminum box (ref 2)*
Cross section of a diode laser welded vacuum case.
top: before bottom: after laser welding

for surface hardening applications. Further, because of the short emission wavelength of these lasers (typically 0.808 µm or 0.94 µm) the surface absorption is generally higher than for the CO_2 laser, thereby avoiding the need for absorbing coatings. The much higher efficiency of the diode laser together with the advantages mentioned above, make it a very efficient, reliable and cost efficient tool for hardening. Examples for this application are hardening of piston rings (Figure 5) and the hardening of the wedges of a diagonal cutter. (Figure 20 of the paper by Poprawe *et. al.* in this issue).

An important surface-related application of high power lasers is the deposition of layers for wear resistance or repair. A widely used and successful method is the deposition of a powder such as Stellite, fed to the laser heated zone through a special nozzle. For this application, for which CO_2 high power lasers have traditionally been used, the high power diode laser provides an ideal tool as illustrated in Figure 6.



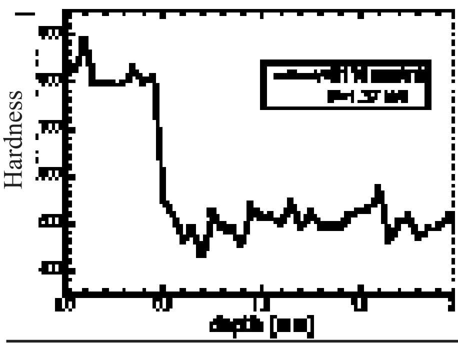
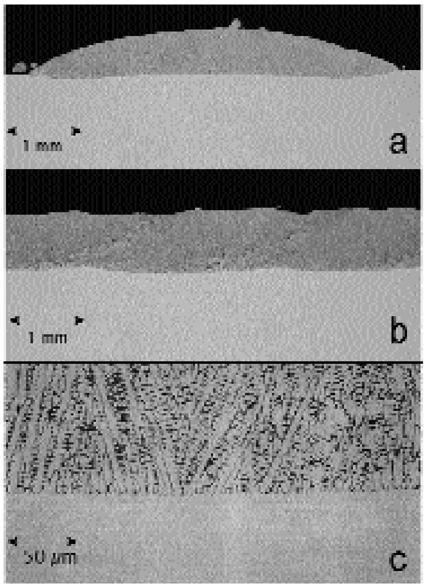


***Fig 5:** High power diode laser hardening of piston rulings. (top left) experimental set-up. (top right) cross section (side left) hardness cross section (ref 2)*

***Fig. 6:** Powder Deposition of Stellite F onto a steel substrate (ref 2)*
a) Deposition of a single track. With typical power density of ca. 2 x 10^4 W.cm^{-2} delivered in a spot of ca. 2 x 4 mm, layers with a thickness of more than 0.5 mm have been deposited with a speed of ca. 400 mm/min.
(b) Overlapping tracks. If tracks are overlapping in parallel, the tracks appears smooth and dense .
c) Cross section of the interface: dendritic structure of the deposited layer (ref 4) Showing the typical dendritic cast structure, a perfect link of the two materials and a very thin melting zone in the basic material.



Summary and Conclusions

High power diode lasers up to several kilowatts are at the threshold of large scale introduction into the industrial environment. Today's systems provide sufficient power for applications which require moderate workpiece intensity (10^4 to 10^5 Wcm^{-2}) at an efficiency of more than 40%, an efficiency unique among lasers. Their very small size makes them an ideal tool for integration into manufacturing machines and for portable systems. With increased beam quality, further increase of lifetime and further reduction of investment cost, these lasers have a bright future with an enormous increase of market share. Ambitious research programs have been launched to reach this goal in a reasonable time.

Acknowledgement

I would like to express my great thanks to my colleagues at the Fraunhofer Institut für Lasertechnik (ILT) in Aachen, Germany, Prof. Poprawe, Dr. Loosen, and B.Schürmann and also of the Fraunhofer Institut für Werkstoff- und Strahltechnik (IWS) in Dresden, Germany, Prof. Beyer, Prof. Brenner, Dr.Nowotny, A.Müller and S.Bonß, who performed the experiments, permitted the use of their results, graphics and photographs in this presentation and also helped me very much by their interpretations and consulting.

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4 W. Nowotny, Fraunhofer-Institut für Werkstoff- und Strahltechnik, private communication

Laser Welding for Structural Fabrication

Steve Riches and Derek Russell

TWI Cambridge

Abington Hall Abington Cambridge CB1 6AL email: striches@twi.co.uk

The growing acceptance of laser welding within the automotive industry has generated interest in applying the process to thicker materials used in structural fabrication. The perceived benefits of using laser welding technology are to reduce structural distortion, increase joint production rates, allow more accurate structures to be fabricated and to facilitate mechanisation and automation.

For structural fabrication, the components are generally made from steel, the thicknesses currently of most relevance to laser welding being up to 1 5 mm. CO_2 lasers are capable of welding 12 mm thick steel at a speed of 1m/min using 10 kW power, whilst 4 kW Nd:YAG lasers can penetrate 6 mm thick steel at a speed of 1 m/min. Laser welding technology has made less in-roads into structural assemblies, which has been attributed to a lack of knowledge of the capabilities of laser welding and the absence of official codes of practice and guidelines for laser welding.

This paper will review the status of laser welding technologies with respect to the fabrication of structural assemblies. The issues to be covered will include details of design, materials, processes, joint quality, joint performance and quality assurance. Work has shown that satisfactory weld quality can be achieved by control of material composition and welding procedure, and weld properties are broadly comparable with those achieved by arc welding.

Introduction

Over the past 20 years, the use of lasers has expanded considerably for automotive manufacture. The main areas of interest have been the assembly of gears/transmission components, in the fabrication of tailored blanks and for body in white structures such as roof rails to side panels. Most of the applications to date have been in steel but developments are occurring to enable fabrication of aluminium alloy components.

For structural fabrication, the components are generally of an order thicker (i.e. 4 -15 mm thick) than those used in the automotive industry (0.7-4 mm thick). Laser welding has been less widely exploited for structural applications due to a lack of industrially proven equipment, a lack of knowledge of the capabilities of laser welding and the absence of officially recognised guidelines governing the quality and performance of laser welds.

Table 1.
Summary of characteristics of CO_2 and Nd:YAG lasers

Property	CO_2 laser	Nd:YAG laser
Lasing medium	CO_2+N2+He gases	Neodymium doped yttrium aluminium garnet crystal rod
Radiation wavelength	10.6 µm	1.06 µm
Excitation method	Electric discharge	Flashlamps
Efficiency	5-10%	2.5-5%
Output powers	Up to 60 kW	Up to 4 kW
Beam transmission	Polished mirrors	Fibre optic cable

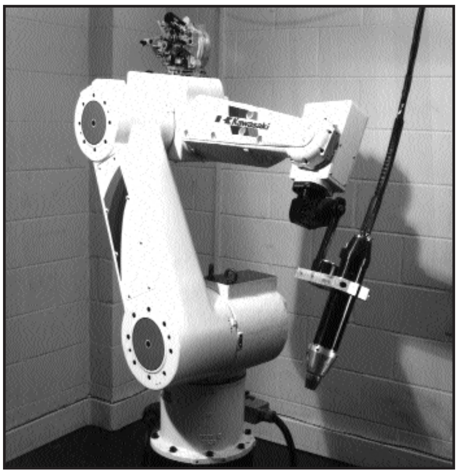

Figure 1. Fibre optic cable and processing head for Nd:YAG laser attached to robot

This paper will review the status of laser welding technology with respect to the manufacture of assemblies relevant to structural fabrication. The issues to be covered will details of design, materials, joint quality, joint performance, quality assurance and economics.

Industrial laser types

There are two main types of industrial laser of interest to structural fabrication; CO_2 and Nd:YAG lasers. The lasers have different characteristics that are summarised in Table 1.

High power CO_2 laser processing of steel is now a competitive process for many structural applications. Laser cutting is now used for plates of up to 20-25 mm thick using 3 kW power and equipment working up to 6 kW power is now being marketed for cutting up to 40 mm thick steel plate. CO2 lasers of up to 60 kW power are commercially available, but industrial welding applications have not been developed to date.

High power Nd:YAG lasers are now available at workpiece powers of 4 kW, which have fibre-optic beam delivery, see Figure 1

Table 2. Tolerance of CO_2 laser welding process for different joint configurations (Values based on 6mm thick C-Mn steel)

Factor	Lap	Butt	Edge	T
Tolerance to gaps	0.4 mm	0.4 mm	0.4 mm	0.4 mm
Tolerance to beam/joint misalignment	±1 mm	±0.2 mm	±0.2 mm	±0.2 mm
Tolerance to beam focus position	±3 mm	±3 mm	±3 mm	±3 mm
Seam tracking	No	Yes	Yes	Yes

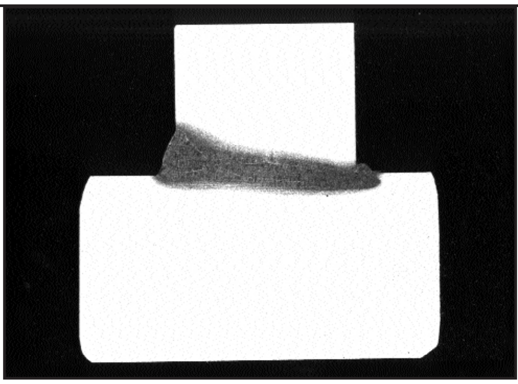

Figure 2. *CO_2 laser welded T-joint in 12mm thick steel*

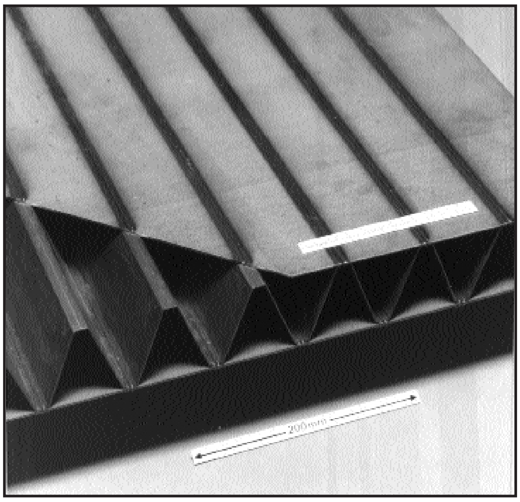

Figure 3. *CO_2 laser welded lightweight steel structure*

and are capable of welding materials up to 10 mm thick. Higher power equipment is likely to be developed in the next 2-3 years.

Joint Design

There are several joint designs that are suitable for laser welding, including lap-, edge-, butt- and T-joints. A summary of the joint designs and their various tolerances to welding process factors (for autogenous CO_2 laser welding of 6mm thick steel) is presented in Table 2.

For structural applications, the use of a laser to produce T joints, see Figure 2, from one side may offer significant benefits in terms of heat input and reduction in distortion when compared to arc welding processes.

It is also possible to use laser welding to produce lightweight structures, such as sandwich panels, see Figure 3, where the capability of laser welding for stake welding through 2 or more sheets can be exploited.

Materials

Details of the effect of material condition on laser weld quality will be discussed in the section on joint quality. The other factors to consider with respect to the materials are the edge quality and surface condition.

For the edge quality, if gaps >0.4 mm are present when the joint is fitted together, wire feed laser welding will be necessary. As the plate thickness increases from 12 mm, it is more difficult to produce edges with the required squareness values (<0.2 mm) using laser, plasma or oxy-fuel cutting and therefore wire feed laser welding will become essential.

Welding of oxidised plate has been shown to be possible, although at the expense of a reduced fatigue performance. The laser welding of steel with a primer present (20 mm thickness) resulted in a similar weld quality (in terms of cracking and porosity) to steel without primer.

Table 3. Typical speeds for laser welding of C-Mn steel in a butt joint configuration

Steel thickness, mm	Welding speed, m/min			
	CO_2 laser		Nd:YAG laser	
	6 kW	10 kW	14 kW	4 kW
6 mm	1.5	3.5	5	1
12 mm	N/A	1	1.4	N/A

Welding Process

Typical welding speeds that can be obtained for different thicknesses and laser types/powers are summarised in Table 3. Addition of wire into the welding process generally reduces the welding speed by about 10-20% compared to autogenous welding at the same power.

For laser welding of 6 mm thickness of C-Mn steel and above, using both CO_2 and Nd:YAG lasers, care is needed to control the plasma formed during welding. Systems normally incorporate a plasma control jet directed at or close to the weld keyhole and helium is normally used as the plasma control and shielding gas. For C-Mn steel, underbead shielding is not considered to be necessary.

Weld Quality

Weld flaw tolerance levels are given in workmanship standards that specify quality levels to be reached during welding procedure approval and in production[1]. In general, cracking is not permitted but other flaws such as porosity and surface imperfections are allowed to some extent. In laser welds solidification cracking and porosity give rise to most problems in production. Both these types of imperfection are related to material composition (which influences residual liquid films leading to cracking), gas content, surface tension and fluidity.

Cracking

Solidification cracking occurs when the solidifying weld metal cannot sustain the applied thermal strain during the first stage of the weld cooling and causes rupture. This arises when the last liquid to solidify is a thin film along the dendrite boundaries, solidifying at a depressed temperature compared with the liquidus temperature for the bulk composition. The resulting segregation of elements forms low melting point compounds or phases.

In structural steels, sulphur and phosphorous combine with other elements in the steel to produce low melting point films. Although the strain associated with the narrow fusion zone of the laser weld is less than that of an arc weld, there may be sufficient strain to cause cracking when steels with high levels of S and P are welded.

Additionally, the primary phase of solidification, either delta ferrite or austenite, is significant because, with austenite, fewer impurities are held in solid solution and more are rejected into the liquid. The elements which promote austenite formation, such as carbon, manganese and nickel, etc, can lead to increased risk of cracking. However, Mn can be beneficial since it combines with sulphur to form higher melting point phases of a globular form which cannot form films at dendrite boundaries. In practical

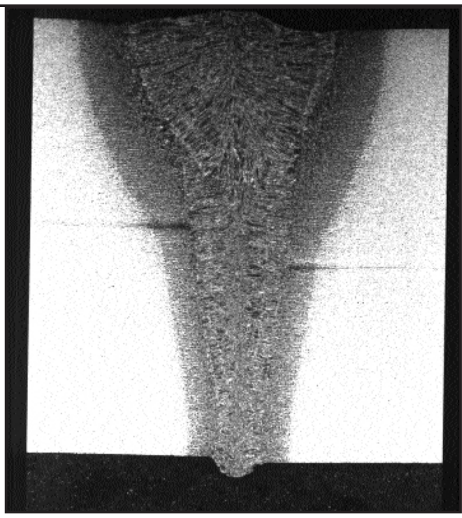

Figure 4. CO_2 laser butt weld in 12 mm thick C-Mn steel

terms, to avoid cracking, it is desirable to have low levels of C, S and P and high level of Mn.

Various formulae have been produced to relate cracking tendency to steel composition, but none is yet fully satisfactory. An index previously used for electron beam welding has, on some occasions, been relevant, but only gives an indication of cracking tendency and must be used together with real component weld tests to determine whether cracking occurs in specific joints, where joint restraint and residual stresses will have an influence. The cracking index used is given below.

Cracking Index = 52.6C+1975S+P(4268C-285)-Mn(1135S-9)-21.2

Solidification structures also influence the extent of cracking due to its effect on the orientation and total amount of dendrite boundary area. Welding speed is important as high speed welding tends to produce a single centre line boundary with limited ability to accommodate liquid films and strain. In contrast, lower speeds give rise to a complex central region solidification structure which is more beneficial. The critical welding speed varies with thickness and material composition, but, for 12 mm thick steel, a speed of 1 m/min is a reasonable guide for steels of good quality, i.e. C< 0.1%, S< 0.01%, P< 0.01%, at a power of 10 kW.

The width and shape of the weld, as illustrated in Figure 4, also influence cracking, since these features control solidification structure and liquid flow in the final stages of solidification. Any deviation from a straight sided weld is undesirable and a weld containing bulges is much more susceptible to solidification cracking.

Other forms of cracking in structural steels, such as hydrogen cracking, liquation cracking or reheat cracking are not usually found in laser welds in steel.

Porosity

In laser welds, porosity is a much more persistent problem than in electron beam or arc welding. Weld porosity originates from excessive gas in the weld metal (i.e. that cannot be held in solid solution) being ejected into the solidifying weld metal as gas bubbles.

One potential source of this gas is surface contamination, such as grease, oil, oxide, cutting fluid residue, etc, on the plate being welded. All of these can be controlled by appropriate preparation and cleaning techniques. The main source is dissolved gas in the base material, such as oxygen and nitrogen and to minimise porosity it is necessary to use steels of low gas content, i.e. fully killed steels, preferably with aluminium. Filler wire can be used to control porosity by providing deoxidising elements such as Si and Al. Effective inert gas shielding is also important, together with careful choice of plasma control system and gas flow, due to the need to minimise gas pick up from the atmosphere.

Weld Properties

Weld properties are, in general, determined by weld metal composition and metallurgical structure, joint geometry and the presence of imperfections. The main properties of interest for structural applications are: strength, hardness, ductility, toughness, corrosion resistance and fatigue strength.

For most engineering steels that transform on heating and cooling, the weld metal is stronger, harder and less ductile than the parent material. Strength, hardness and ductility are controlled by carbon content and steel hardenability (influenced by elements such as Mn, Ni, Cr, etc) as well as weld cooling rate. Therefore, maximum weld metal hardness can be increased with higher carbon equivalents and decreased applied energy. The requirements of many fabrication codes for a maximum weld metal hardness can normally be satisfied by control of the parent material composition and applied energy. However, the required applied energy may not be the maximum rate at which full penetration welding can be obtained and may have an adverse effect on distortion levels.

Due to the narrow fused zone width of laser welds, strength and ductility are difficult to measure using conventional techniques. Nevertheless, strength may be inferred from hardness measurements and ductility may be estimated using longitudinal root and face bend tests. The most widely used method of measuring toughness, Charpy testing, is difficult to apply to laser welding because the fracture path deviates from the weld metal to parent material, particularly at temperatures above the lower shelf. Attention has been directed towards modifying the Charpy test or to alternative methods of characterising toughness. CTOD testing can provide valuable quantitative information for fitness for purpose flaw evaluations.

Current fatigue design rules for arc welded joints are based on an extensive database of fatigue tests. Although the database for laser welded joints is not yet as extensive, results indicate that existing fatigue design rules may be applied to laser welds. Little published information exists regarding the corrosion and stress corrosion performance of laser welded joints.

Distortion

Although the assessment of distortion is component specific, the amount of distortion caused by the welding process can govern the level of post weld operations required for the application and contribute a significant amount to the manufacturing cost. A simple relation between the heat input and level of distortion can be derived empirically, but quantitative data is more difficult to procure. Laser welding is claimed as a low distortion process and in tests on butt welds in 12 mm thick C-Mn steel plate, shrinkage caused by the laser welding of <0.3 mm were obtained.

Quality Assurance

The assurance of quality for laser welded components falls into a number of categories. During production, manufacturers are seeking ways of measuring parameters to provide some assurance of quality, such as voltage and current for arc welding. For laser welding, there is no contact and remote sensors monitoring plasma, temperature and spatter emissions during welding are in development[2].

After the component has been produced, standard NDT and destructive test methods can be used to assess the weld quality. Until recently, there were no guidelines available for the CO_2 laser welding process on structural steels. This situation has changed[3] and one of the main barriers hindering the widespread exploitation of laser welding has been removed.

Economics

Another major obstacle to the exploitation of laser technology in manufacturing industry is the high capital cost of laser equipment. A 6kW CO_2 laser and a 4kW Nd:YAG laser are likely to cost in the region of £250-300k. The cost of the installation for a mechanised or automated cell is likely to be at least double the cost of the laser source. Therefore, justification of a laser system must be based on consideration of upstream and downstream factors as well as direct comparison of production rates with other welding processes.

Conclusion

Laser welding offers significant potential advantages for the fabrication of structural assemblies by exploiting the benefits of reduced distortion compared to arc welding. Satisfactory weld quality can be achieved by control of material composition and welding procedure, and weld properties are broadly comparable with those obtained by arc welding.

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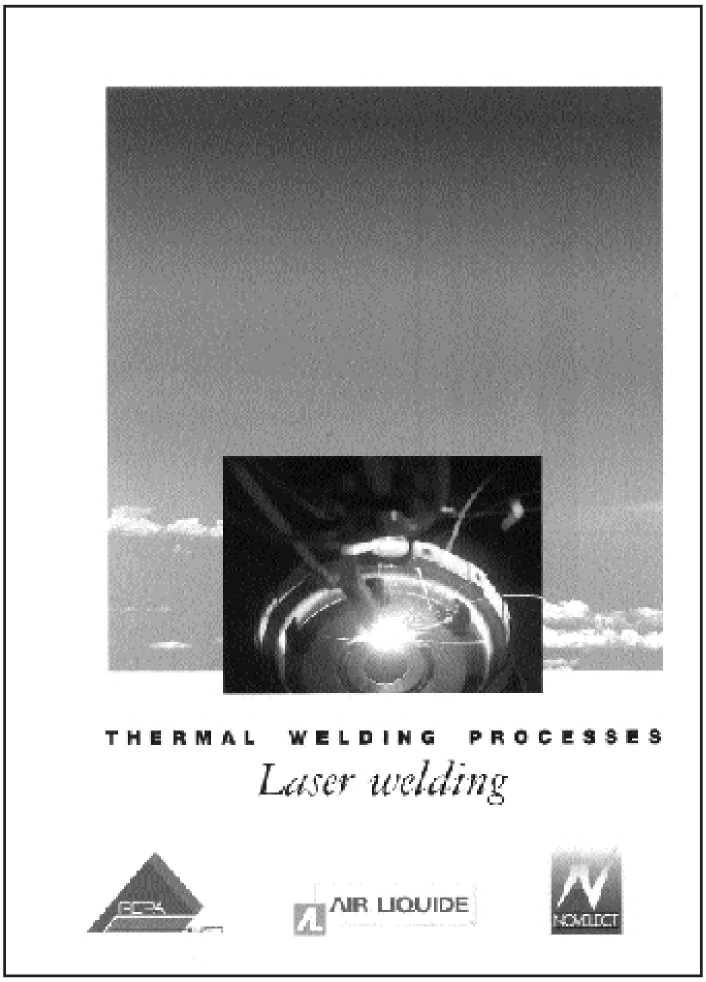


Lasers in aerospace manufacturing

Len Cooke
Sowerby Research Centre British Aerospace
PO Box 5 Filton Bristol BS12 7QW email: len.cooke@src.bae.co.uk

Photonics technology has always been important in the Aerospace and Defence industry where the use of lasers in weapon systems, for range-finding, target acquisition and tracking, and target designation is widespread. The use of laser and photonics technology in manufacturing within the Aerospace industry is however much less well developed. Here we present an overview of the research and development of the applications of lasers to manufacturing in British Aerospace. The applications discussed in each of the sections have been developed at the Sowerby Research Centre, many within collaborative projects partly funded by the EU.

Three important areas will be discussed. Firstly, the use of high power lasers as tools for drilling large arrays of process multiple holes over large areas for the production of porous surfaces for laminar flow control will be described. Secondly, the application of industrial lasers to forming or bending of Aluminium and titanium alloys will be discussed.

Finally, the paper will describe recent developments in holographic interferometry of large-scale components. In particular the technique of electronic sheargraphy will be discussed in relation to non-destructive evaluation. Significant improvements in signal-to-noise ratios in the images, through the use of laser scanning and temporal phase stepping, will be reported.

Laser Hole Drilling

The application of interest here is Hybrid Laminar Flow Control, a process involving the drilling of millions of small holes in an aircraft wing to produce a porous surface. Applying suction through the wing skin can decrease the turbulent flow over the wing and hence reduce the drag. A typical wing requires some 240 million 50mm holes.

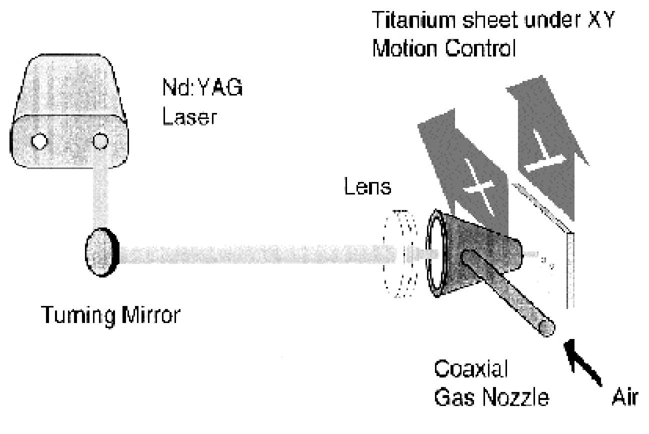


Figure 1. *Pulsed Nd:YAG laser drilling*

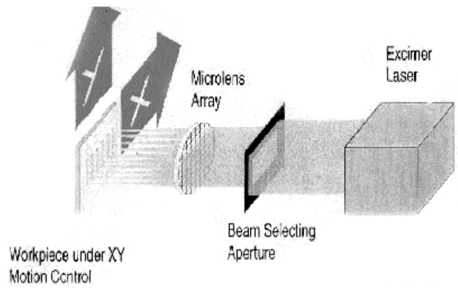


Figure 2. *(above) Parallel drilling with excimer laser*

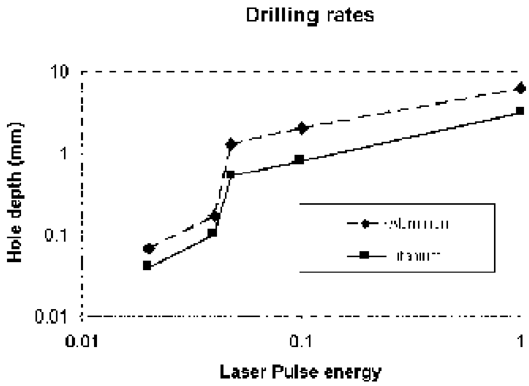


Figure 3. *(right) Excimer laser drilling rates in aluminium and titanium*

Current techniques use Nd-Yag laser drilling as shown in Figure 1. Here each hole is drilled by a single laser pulse giving a process rate of approximately 50 holes per second. We have developed a technique of multiple hole drilling using a high power Excimer laser and a micro-lens array and have achieved rates in excess of 300 holes per second (Figure 2). Figure 3 is a plot of hole depth as a function of laser pulse energy for both Aluminium and Titanium, and shows the enhanced drilling rates above a pulse energy of 100mJ. Figure 4 shows the improvements in process rate achieved since 1991 through the optimisation of the pulse energy and parallel processing techniques. Much of the Excimer laser drilling work was carried out in collaboration with NCLR in Holland using a prototype 1KW excimer laser. Figure 5 shows a panel drilled recently with approximately 7 million holes.

Laser Forming

Laser forming or bending is potentially a very flexible and cost effective technique for forming large Aluminium or Titanium sheet into 3D components. The use of optical energy to the forming process removes the need to manufacture expensive inflexible tools for the fabrication of a few components. Figure 6 shows a typical arrangement for laser bending, indicating the important material and laser parameters that affect the process.

Several mechanisms[1] have been proposed for the bending process, the most widely published of which is the so-called temper-

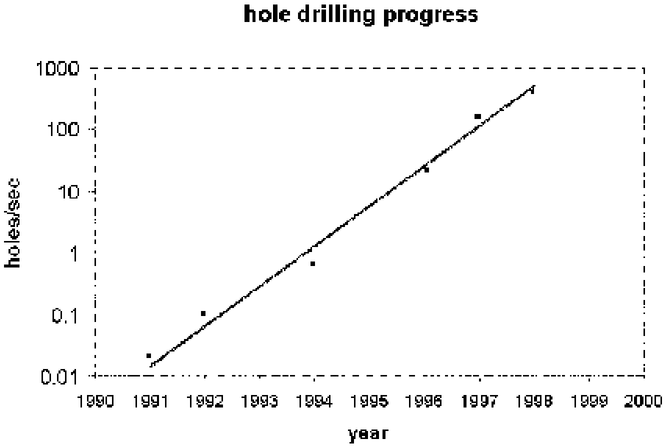


Figure 4. *(above) Plot of maximum hole drilling rate achieved over the years*

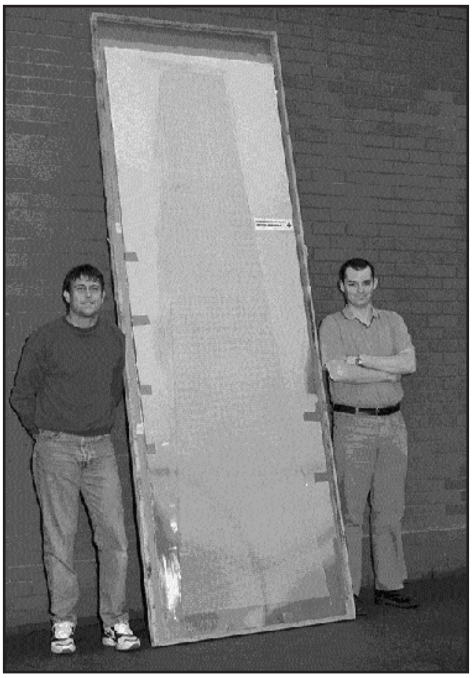


Figure 5. *(right) Panel with approximately 7 million laser drilled holes*

ature Gradient Mechanism (Figure 7). The rapid heating of the sheet sets up a temperature gradient with slow heat conduction into the sheet. Thermal expansion is converted into elastic and plastic strains as free expansion of the heated region of the sheet is inhibited by the surrounding material. Due to the temperature asymmetry during heating and cooling, the plastic strains are not cancelled and the upper (heated) layer of the sheet is shorter than the lower layer. The sheet therefore bends towards the laser.

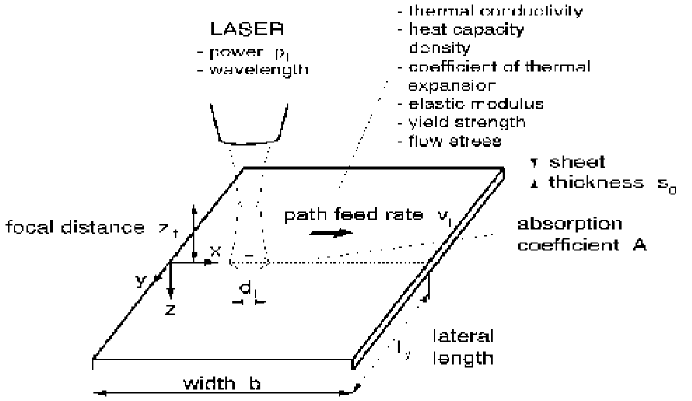
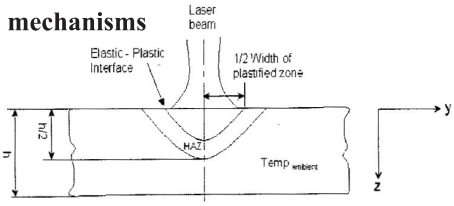


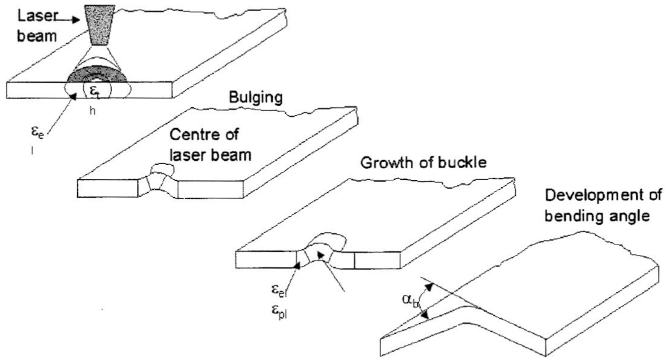
Figure 6. Typical arrangement for a laser bending job, listing the influential parameters

Alternative bending mechanisms

Figure 7. (right) *The temperature gradient mechanism*

Figure 8. *(below) The buckling mechanism.*





A second process is the so-called 'Buckling Mechanism' (Figure 8). Here the laser spot size is much greater than the sheet thickness and the sheet is uniformly heated in the direction (i.e. no normal temperature gradient exists). Attempted expansion of the material in the XY plane is resisted by the cold surrounding material, causing compressive stresses to develop which leads to a buckling of the material. The centre of the buckle becomes plastically deformed and a bend angle develops. The bend angle developed in both the thermal gradient model and the buckling mechanism is a complex function of the laser parameters and the material properties and also the geometry.

Figure 9 shows the results of several experiments carried out at Liverpool University. Laser powers of between 250 - 1300W at 10.6 μn were used to bend a 0.8mm thick titanium alloy sheet in a single scan and the resulting bend angles were measured. As

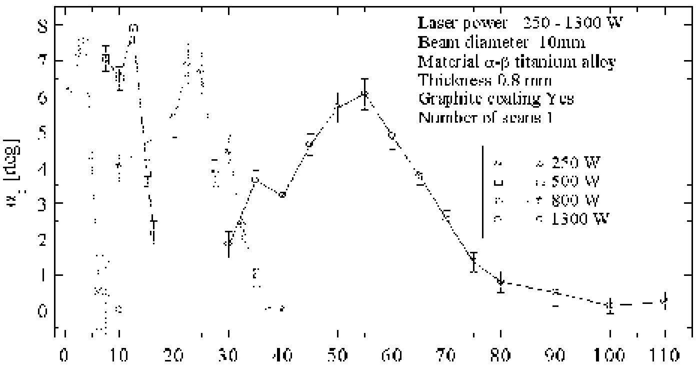


Figure 9. *(above) Plot of bend angle againsttraverse velocity for various laser powers*

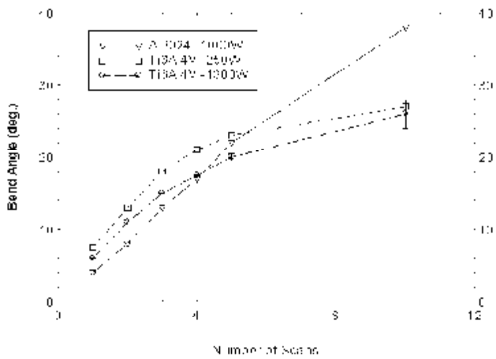


Figure 10. *(right) Bend angle against number of scans*

expected the results show that as the traverse speed of the laser spot is reduced the bend angle increases. A reduction in the scan speed for constant laser power increases the energy input to the sheet, which increases the temperature gradient. The curves show a critical scan speed, below which the measured bend angle begins to decrease. The energy input at this point is still insufficient to cause melting so it is believed that the reduced bend angles are as a result of a change in the crystal structure of the alloy. Titanium has an HCP crystal structure (α) below 882°C and a BCG (β) structure above.

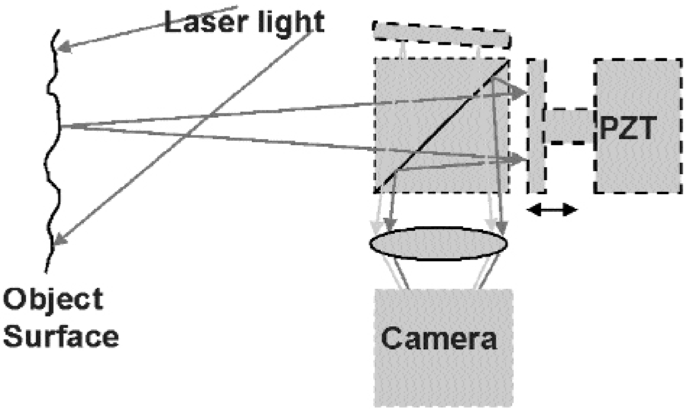
Figure 10 shows measured bend angles against number of scans for various alloys and laser powers. The plots show a saturation effect with number of scans which is a result of strain hardening of the metal with each scan.

Optical non-destructive evaluation

A third important application of laser technology to the manufacturing process in inspection or non-destructive evaluation (NDE) of fabricated components. In the aerospace industry inspection of carbon fibre composite (e.g. carbon fibre skin/nomex honeycomb core) or metallic composites (aluminium skin/Al honeycomb core) is required to test for defects such as delamination, resin depleted areas and skin/core debonds.

Optical inspection of such panels offers many advantages over other methods of NDE such as ultrasound or radiography. The whole field non-contact operation reduces inspection time and eliminates the need for complex geometry scanning and immersion of the component.

Holographic interferometry and electronic speckle pattern interferometry (ESPI) have been used but are difficult to apply in an industrial environment or produce very noisy images. At the Sowerby Research Centre of BAe we have developed an improved inspection system based on shearography[2].



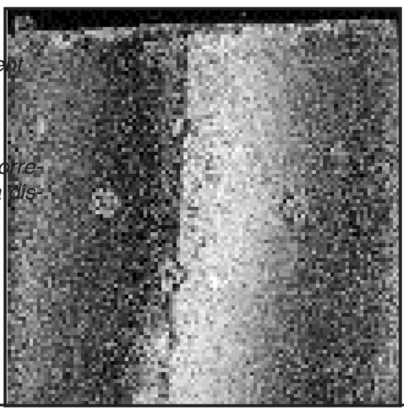


Figure 11. *(above)* *Schematic of optical arrangement for shearography.*

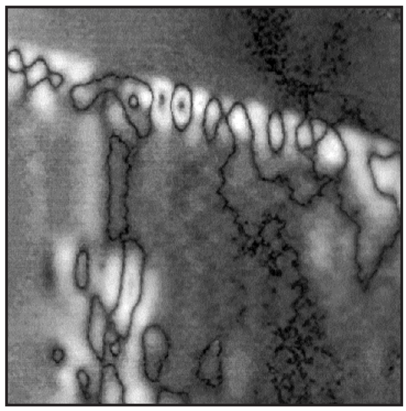
Figure 12. *(right)* *Non-destructive evaluation: a correlation fringe pattern highlights a distortion when a uniform force is applied..*

The principle of shearography is shown in figure 11. Light, (frequency doubled Nd:YAG laser) scattered from an object, enters a Michelson interferometer and is captured using a CCD camera and digital framestore. When one of the mirrors of the interferometer is slightly tilted, a pair of 'sheared' speckle images of the surface is produced. With this configuration the intensity at a point in the image is affected by any distortion of the object's surface. Defects can be detected by recording a pair of sheared speckle images with a stressing force applied to the object between image captures. Subtraction of these images produces a fringe pattern image (correlation fringes) which highlight the distortion (Figure 12). Various stressing forces may be applied but our research has shown that the most effective technique for large components is pressure stressing.

The quality of the images can be greatly improved if phase stepping is used during the illumination phase. This involves capturing several speckle patterns that are stepped sequentially in phase by a fixed amount. Typically five images spaced by P/2 are captured. A 'phase map' of the object can therefore be produced which exhibits higher contrast than a record using intensity fringes. The illuminating beam is phase stepped by moving one of the Michelson mirrors by a fixed increment between captures. A piezo driver is used to effect this.

At the research centre we have developed improved fringe analysis algorithms (A full description of the fringe analysis techniques is beyond the scope of this article) which involve the capture of up to 100 images and temporal averaging to improve signal to noise (figure 13).

Figure 13. *Shearographic image with improved fringe analysis*



Conclusion

In this paper I have described the development of some applications of industrial laser technology to manufacturing in the Aerospace industry. The examples used are only a small set of applications from a much larger group of existing and potential applications. The use of laser technology in Aerospace manufacturing is not mature and much work will be required to ensure that the industry can take full advantage of the flexibility offered by this source of optical energy.

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Laser-Based Rapid Production Technologies

Bill O'Neill

University of Liverpool

Department of Engineering, Liverpool L69 3BX email: w.oneill@liverpool.ac.uk

Dr Bill O'Neill of the University of Liverpool's Rapid Prototyping Centre describes the key features of laser based rapid production technologies and discusses the main areas of development that are being pursued in the numerous research laboratories interested in producing the ultimate 'replicator' machine.

Introduction

Rapid Prototyping (RP), FreeForm Fabrication (FFF), Time Compression Technologies (TCT): all of these terms describe the production of an object from virtual or real data by some means capable of additive production. That is, being in a position to place material where you want it and when you want it. This is very much unlike existing manufacturing technologies which form, remove or join materials to produce the desired object.

When lecturing to undergraduate and postgraduate students on the subject of RP, I always begin in the 23rd century, see Figure.1. In the year 2300 or sooner, man will be able to instruct a machine to construct by whatever means the object of desire. This could be a lawnmower, a meal, or a replacement part for the broken family vehicle. This may sound far fetched, but isn't it strange that the predictions of science fiction writers tend to become reality rather more often than those of conservative scientists and engineers?

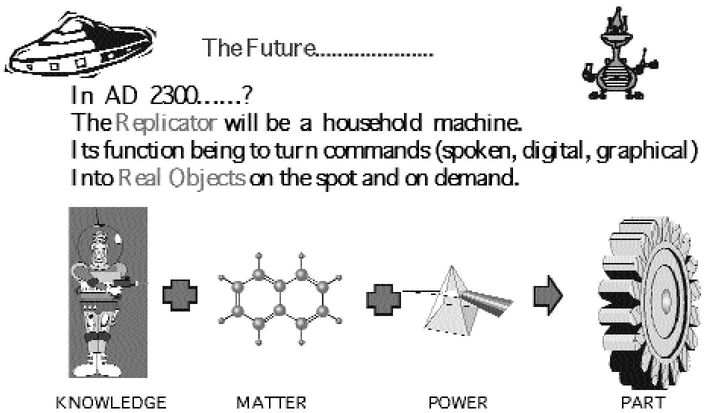


Figure.1 *A vision of the future*

Three advances are required in order to realise a Replicator: (i) the knowledge to develop advanced manufacturing technologies, (ii) the understanding of materials necessary to enable matter to be structured on an atomic scale (see K. Eric Drexler *Engines of Creation*) and (iii) advanced power sources that can selectively control and position matter. Achieving the above will go some way towards the Personal Factory, a means of constructing and de-constructing objects at will and on demand. One can see that advanced RP systems have the potential to work both forward and in reverse and therefore are very 'green'. Enough of science fiction and the fancies of clumsy modern scientists!

The real beginning of RP technologies as we know them began in 1981 when Prof Kadama of the Municipal Industrial Research

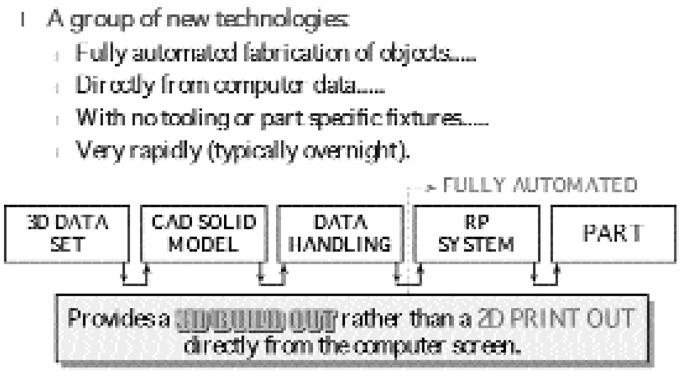


Figure.2*. Rapid Production Technologies*

Institute was the first to publish an account of a functional photopolymer RP system. In this case a laser was used to selectively cure a photopolymer in a layerwise build strategy resulting in a 3D object. Parallel developments were made by Herbet of 3M in 1982. Present RP methodologies acquire object data from the human mind, matter or mathematics, see Figure.2. Once acquired this data is transformed into a virtual 3D solid that carries all the essential information necessary to create the object. The data is then processed via data handling algorithms and sent to a RP fabrication unit of whatever description. The part then appears within hours rather than weeks or months as with traditional routes. We have then the capability of a 3D build-out rather than a 2D print-out. In the RP arena there are two worlds that must be managed in order to properly construct objects, the virtual world and the real world, Figure.3. In the virtual world the 3D object is examined to assess the need for supporting structures. These supports maintain overhangs and undercuts since the object is built in a layerwise fashion which means that a particular slice may contain parts which are completely separate from each other within the layer. Once the supports are determined the object data is formatted into a de-facto standard called an STL file. The STL file essentially represents the object by a collection of tessellated triangles which reduces the size of the object data and renders it ready for slicing followed by production. Most good three dimensional solid or surface CAD packages are capable of outputing STL file formats which all RP systems can input. The STL file format is a leftover from the early days of RP development and is slowly being replaced by a range of file formats which offer better accuracy and are less prone to errors in interpretation.

Having delivered the STL file format to the RP machine in a layer by layer approach the machine begins to form the object from the bottom up by whatever production process has been chosen.

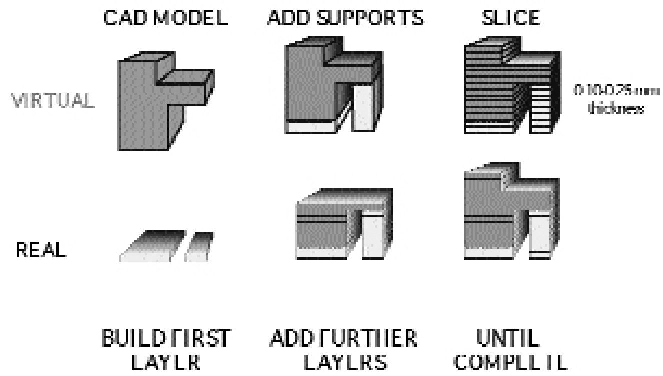


Figure 3 *Virtual and real operations in RP*

Rapid Production Technologies

The first commercial RP developments came from 3D systems of Valencia, California, in 1986. In this case the technology was not far from that developed independently by Kadama and Herbet in the early eighties. In the Stereolithography Apparatus (SLA) a HeCd laser operating at 352 nm was used to cure a photopolymeric material with the aid of scanning optics and associated resin control. A build platform progressively lowers into the vat providing a new resin surface which can be cured onto the previous layer which is submerged to a depth of 1 layer. The process repeats until all of the layers are cured and the object is then magically raised from the vat like ‘Excalibur’ from the lake. If one examines a cured line one would see a parabolic cylinder which has been constructed by the overlapping ‘voxels’ formed by the pulsed laser source. Very complex components can be made with this technique such as the engine manifold shown in the Figure.4. Here the component was built with a SLA system and used to test the fluid flow properties of the cooling system. Subsequent design changes can be made quickly by providing an add-on or the whole part could be re-built within hours or days depending on the size and complexity of the object. SLA systems are used in a wide range of industrial sectors for the production of ‘touchy feely’ models to injection mould inserts that can withstand a few thousand injection cycles depending upon the material being injected. There are several SLA type processes on sale around the world with varying degrees of innovation, accuracy and ability.

One of the biggest drawbacks with SLA technologies is the limited use that the photopolymeric materials offer to a designer. The materials are brittle and fall short of providing a wide range of properties that are required in the production of modern goods. The late eighties saw the introduction of another RP system called Selective Laser Sintering (SLS) by DTM Corporation, a spin-off company from the University of Texas where the technique was developed. In this process the vat of resin is replaced by a container of powder in which a thermal laser interaction is used to selectively fuse powder particles together layer by layer. The powder is spread over the fused layer by a roller mechanism and a CO_2 laser is scanned over the new powder layer fusing it to the layer below. This cycle is repeated until the object is complete. In this process one could use a variety of plastic, metal or ceramic powders hence the process provides components that are more functional than those from the SLA process. The limitation here is the high levels of porosity that results when fusing metal and ceramic parts. Quite complex components can be constructed with this technique as shown in Figure.5 although the surface finish is limited by the diameter of the particles used in the process. One innovative development of the SLS process is RapidToolTM, figure 6. Here a polymeric coated steel powder is selectively fused to produce two injection mould halves.

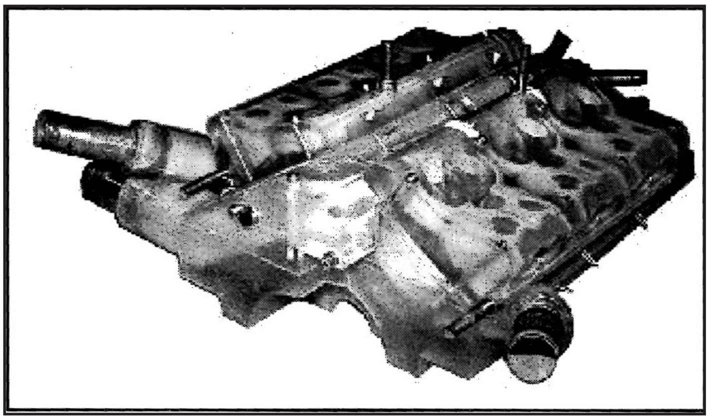


Figure 4 *Engine manifold produced using a SLA machine in order to study the fluid flow within the cooling circuit*

These mould halves are porous with little mechanical strength. The two halves are then sintered in a high temperature oven to burn out the polymer and then sintered further to increase the strength and density. Full density is not achieved however and an infiltration step is performed with a copper-bronze alloy to bring the two mould halves to full density. The mould halves are then capable of several thousand injections. The distinct savings of time and money compared to standard injection mould production routes have placed RapidToolTM at the forefront of advanced ‘soft’ tooling technology. The past few years have seen rapid tooling take the centre stage in the relatively youthful activity of time compression technologies. The SLS process has stimulated high levels of research activity across the world aimed at developing SLS process technology to provide full density metal parts straight from the machine. In the UK, Liverpool and Leeds universities are both developing their own versions of the SLS process using Nd:YAG and CO_2 lasers respectively. It will not be long before industry has the ability to build accurate fully functional metal parts directly from the new SLS based systems.

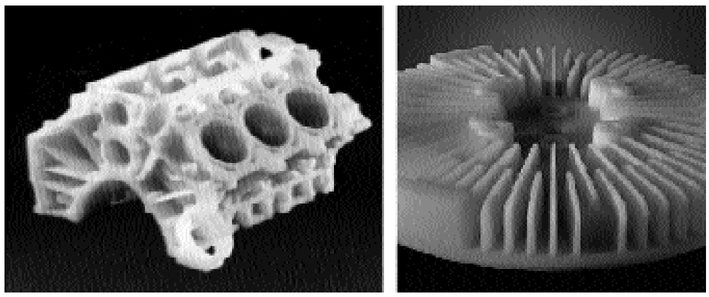


Figure 5 *Typical components produced via the SLS process.*

Another process which stands with the above is Laminated Object Manufacturing (LOM). This process involves the construction of an object by bonding pre-cut layers of material. Materials that have been used successfully include, paper, ceramics, plastics and metals. The accuracy of the route is comparable with those mentioned above and the cost is low since sheet materials are always used The LOM process has been commercialised by Helysis Corp. In this case a flatbed CO_2 laser cutter is used to profile cut the paper according to the specification of the particular CAD slice of the object. A paper handling system moves the waste

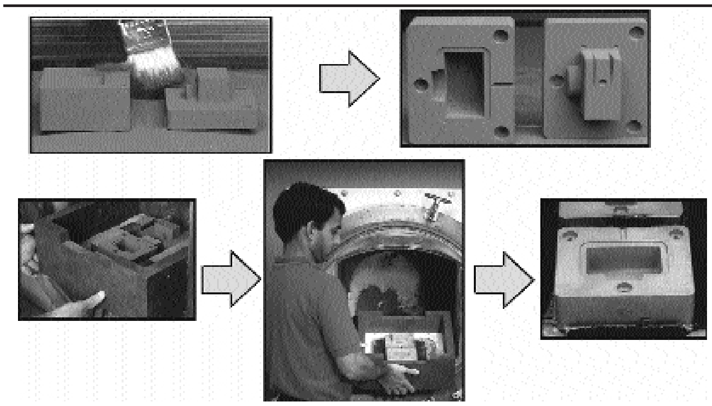


Figure 6 *Process steps in DTM's RapidToolTM process.*

material onto a take-up roller and a heater compresses and activates the adhesive on the underside of the sheet part to make good contact with the layer below. This process is repeated until the whole object is complete. The waste areas around the individual slices are cut such that they can be easily removed by the operator once the whole object is complete, see figure 7. LOM is such a simple process and many research groups are working to develop the route for tooling applications. A consortium of UK Universities, Liverpool, Warwick and Leeds are working with a wide range of aerospace and automotive companies to examine the process route for large scale tooling applications under an EPSRC IMI research programme. De-Montfort University is also examining the route for a range of tooling applications. The metal LOM process provides significant time and cost savings for a range of tooling applications.

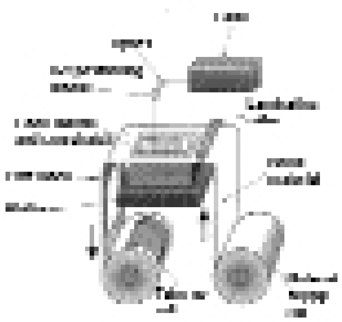


Figure 7 *Principles of the LOM machine and the break-out process*

Another process that has captured the imagination of RP users is Laser Assisted Deposition (LAD), or Laser Forming, or Direct Laser Casting depending upon from which laboratory you saw it first. It essentially involves the controlled deposition of metal by a laser cladding route followed by mechanical machining to bring the process into good manufacturing tolerances. It has the capability to produce solid metal objects, even variable material gradients such that the correct material can be located in the required position, i.e. stainless steel skin for injection moulds with a graduation to an invar core for thermal stability followed by copper walled cooling channels for good heat removal.

This principle has been applied to good effect by a team at the University of Standford using the Laser Assisted Deposition process. Figure.8 shows a stainless steel bust produced by the Standford team and a cross sectional schematic of graded mould tool using stainless steel, invar and copper.

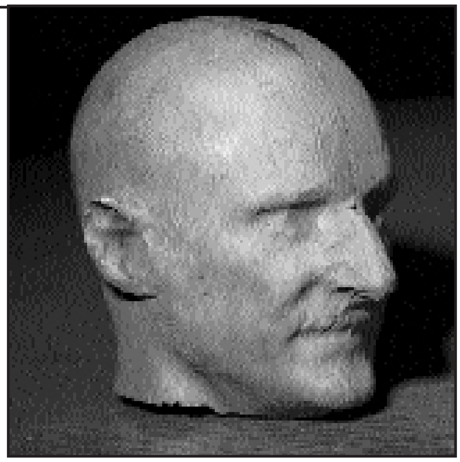
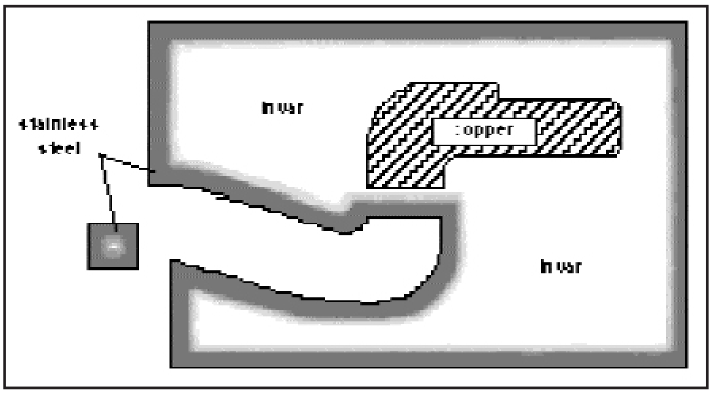


Figure 8 *Full size bust produced using Stanfords Laser Assisted Deposition process and a cross-sectional schematic of a graded mould tool using stainless steel, invar and copper*



Summary

There are many other processes both commercial and laboratory based that can produce components in a particular material, Fused Deposition Modelling, Ink Jet Systems, Freeform Powder Moulding, etc. Many of the above systems utilise simple deposition techniques such as squirting and squeezing materials from nozzles. They are just as accurate if not more so than the expensive laser based systems that lead the markets. I believe that the future of widespread RP systems will not rely on laser based technology. Lasers might be used to fabricate the devices such as ultra-high resolution ink-jet units. Such systems can deliver metallic inks, ceramic inks and polymeric materials with very high levels of accuracy. Already inkjet based systems are providing ceramic, metallic and polymeric parts in a fraction of the time and at a fraction of the cost of the Mark-I units such as SLA, SLS and LOM. You will begin to see these units influence your lives within the next few years. There are many reasons why these systems will become widespread sooner rather than later. Lookout shoppers, it won't be long before you'll see your chosen purchase being grown before your very eyes !

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Forthcoming Events

February 99

10 Manufacturing possibilities with lasers
Make it with lasers event, Lincoln
Carol Fielding
Tel: 01223 891162 Fax: 01223 892588

association of industrial AILU laser users

24 AILU Workshop
Laser-based Rapid Production Technologies
PERA, Melton Mowbray
Further info: AILU
Tel: 01235 539595 Fax: 01235 550499

March 99

association of industrial AILU laser users
AILU supported

8 - 11 ILSC '99
Orlando, Florida, USA
Further info: Laser Institute of America
Tel: +1 407 380 1553

See advert, p41

April 99

13-15 Fluids Processing and Handling Exhibition
Harrogate International Centre
A new specialist trade show.
The organisers, DMG, will provide an optical technologies area as a feature. Stands in this area will be subsidised. DMG are also sponsoring an optical technologies workshop of short presentations, including case studies, on different aspects of optics and photonics in fluids processing and handling, including flow measurement and diagnostics and materials processing
Mike Green
Tel: 01235 539595 Fax: 01235 550499

18 Processing non-metals
Make it with lasers event, Bristol
Carol Fielding
Tel: 01223 891162 Fax: 01223 892588

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LASER JOB SHOP
From fume to water cooling
Nitty gritty solutions to practical problems from safety to gas purging and water cooling

OPTICS
Lenses for scanning laser systems
Dave Greening reviews the options for focussing scanning beams

SAFETY
Current developments in laser standards
A review of the current safety and performance standards for lasers

Editorial Policy

The Industrial Laser User is the house magazine of the Association of Industrial Laser Users. Its primary aim is to disseminate technical information and to present the views of its members.

The editor reserves the right to edit any submissions for space and other considerations.

Authors maintain the right to extract, in part or in whole, their material for future use.

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Editor: Mike Green
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AILU, Oxford House, 100 Ock Street, Abingdon, Oxon. OX14 5DH
Tel: 01235 539595 Fax: 01235 550499 e-mail: admin@ailu.org.uk