The Industrial LASER USER

association of industrial AILU laser users

Issue 24 September 2001

David Dyson in 1975 with the Ferranti MF 400, claimed as the world's first CO_2 laser and most certainly the best known.

David Dyson wins 2001 Award

The 2001 AILU Award for an outstanding contribution to the industrial use of lasers in the UK has been won by David Dyson.

David started work in 1963 in the Laser Group of the Ferranti Valve Lab in Edinburgh, under the late Neil Forbes, two years before the first reports of CW CO_2 laser operation. The group's commercial involvement in CO_2 lasers began by supplying a design based on work carried out at SERL Baldock to produce a system for RRE Malvern, a 'conventional' slow flow device with a water-cooled AC (50Hz) excited gas discharge. The main feature of the design was the electrode which acted as a coupling between successive tubes and also between the inner and outer tubes forming the water jacket. As such, the electrode was itself water cooled. Any number of tubes could be coupled together. Each had to be supported, at the electrodes and mirrors, on suitable floor stands. The customers specified how many sections they required. David became seriously involved with this project in 1968, and over a number of design developments became instrumental in solving problems leading up to the optically-folded 12-section design of the MF 400.

BOC bought one of the early Ferranti folded systems for their Welding Research Laboratory in Cricklewood and won a contract to supply Thynes of Edinburgh with a laser die-board cutting machine. This was based on a line-following guidance system, with Ferranti supplying the laser, comprising four in-line 1 metre long sections, providing in excess of 200W. There were problems to overcome, including the suppression of high order modes, prevention of damage to o-ring seals, the use of composite electrode design to reduce overheating, electrical breakdown of the mirror block insulation and electrolytic attack of aluminium in a water-cooling channel in the output window support. Despite all this, BOC made their first delivery in the summer of 1970.

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Microengineering at Exitech packs them in!

Review by Microengineering Workshop Chair, Jim Fieret.

Over 80 delegates filled Exitech's conference room to its maximum capacity for AILU's Microengineering Technology Workshop on 13 June. The meeting brought together European industrialists from a wide range of industries.

The introductory overview by Malcolm Gower (Exitech) highlighted the growing and increasingly diverse industrial demand for miniaturisation and how laser-based systems meet the performance required by industry. John Abbott (Coherent UK) illustrated this point in his review of solid state laser technology, quoting lifetimes of diodes pumping Nd:YAG and Nd:Vanadate lasers of well above 10,000 hours, with comparable lifetimes of frequency doubling and trebling crystals by active monitoring and control.

Micro-hole drilling was addressed by several speakers. Prof. Lin Li (UMIST) presented the latest research results in laser percussion drilling of small holes in metals, including methods for controlling hole taper and avoiding spatter deposition. Michael Kauf (Excellon Automation Co, USA) reviewed laser technology for via interconnect drilling. Computers and hand-held digital devices now required interconnects to have a diameter well below 100µm, but whereas mechanically drilling becomes slower and more expensive as 100µm is approached, laser drilling becomes faster and cheaper. Similarly, in the printing industry there is a strong pressure on device dimensions, with higher print resolution requiring more and smaller nozzles, and Pier Luigi Soriani (Olivetti I-Jet, Italy) showed how laser-assisted microsystem technology is applied in the inkjet printing industry. He showed examples of how I-Jet achieves nozzle diameters down to 10µm by excimer laser mask imaging photo-ablation.

Speakers at the Microengineering workshop. *(l to r) Nigel Mason (BP Solar), Julian Burt (Univ. Wales), Michael Kauf (Excellon), Jim Fieret (Exitech), Lin Li (UMIST), Michael Charrier (Thales), John Abbott (Coherent), Keren Hamilton (Microsharp) and Pier Luigi Soriani (Olivetti I-Jet). Missing is Malcolm Gower.*

Other presentations highlighted the diversity of applications of laser microengineering technology, including Nigel Mason (BP Solar Ltd) on the use of lasers to scribe thin shallow grooves on wafers for silicon photovoltaic cells production, Michel Charrier (Thales, France) on micromachining on 3-dimensional substrates for aerospace and telecoms applications (see feature article in this issue), Julian Burt (University of Wales, Bangor) on high resolution patterning for miniature Lab-on-a-Chip systems and Keren Hamilton (Microsharp Corporation Ltd) on laser ablation of microprisms in the backplane of LCD's for passive contrast enhancement.

Letters to the editor

Laser safety training

In response to the correspondence in the issue 23 on meeting laser safety training needs for industrial laser users, I would like to draw readers attention to a new distance learning qualification for Laser Safety Officers offered by the Laser Centre at Loughborough.

A new work-based qualification, BTEC Advanced Award Industrial Laser Protection, has been written for those who find themselves responsible for laser protection, in particular those acting as Laser Safety Officers. The qualification can be taken at the candidates own pace by completion of a series of modules, assessments and course work and by submitting evidence of particular tasks. For example, a candidate will be expected to undertake risk assessments, write local rules, design and implement laser safety policies. The qualification is designed for distance learning, reducing the amount of time spent away from work. Candidates will be required to spend no more than two days away from work for assessments and tests here at the Laser Centre, or if appropriate, in their own workplace. Course notes, workbooks and assignments and access to tutors via email or telephone support the learning process.

The new qualification offers more than just attendance on a short course – it requires candidates to demonstrate competency – which is a real measure of what someone can or can not do!

The qualification hopes to offer a more hands-on and relevant form of training, and at the same time give recognition to the role of Laser Safety Officers and the many tasks it involves.

The first qualification is for industrial laser protection with a second qualification for medical laser protection available soon.

Elizabeth Raymond
Loughborough College

Hole drilling

I read with interest the article ‘Effect of processing gas in the single pulse laser drilling of titanium’ by William Rodden et.al. It demonstrates just how unpredictable percussion laser drilling can be. I would be interested to know what the stability of the laser power was during drilling and what chemical reactions were taking place between the titanium and the air. A variability of 10% in hole size was shown and it is not unreasonable to expect a variation in power of a similar order from pulse to pulse. Also, depending on the nature of the air supply, contaminants may be present intermittently (oils/water vapour in shop supply). Inert gases are often used in processing titanium as the reaction with oxygen can be unpredictable, not to say dangerous!

Pam Byrd
Rolls-Royce Manufacturing Technology, Bristol.

The stability of the energy of the drilling pulses was indeed around 10%. However, the hole sizes were very poorly correlated with the energy of the corresponding drilling pulses, so the size distribution of the holes is not simply the result of this energy variation. We have performed a correlation analysis and found that higher energy pulses are actually slightly inclined to produce smaller holes. This counter intuitive behaviour has its origins in the pulse to pulse variation in the temporal shape of the drilling pulses. Each pulse consists of train of random spikes, resulting from relaxation oscillations in the gain medium. We have found that lower energy pulses are more inclined to have a temporal shape which drills better (more of their energy is contained in the larger spikes near the start of the pulse). We believe the hole size distribution is to a large degree the result of the random nature of the expulsion of molten material from the holes, which is a significant effect in the long pulse Nd:YAG drilling of titanium. These are among the results that we shall be presenting at this year's ICALEO conference. The effect of the reaction with oxygen is to increase the size of the holes. Our paper, "The Use of O_2 Assist Gas in the Laser Drilling of Titanium" (accepted for the Journal of Laser Applications), studies this effect for nitrogen/oxygen mixtures with increasing oxygen content. So the oxygen content could in principle be used as an additional variable with which to control the hole dimensions - although Pam Byrd's comment regarding the unpredictable, and potentially dangerous, nature of this reaction is entirely justified.

William Rodden:
Heriot-Watt University

Note from the editor

Soliciting members for papers for the magazine is never easy, particularly during the holiday season, and I have rarely enjoyed the luxury of having an excess of suitable text from which to choose. So it is more good luck than judgement that this issue manages to at least touch on most application areas, many laser sources, business, safety and optics as well.

One point that particularly attracted my attention in this issue came from David Dyson, this year’s winner of the AILU Award. He recalls that the development of the Ferranti MF400 laser, surely a milestone in compact CO_2 laser design, was not initially motivated with a view to mounting the laser head directly on a cutting machine. But without the wisdom of hindsight, who could have foreseen the dramatic growth in the packaging industry and the demand for portable lasers in dieboard cutting? Some 30 years later and we find three dimensional laser processing taking off and portable (mainly diode) lasers finding new roles to play in industry. One such application area is the manufacture and repair of dies (for stamping metal, not card), in which a laser is used to build parts out of metal powder.

Some exciting applications of diode lasers, the ultimate compact high-power laser source, are also covered in this issue, together with 3-D micromachining and some useful notes on cutting aluminium for laser job shops. On this last point, members may like to note the new job shop logo and slogan on p 35.

With the holiday season at an end, there are a number of exciting meetings to look forward to in the next few months, including our own ‘Laser Job Shop 01’ and ‘Design for Manufacture by Laser’ as well as the Laser Institute of America’s ICALEO 2001, all fertile ground for hunting out new authors and articles for the magazine.

David Dyson's Award (continued)

Work on these various systems continued throughout 1970 and beyond, but the work that led to the MF400 began in late 1969. "I recall feeling that given the scale of new problems which seemed to arise from any new design, it was important that the design on which we were working must ultimately be worth the effort. It had always been felt that we must eventually make the system more compact, by increasing the number of folds and I thought it important that we make a start as soon as possible, rather than get involved in any further unfolded or single-fold designs," said David.

"One of the problems in any conventional design, but particularly when considering folded systems with long overall discharge length, is electrical isolation. One attractive solution was to use two discharges per leg and to isolate these from each other at the centre with a short dead space between a central pair of live electrodes, allowing all the end electrodes and mirrors to be essentially grounded. This also had the advantage of greatly simplifying the power supply design since a single HV source could be used. An experiment was set up in December 1969 to test this, using two BOC-style tubes. This showed that, provided the applied voltage had a sufficiently short rise time, the discharges could be initiated correctly with a dead space of only about 10% of the overall length."

"The original plan had been to make use of the advantages of corner-cube folds, but zig-zag (single mirror) folds proved the most successful," said David. "The simplicity of the fold meant that cost of the optics and supports was much less and the only apparent disadvantage, that of wasted length, was not significant."

The first MF400 was delivered to Plascut in Rotherham in 1971 and David set about converting what was essentially an experimental rig into an engineered design. "What had initially attracted Plascut was the possibility of mounting the MF400 head directly on the beam of a plasma-cutting machine, avoiding the need for moving the workpiece or using moving mirrors. Although this possibility had not been considered originally, and was certainly not the original motive for producing a small design, we were able to take account of it in the design of the suspension for the cavity support structure," said David.

"Looking back, it does seem that my original concern that any new design would lead to a range of problems was even more prophetic than intended. This seems to have been the experience of many laser manufacturers. Although it is inevitable that there will be some problems, I wonder if this may partly reflect the difficulties in bringing together and co-ordinating the very wide range of engineering skills needed, ranging from optical and electrical to mechanical, heat and fluid flow," said David.

"I have enjoyed meeting the intellectual challenges presented, as well as meeting many customers," commented David adding, with characteristic modesty, "I am aware that the opportunity I had does not come to everybody and that there is an element of luck in being in the right place in the right time."

The presentation to David Dyson will be made at the AILU meeting at the Rutherford Laboratory on 19 September.

Members' News

AOT's first short pulse products

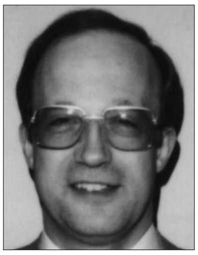
Advanced Optical Technology, formed in 1999 to commercialise novel optoelectronic technology, have recently started shipping their first products. These ACETM Q-switched YAG and YVO solid-state lasers produce TEMoo pulses down to ~ 1ns duration and to ~ 50kW peak power, and can operate at up to 20kHz repetition rate. The units are highly compact and efficient, obviating the need for water cooling. The excellent beam quality, active Q-switching and harmonic options allow the sources to be used for many precision applications where very-short, well-synchronised pulses are essential for success.

Name change for V&S Scientific

In December V&S Scientific were acquired by Union Miniére. The group has recently changed its name to Umicore and V&S Scientific will in future be known as Umicore Laser Optics, part of Umicore Electro Optic Materials.

"As Umicore Laser Optics we intend to maintain and further improve our commitment to our world-wide customer base. Continuing the innovative spirit inspired by our founder David Greening, we will be launching a range of new products including telecentric scanner lenses, adaptive optics and optical products requiring diamond machining techniques such as Dual-Focus lenses and other aspheric components," said Paul MacLennan. "We are looking forward to expanding our role as the dynamic force in laser optics world-wide as Umicore Laser Optics."

Keith launches new consultancy business



Former GSI Lumonics' employee Keith Withnall has launched a new consultancy service providing support to prospective or existing laser users, as well as laser source and component manufacturers.

Keith has almost 25 years experience in the design, application, sales and marketing of industrial laser systems for materials processing applications – especially using solid-state lasers.

"Our service can assist laser users on all aspects of design, selection and purchase of laser processing equipment, while for suppliers to the laser industry we offer market surveys and other business development techniques," said Keith.

New man at Oxford Lasers

Oxford Lasers Ltd has appointed Adrian Baughan as their new Sales Manager for it's Industrial Division - Micro-machining Department. Adrian, a Mechanical Engineer, was previously employed at Oxford Lasers in a variety of roles for thirteen years, prior to a career break to travel. He re-joins the company to promote worldwide sales of Oxford Lasers' application laboratories and micro-machining equipment.

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Success for Herfurth Laser Technology (HLT) Ltd

Herfurth Laser TEchnology have received the first of two orders for transmission laser welding systems, for use on production lines for manufacture of high-volume automotive components. This order was placed after successful trials of prototype components carried out in conjunction with Warwick University who are venture partners in the company.

Diode laser head on a rig at the IMC, University of Warwick.

"A major assembly constraint required a totally new process to be developed and proven, late in the design cycle of the product. The flexibility of HLT's diode-laser-based welding system provided an ideal solution," said Richard Icke, a director of HLT.

"HLT have particular expertise in the area of plastic welding, building upon processes developed at Warwick that provide an enabling technology who's worth is starting to be realised by a wide range of industries, particularly in the plastics sector," said Peter. "Automotive and medical component manufacturers have been the first to capitalise upon this new production technology," he added.

As a result of increasing sales, HLT has moved into an office within the Barclays Venture Centre on the Warwick University Science Park. This office handles sales enquires, coordinates sample and process development work in conjunction with the nearby Warwick University and project manages the production of laser and similar high-tech systems for industry.

Hydram goes for growth

North-Eastern sheet metalwork supplier and AILU job shop member, Hydram Engineering, has recently completed an expansion programme, including a factory extension and installation of a powder paint plant.

Privately owned, Hydram was established in 1977 to provide sub-contract engineering services to local businesses. The company has grown steadily over the years and now occupies a 50,000 sq ft factory supplying components all over the UK and Europe.

Newly appointed Operations Director, David Greatorex, is enthusiastic about the developments. "Hydram has always followed a policy of continuous improvement and has maintained investment in the latest precision processes, including CNC laser cutting, punching and folding," he says. "With the addition of a paint plant, Hydram now offers a complete range of subcontract sheet metalwork and associated services on one site." Full details can be found at *http://www.hydram.co.uk*.

Liverpool's New Masters Course

A new one year course leading to the degree of MSc(Eng) has been launched by University of Liverpool. The course, Engineering Applications of Lasers (EAL), is the only course of its kind in the UK to concentrate on laser materials processes and represents the fulfilment of plans initially devised by Bill Steen and Ken Watkins for a wholly modular degree programme in lasers at Liverpool. The programme, developed by Ken Watkins and Geoff Dearden with the support of visiting professors Len Cooke (BAE Systems, Sowerby Research Laboratory) and Neville Krasner (Aintree Hospitals and Lasers for Life) will accept its first full-time students in September 2001. Prof Cooke with Dr Dearden and Prof Krasner with Dr Watkins are co-ordinating modules on optics in laser processing and lasers in medical treatments, respectively. Peter Oakley is providing significant input into a module on economics of laser processing.

Common features of all modules:

- Can be taken as one week stand-alone courses.
- Mixture of formal lectures, talks by industry speakers and hands-on experience in the laser laboratory at Liverpool or at the nearby Lairdside Laser Engineering Centre.
- Can be taken directly on a single short-course basis.

The programme is supported for three years by the Engineering and Physical Sciences Research Council (EPSRC) through its Masters Training Packages programme. For full-time students, up to ten studentships are available per year to cover the costs of fees and maintenance. A smaller number of fees only bursaries are available to EU-based students.

In an innovative development programme supported through the EPSRC award, a part-time version of the course will be launched in September 2002. The part-time version is aimed at those with posts in the laser industry who wish to remain in their position while gaining a higher degree. For the full-time and part-time courses, there is also a substantial research project in a subject relevant to laser processing in industry.

A distance learning version of the course (on CD-ROM and the world wide web) will be launched in 2004. Development of the distance learning materials will be carried out by Chris Taylor in collaboration with the University of Liverpool MATTER unit and with assistance from Roger Crafer.

Engineering Applications of Lasers Modules 2001/2

Introduction to Laser Materials Processing	24/9–28/9 01
Optics and Optical Effects in Laser Engineering	8/10 –12/10 01
Economics in Laser Engineering	22/10 –26/10 01
Medical Applications of Lasers	12/11 – 16/11 01
Laser Cutting and Marking	28/01 – 1/02 02
Laser Welding and Drilling	11/02 – 15/02 02
Laser Surface Processing	25/02 – 1/03 02
Laser Manufacturing Systems and Automation	11/03 - 15/03 02

N.B. Dates subject to change. Please confirm your interest in attending well in advance.

See *www.lasers.org.uk* for further details

Loughborough College Successes

Successful BTEC's in Laser Materials Processing

Congratulations to the 10 students who have gained a BTEC (Intermediate) Award in Laser Material Processing from Loughborough College's Laser Centre. The standard of post course work was extremely high and recognised by the course assessors and external examiners who commented on the excellent standard of work submitted by the students. The portfolio work included processed samples, photographs and examples showing the effects of variables in laser material processing.

Delegates attending the 4-day course included experienced laser practitioners, research students and relative newcomers to laser material processing from laser manufacturers, university research departments, and laser material processing industries.

The successful students were Paul Ashworth, Lawrence Bailey, Elliot Burbage, Sean Carr, Anand Dwarkanath, Edward Eyres, Chris Hogan, Derek Hughes, Su Wei-nien, Simon Sutton.

The Laser Centre continues to hold a short courses covering different aspects of laser material processing. Anyone interested in these courses should contact the College for more information.

'Great Expectations' - lasers extend into fashion

The Laser Centre has just completed a series of intricately cut fabrics that are being shown in New York in October 2001 as part of the UK 'Great Expectations' exhibition. Savithri Bartlett, a top UK textiles designer currently working towards a PhD at LUSAD, in collaboration with fashion designer Deborah Milner, used the skills and lasers at the Laser Centre to produce the work.

The exhibition will put British innovation right in the heart of New York at the Grand Central Terminal, Manhattan. It will feature more than 100 examples of the best of British design and innovation, from the London Eye and Gateshead Bridge to an e-mail pen, a talking paper clip and even a re-invented dog kennel. Developed by the Design Council to blow away old-fashioned stereotypes of Britain and boost UK business ties with the USA, exhibits have been picked to reflect the diversity of world-leading British design. Sectors represented include consumer and medical products, engineering and automotive, film and new media, fashion and textiles, advertising and architecture.

Congratulations to Savithri on taking up the challenge to promote and use laser technology in the arts and design sector. The Laser Centre look forward to helping more designers and artists use lasers to achieve their designs.

Welcome to New Corporate Members

(since November 2000)

Ancon Building Products

Avesta Sheffield Ltd

Boston Scientific Scimed

Bristow Laser Systems

Brown McFarlane Ltd

Ceandess Ltd

Cirrus Laser Ltd

ESP Laser Cutting Ltd

Eurolux Plastics Ltd

Lasag Industrial Lasers

Laser Optical Engineering Ltd

Laser Trader Ltd

Metalworking Production - Subcon

PBE Marking Systems

Plasmax/Centricut

Redditch Lasercutting Ltd

Richards Sheet Metal

Rofin-Sinar (UK) Ltd

Serra Soldarura SA

Tampere University of Technology

TRS Engineering Services Ltd

AILU members receive I Mech E prize

Duncan Hand (far left) and Chris Peters (far right), with the other prize-winners at the recent awards ceremony which took place at the IMechE in London

Congratulations to AILU members Dr Duncan Hand of Heriot-Watt University and Dr Chris Peters of GSI Lumonics Ltd who received the Donald Julius Groen Prize from the Institution of Mechanical Engineers, Manufacturing Industries Division, for their paper 'Optical sensor for detection of errors in Nd:YAG laser overlap welding of zinc-coated steel', which was co-authored by Prof Julian Jones and Mahlen Fox of Heriot-Watt.

LOE beats counterfeit crime with holography

Photo courtesy of Lionel Heap [01664 424 929]

Leon Lobo, one of LOE's Development Engineers

Laser Optical Engineering, a spin-out company from Loughborough University, will spend 18 months testing an 'invisible' hologram that will only respond to infra red light using a special reading device. The hologram will be marked on high-value products to prove their authenticity. The company has just a £45,000 Government Smart award for small businesses to help turn its innovative idea into commercial reality.

Visible holograms on credit cards are widely accepted as authenticity guarantees throughout the commercial world. However, such holograms are relatively easy to produce, and are invariably checked with just a cursory glance. "Tests have proved that people spot a small glittery patch and assume it's a hologram, rather than checking carefully, thus making it easier for counterfeits to be bought inadvertently," said Simon Hargrave, Business Manager of Laser Optical Engineering.

"Our technique involves using a high powered laser to burn a pattern onto the surface of the product that is not visible to the naked eye," he continued. "A small hand-held infra red reader will then be used to detect the pattern and guarantee authenticity, and also to hopefully identify the product - rather like a bar code reader. We're confident that this new technology will be vital in areas where counterfeiting is rife and companies want to protect their brand identity. The feasibility of the project will take 18 months to test, so the Smart funding is invaluable," concluded Simon.

Smart grants are a DTI initiative awarded for ideas that are both technically innovative and a sound commercial prospect. Laser Optical Engineering is the sixth Loughborough University spin-out company to receive a Smart award this year. The technology behind this particular award sprang from research pioneered in Loughborough University's Wolfson School of Mechanical and Manufacturing Engineering.

Fanuc now offers robot plus laser

The Fanuc robots are nothing new to the laser industry, but in the past Fanuc Robotics have limited themselves to be the robot supplier. With the new laser cell they concentrated on the beam sources of their own company, which lead to developing a laser cutting-cell, which at first sight already leads to the assumption of a drastic reduction of the problematic nature of interfaces for those systems. The users can only profit by this.

Cutting holes with a laser is often cheaper than stamping, especially for thin sheet metal, when the holes are in non-flat material, or when high flexibility is needed. For these cases, Fanuc Robotics has created a new Nd:YAG-laser cell, offering a completely integrated package of industry robot and laser source.

On the basis of the proven and reliable robot M-16i, the type Y-16i has been developed; it comes equipped with a beam delivery guide but otherwise has an identical specification to the M-16i. The laser source is Fanuc's own 1kW lamp-pumped Nd:YAG. A simple cutting head is used as default tool but a two axis cutting-tool can be optionally mounted to the laser robot.

Fanuc Robotics anticipates a demand for the laser system-package, especially in the automobile industry and its suppliers, in the medical technology and in the general industry. "Since the complete system, including the laser, is made by our company, there are no interface problems," said Michael Knaf, business manager of Fanuc Robotics Germany. "The YAG-laser cell is an economic investment and its high level of integration means that the user can start operations quickly and can work productively with it."

Rofin UK slab in great demand

The success of Rofin-Sinar UK's 300W sealed CO_2 Slab laser (the SC x30) is driving strong growth at their UK manufacturing facility in Hull. The laser has been designed to be integrated into industrial processing systems for marking, cutting, drilling, welding or heat treating. According to Rofin, demand for the SC x30 has outstripped all expectations since it's launch last year and it is currently their fastest growing product.

The SC x30 is a diffusion-cooled RF excited laser, which produces high peak power and a high quality, symmetrical beam. Its 'slab' construction allows for a compact, rugged design while the hard-sealed construction of the laser tube ensures long gas lifetime, and virtually no maintenance.

"We are delighted with the success of the SC series as a whole, and with the SC x30 in particular," said Andrew Chambers, Sales Director of Rofin-Sinar UK. "Its success is undoubtedly due to the underlying proprietary diffusion-cooled slab technology, which yields so many functional benefits, and the fact that we offer OEMs a professional all-round service. You also get additional value, since each of our standard SC systems is supplied with an integrated electro-mechanical beam shutter and output collimating lens to make it easy to integrate into processing machinery."

New 220W F-O system from Lasag

LASAG has launched a new addition to its very successful, field proven SLS laser series, .the SLS 200 C pulsed Nd:YAG, fibre optic beam delivery laser system. This new addition was introduced at the Munich Laser Show in June.

The new laser system covers a working range up to 220 Watts. Its compact design requires little floor space and it can be easily integrated into new or existing workstations. The Real-Time Power Supply, unique to the SLS 200 C, makes this laser even more attractive for peak-power controlled welding applications with high demands on precision, quality and throughput.

The system is available with up to 6 fibre outputs for energy and time-sharing with pulsed on demand operation. Fibres available in 100, 200, 400 & 600 µm core diameters. Other features are the completely sealed power supply with active water or air-cooling, interface and software to PC terminal with Windows convenience and modem for remote operation and diagnostics.

Spectrum's new laser wire stripper

Spectrum Technologies PLC, has announced the launch of their latest product. The CAPRIS“ 50 – 200 has taken many of the original features of the CAPRIS“ 50 and through close co-operation with their existing customer base have also added a number of new improved features, most notably a new windows software user interface.

Spectrum purchased RTMC Inc, of Phoenix, Arizona back in April, enabling them to add laser wire stripping equipment to their impressive product portfolio. Laser wire stripping improves the quality and reliability of stripping insulation from wire, making it ready for electrical termination.

The WD family of laser wire strippers are used for an array of applications, across a multitude of industries worldwide, including the medical, telecommunications, aerospace, consumer and computer markets. A focused laser beam is passed over the wire at a pre-set speed, selectively vapourising the insulation, removing it in a narrow line, but .does not damage the wire because it is highly reflective. This is of particular importance in precision wiring applications where damage to the conductor is unacceptable.

An RTMC laser wire stripper and an example of a laser-slit wire.

Electrox Lazerblade boosts productivity

The recent introduction of a Lazerblade Laser Profiler from Electrox has had a dramatic impact on productivity at Penn Fabrication and has been met with unreserved enthusiasm by operators, designers and management at the Hastings-based manufacturer.

Supplier to some of the world's leading names in the entertainment hardware industry, Penn Fabrication has a workforce of 180 and manufactures an extensive range of components and accessories including flight-cases, braces, trusses, protective corners, grills and storage racking systems.

Installed in September 2000 the Lazerblade operates a two-shift pattern alongside 3 punch machines, much of whose work is now undertaken on the laser profiler. The Penn team's unreserved enthusiasm for the Lazerblade underlines the machine's suitability for a wide range of OEM operations looking for a radical yet proven solution, delivering massive improvements in productivity coupled with scope for product development and entry to new markets.

Company Chairman, Roger Willems, explained " Although the purchase of a laser profiler marked a dramatic departure from a previous reliance upon more traditional punch press technology, the Lazerblade's unique combination of performance and flexibility has quickly won the wholehearted approval of all those involved in the machine's programming and operation".

The Lazerblade's large bed size of 3000mm x 1500mm has increased Penn Fabrication's scope for large volume production while the incorporation of an automated pallet allows the set-up of components while the Lazerblade is in operation and has contributed to further reductions in product cycle time. The Lazerblade's ability to operate for extended periods without supervision is another significant advantage.

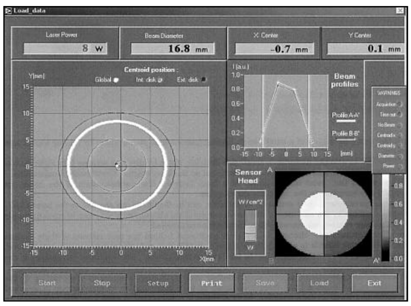
Armstrong offers high power laser beam delivery and monitoring

Armstrong Optical Ltd. have been appointed to represent Haas Laser Technology of the USA for their complete range of delivery optics for high power Nd:YAG and CO_2 lasers.

The range of products includes complete cutting and welding heads with modular autofocus systems and gas delivery. Other beam handling components such as fold mirrors and fibre optic cabling are also available and are adaptable to virtually any laser system.

Armstrong are also the UK representatives of Laserpoint srl of Milan, and have introduced the Octavo, a laser beam sensor system providing low-cost on-line monitoring of high power lasers. Octavo utilises a multi-segment thermopile detector and provides information on beam power, diameter, positioning and changes in intensity distribution. Upper and lower threshold values can be set on any of these parameters, which if violated, can be used to trigger a response (eg. a flashing LED). The sensor is able to withstand irradiance levels of up to 20kWcm^{-2} over a wavelength range of 250nm to 13µm.

By using a diffractive optical element, the sensor can be incorporated into a beam delivery system, allowing on-line monitoring to be achieved. Diffractive optical elements, available from Armstrong and tailored to the user's specification can be manufactured onto a fold mirrors and will sample a set fraction of the main beam onto the sensor.



Octavo display showing beam profile

Hi-Tech's new web site

Hi-Tech UK, manufacturers of Purex fume extraction and purification systems have just launched a new website, *www.purexltd.co.uk* containing information on the processes that can produce hazardous materials and highlighting a range of Purex systems designed as a solution.

Phil Mullins, MD of Hi-Tech UK comments, "We are also starting a news service to keep customers up to date with developments, including special filters for use in PVC laser marking applications."

Jambalaya demo CD

Jambalaya has released a Demo CD of their software Juggler v1.2, designed specifically for laser job shops. This Interactive Demo, preloaded with typical jobs & machines, allow users to:

- Experience the look and feel of the product and the many features to aid visualisation of complex shop data.
- See how the built-in expert system and laser cutting model matches and scales jobs to machines, as well as new features, such as the optimisation of lens changes
- Learn how Juggler and you can get more from your shop and increase profitability.

Request a copy at *http://www.jambalaya.ca/requestinfo.htm.*

Linos expands range

Linos Photonics have added a new model to their range of beam expanders, optimised for 405 nm for use with violet diodes. The current range includes models for 1064 nm, 633 nm, 532 nm, and 405 nm and all have variable expansion factors of 2x to 8x.

For applications requiring remote adjustment motorised beam expanders are available for 1064 nm and 532 nm which offer a guaranteed reproducibility precision of better than 0.05 mm. Applications include laser engraving, laser material processing systems and laser scanners.

Name change at Neslab

NESLAB are now known as 'Thermo NESLAB' to reflect the name of their parent company Thermo Electron. For more information on this global technology company, see *www.thermo.com*

Alltec offers laser for jewellery

Alltec multi-axis machine

Alltec have recently introduced a new range of laser machining centres. The ECO-G is aimed primarily at the Jewellery market, allowing the designer of new products to have a finished model in less than 2 hours.

The laser offers the opportunity to machine fine details, and cut intricate patterns without the need to change tools or product profile. The laser can machine the out or inside of a blank ring and can be used to change the surface texture of precious metal if required. For more complex parts Alltec have introduced the LGM 50 which allows machining of parts in up to 7 axes. This allows for the machining of complex logos in full 3D and also for the ability to engrave random surface textures in complex structures.

Trumpf new twinhead CO_2

Trumpf's new twin head, the HSL 2502C

The CO_2 version of the Nd:YAG twinhead HSL, launched last year, has been put through its paces.

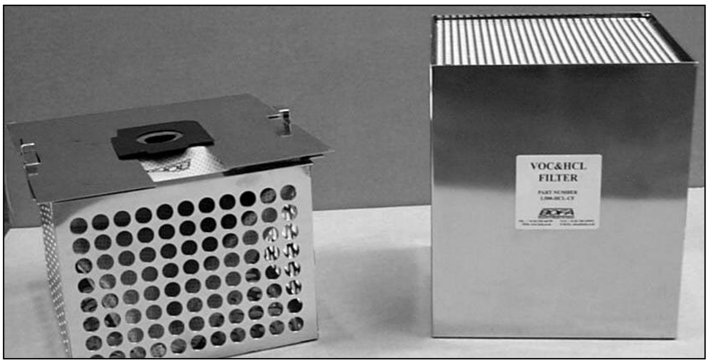
"It's more flexible than the solid state HSL because it cuts with really high productivity, from thin sheets all the way to 20 mm mild steel," said Ludger Meier, head of LST, a German job shop which recently installed the CO_2 machine. "Its high productivity, especially with thin sheets, is due to the linear drive technology as well as the twinhead capability. For sheet metal thicknesses greater than 5 mm, however, the slower cutting speed makes the fast drive less useful, but the second cutting head doubles productivity," he added.

BOFA launch expanded range of filters for laser applications

BOFA (UK) Ltd have recently launched their latest comprehensive range of laser fume extraction units, from 70m^{3}h for low power up to 510m^{3}h air flow for more powerful laser applications or to extract fumes from multiple heads simultaneously.

All systems are available as straight plug in units or fitted with standard options to interface the extractor with the laser. The full range of ancilliaries offered allows turnkey solutions for all applications. Bofa also offers special filters and acid-resistant contact parts for use in with materials such as PET or PVC. Safety features available include particulate, VOC and HCL gas monitoring options.

All units are fitted as standard with a high capacity bag filter, giving pre-micro filtration efficiency of 98% down to 1 µm. Standard particulate/gas combined filters cover 99.997% capture of particulate down to 0.3 µm with activated carbon mixed with potassium iodide for gas neutralisation. For heavier or more specialist applications i.e. PET or PVC laser processing, BOFA have a range of heavy-duty filters to suit specific gas/vapour mixtures and concentrations. For extreme particulate environments, external in-line multi-pocket filters are available.



Nickel plated, corrosion resistant filter components for acidic fume

Systems are designed to enable clean and quick filter replacement within seconds minimising costly down time. This is of particular benefit on high speed production lines.

Disjointed jottings of a marketing man

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The Chinese have a saying 'It's the nail which sticks out that receives the hammer.' And these words came into mind after I'd put the telephone down following a call from Liz at the AILU office. It had been a brief conversation, with Liz asking if I'd like to make a contribution to the magazine. "Er, yes – well maybe,…..what do you want me to write about?" "Oh, how about 'A day in the life of Peter Charnley', or a profile of R E Cooke & Son?" "Er, I'm flattered," I said "but let me think about it."

It was my own fault; I'd been corresponding quite a bit with AILU recently, giving them the benefit of my view of things. As nails go, I'd left myself way exposed and ready to get knocked back into the wood! Anyone who knows Liz will vouch for her tenacity, so it wasn't too much of a surprise when, two days later, I opened her letter, thanking me for my forthcoming contribution, and tactfully reminding me that I had an improbably short time to get the thing submitted. Had I volunteered? Oh well, no time to waste.

One of the things that I'd spoken to AILU about in the past was the 'dryness' of the magazine. To me, it seems to have more the feel of an academic journal than a commercially focused magazine. Don't get me wrong, I am no stranger to academia, and I subscribe to three academic journals, and have associations with two universities. But I work within an industry which is desperately fragmented, and crying out for a trade association or similar, and feel that AILU could fulfil a bigger role and win more converts from within manufacturing industry if its publications had more relevance.

More relevance? I can hear the cries of so many other readers of, and contributors to, this magazine that believe that it's just right for them. And that's the dilemma, I feel. The readership falls into two main camps: the academics and, to an extent, equipment manufacturers who recognise the importance of research to their long-term health. And the people actually manufacturing things using laser technology, generally the 'Job Shops'. The interests and needs of both camps are usually quite different.

We already have a Job Shop Group within AILU, but I know that it's hard work winning new membership into this area. And, like the proverbial chicken & egg, it's hard to justify a more commercially focused publication when there is a membership imbalance – but the potential membership out there isn't turned on by our publication, so probably won't be beating a path to our door to find out more about AILU.

But I digress. Let me analyse for a moment the commercial content that does get published. It's almost invariably from the perspective of manufacturing, discussing such worthy points as choice of lenses, gas suppliers, maximising output from flatbed CO_2 lasers etc. etc. All important (if dry!) stuff, but I've seen little input from the other side of manufacturing, which is marketing.

For those readers who have managed to read this far, I think that some sort of introduction of the writer is well overdue. I have been involved in sales and marketing within the metals industry for nearly 30 years, most of those years spent within aluminium extrusion mills. I joined my present employer, R E Cooke & Son (Burton) Limited just over four years ago. This was the first time that I became aware of the potential of the flatbed laser.

R E Cooke & Son (Burton) Limited is a jobbing sheet metal worker, established over 60 years ago and employing around 50 people. The present Managing Director, Harvey Cooke, is the grandson of the founder. The shop is well equipped, having CNC punching, 5-Axis and 7-Axis CNC benders, MIG/TIG and Spot welding and a powder paint shop on site. Harvey Cooke saw the potential of CO_2 flatbed lasers, and purchased the first machine seven years ago. We purchased our second Trumpf machine a year ago.

My role within the business is Commercial & Marketing Director, which gives me a broad scope of operation; but essentially it can be summarised as winning new, profitable business, and ensuring that our internal structures and systems result in customer satisfaction and efficient production. We've increased our turnover by around 36% in the last four years, which isn't at all bad considering the variable market conditions that have been prevailing during this time.

A typical day? This was the theme that Liz had originally suggested so here is my submission. I arrive at the office between 7:00 - 7:15 a.m. and my first job is to sort through the mail. At about 7:30 a.m. the telephones start to ring.

Both the mail and the first telephone calls can define the day, for example a customer getting into financial trouble, or a major order being put back. Usually, however, things go more or less to plan. From around 7:30 a.m. to 9:00 a.m. I selectively brief colleagues regarding any relevant information that may affect them or their function within the business. It's at this time, too, that I check on the progress of orders. My views on delivery on time are well known and I maintain records of delivery performance, which I consider to be one of the key determinants of customer satisfaction. Similarly, this is the time to chase up outstanding quotations, because this is another of those critically measured performance factors.

I try to plan my days so that I can spend either the morning or the afternoon visiting clients. We've established an enviable record of sales growth, and our business plan sees more of the same. Ultimately I'm answerable for the success or failure of the plan, so my field visits are made up of market research, prospecting and customer visits, all with a very clear focus on objectives.

I'm a great portfolio planner, and I select which markets we target and what proportion of those markets make up our total customer load. (Having said that, as a jobbing sheet metalworker, we often win work that falls outside of my ideal!) I'm no stranger to Companies House either, as I think that it's important to make credit checks on new prospects and customers.

The other half of the day is taken up with a hectic series of activities, including getting quotations out, following up earlier quotations by telephone and letter, and responding to outside agencies such as National Statistics Office etc. etc. Similarly I typically receive a visit or two during the day from any variety of outside people. (I'm currently looking at grant funding for a new computer system, and that's giving rise to a number of meetings.)

Part of my method of working invariably sees me with at least one 'project' on the go, and often more than one. I'm currently revising our Terms & Conditions of Sale, and negotiating with a supplier for the implementation of a new computer system to help run the business. Both are complex, tedious and time consuming, and I have little time to review my decisions, so it's important that I make the right ones, which kind of adds to the pressure!

The end of the working day gives a chance for the management team to get together and review the day's events. It's all very informal, and usually good-humoured. Harvey is an incorrigible comedian, and together with Jim Williams and Rebecca Mallinson, my fellow directors, we represent a good, synergistic mix of personalities.

I'm fortunate to live close to the office, so my trip home is short. I usually get back before 6:00 p.m. and spend a while working through my briefcase, and generally preparing for the next day.

In conclusion, then, I suspect that the commercial and marketing role is quite different from that of many of the readers'. I hope that it has given an insight into the "touchy feely" world of managing both a business and its customers. In a world that has seen so many fundamental changes in the last 50 years, the one reassuring constant is that, as customers, we all continue to expect service and value for money. Once that changes, I'm out of a job – but I don't expect that to happen any time soon!

Well, Liz, deadline met! Now have I ever told you the story about the green finch, a marketing plan, the professional salesman and the 20 tonne steel lorry? No? Well perhaps that's another story!

Having read Peter Charnley's comments on the magazine, what are your views?

What changes would <u>you</u> like to see?

Please send your comments to the AILU office. Full contact details at the back of the magazine.

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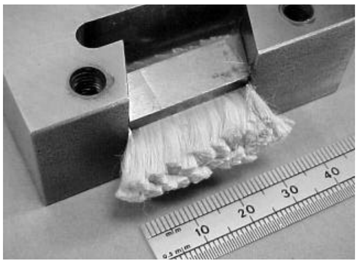
QUESTION AND ANSWER

How do I laser-cut Kevlar fibre?



We would like to trim the 13µm diameter Kevlar fibres shown in the photograph to leave approx 2.5mm protruding from the block.

The depth from the top of the block to the top of the fibre pack is approx 10mm. If necessary, the top of the block can be machined to make this depth approx 3mm. If successful, a 5" diameter bore will need to be cut in the production parts.

Kevlar can be cut, but depending on the type of coatings and matrix material, you can get bad or even worse results.

The best results I have seen was from a University in Sweden using supersonic gas "assist" which blew the carbon residue away, leaving a clean cut edge. A CO_2 laser was used.

I would suggest that this could be accomplished with a CO_2 slab laser (the better beam quality giving you the possibility of using a longer focal length lens so getting access to the material would be easier), probably a 5 inch lens, pulsed mode (but could try CW), with a special nozzle (suitable for clearing the clamping) and high pressure inert gas (>25 bar). But it really all depends on what edge finish is require and what the exact Kevlar composition is.

Tim Holt

CO_2 Lasers are able to cut Kevlar. However, there are several things to consider.

The thickness of the pack is important, the thicker the worse the cut. For any power laser the thicker the part the slower the forward speed and the longer the time spent at any particular point. The longer the time the greater the thermal degradation to the surrounding product. The photo shows something that may be 5mm - this is quite thick for 'nice' cutting.

Most Kevlar applications involve gluing the part with some resin. Will the real part be a fibre reinforced resin or bare fibre? IF there is resin then the cutting characteristics of that will be as important as the Kevlar.

Loose bundles (of anything) do not cut well. Probably something to do with gas dynamics. Is it possible to clamp both sides of the cut? And lastly, the reason that we do NOT cut much organic material, there is a severe fume hazard from laser cutting this sort of product.

Neil Main

Continued market growth for laser materials processing

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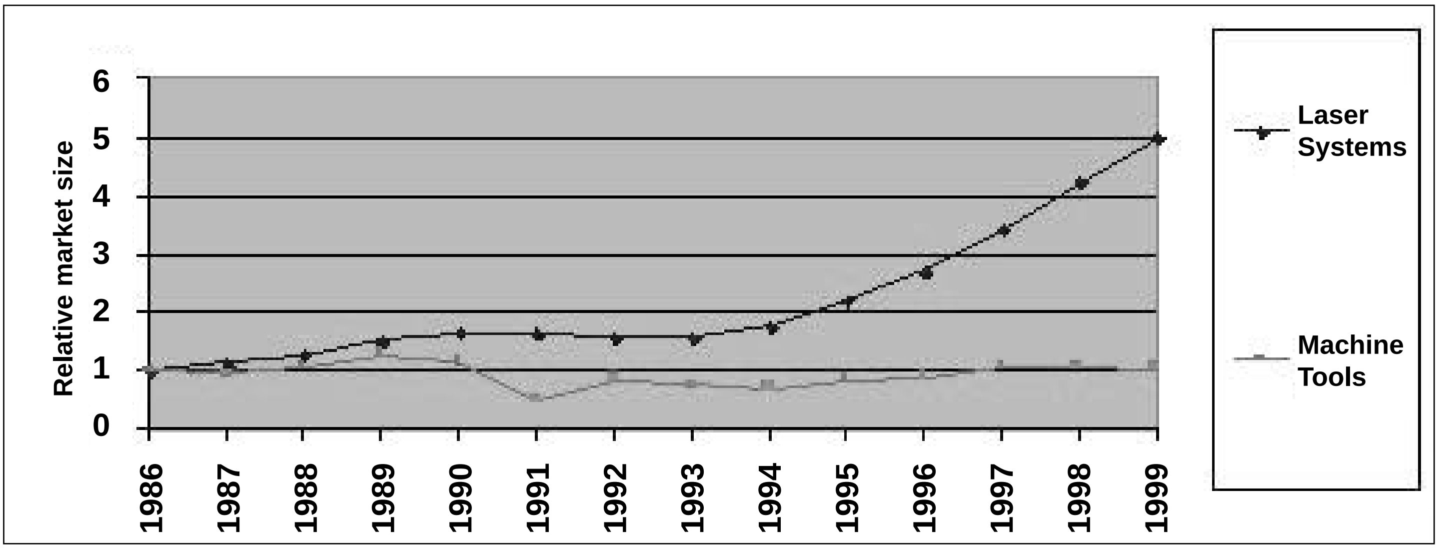
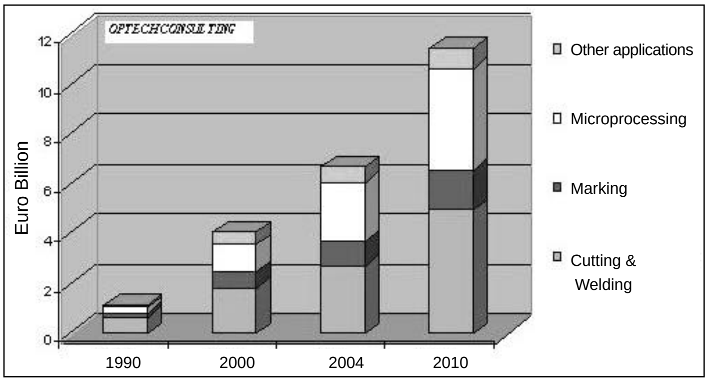
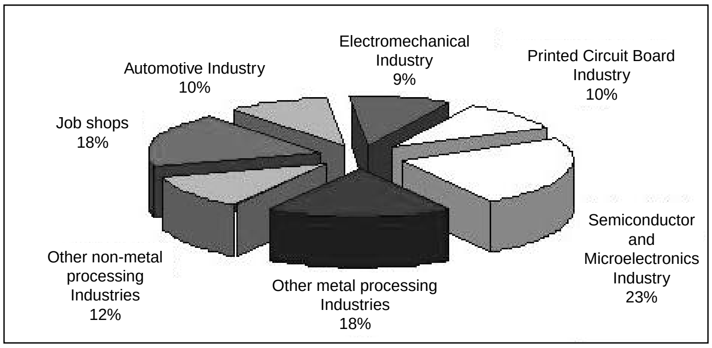
Data that speaks for itself: A visual presentation of the analysis and predictions shown during Dr Mayer's 'Industrial Laser Marketplace 2001' seminar held at the Munich Laser Fair 2001



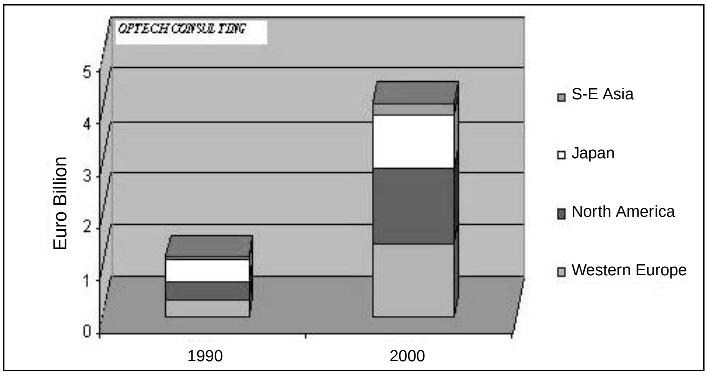
Laser Systems vs. Machine tools Worldwide market growth since 1986
Data: Optech Consulting (Laser Systems) and VDW - German Machine Tools Association (Machine Tools)



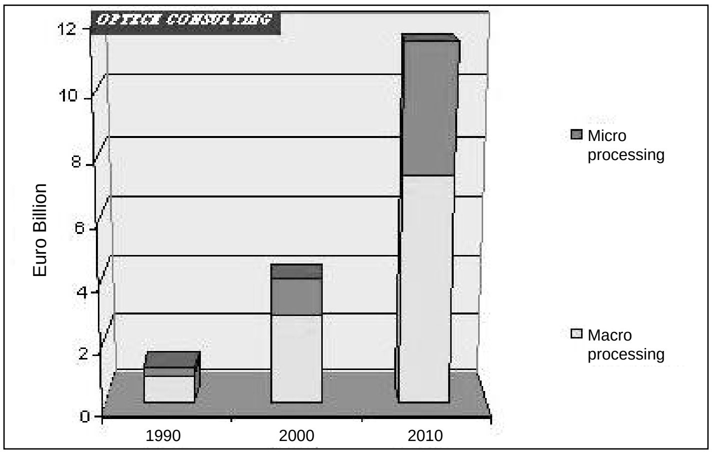
World Market for laser materials processing systems - by application



World Market for laser materials processing systems , 2000- by user industry



World Market for laser materials processing systems - by geography



World Market for laser materials processing systems

CO_2 laser cutting of Aluminium alloys

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In the early days of laser cutting aluminium alloys was considered to be almost impossible. Even for thicknesses of 1.5 mm it was necessary to make the surface less reflective by roughening it or coating it with an antireflection material*. However, with the availability of higher laser beam powers and improved beam quality, it has become progressively easier to cut aluminium alloys.

The current industry standard maximum thickness for aluminium alloys is approximately 8 mm and thicker sections are possible in some cases. For cutting thin sections (less than 2 mm), cutting speeds are higher than for steel. Nevertheless aluminium alloys are less forgiving to the laser cutting process than nearly all other alloys except those based on copper. (Silver and gold are even less forgiving, but we have been waiting fifteen years for a pallet load of gold to be free issued to us!)

The reasons why aluminium alloys are troublesome are twofold: first, the material is highly reflective to CO_2 laser light and second, aluminium alloys have a high thermal conductivity (2.5 times that of mild steel). Both of these properties make the material more difficult to pierce and cut.

Piercing

For any laser/material combination piercing is more difficult than cutting. The cold flat surface of the material reflects light far better than the sloping, rough, molten surface of the cut zone which exists during cutting. During the initial stages of piercing only a small amount of laser light enters the material and the heat generated is conducted away in all directions. Figure 1 illustrates this difference.

Even with high-power modern laser cutting machines the laser can have tremendous difficulty piercing aluminium if the surface is too reflective, as can be the case for certain shiny decorative finishes. On the other hand, anodised aluminium is very easy to pierce as it is covered in a layer of aluminium oxide. This surface layer can be produced in a large number of colours including shiny metallic and it has a very low reflectivity for CO_2 laser light. This is a major advantage for laser cutters but there are two drawbacks: first, anodised aluminium is more expensive than normal aluminium and secondly, anodised aluminium is very difficult to weld or bend.

Cutting aluminium alloys

Cutting and piercing are both strongly affected by the reflectivity and thermal conductivity of the aluminium alloy in question.

**Windowlene™ was a favourite as it dries to leave a highly absorptive ceramic dust on the aluminium surface*

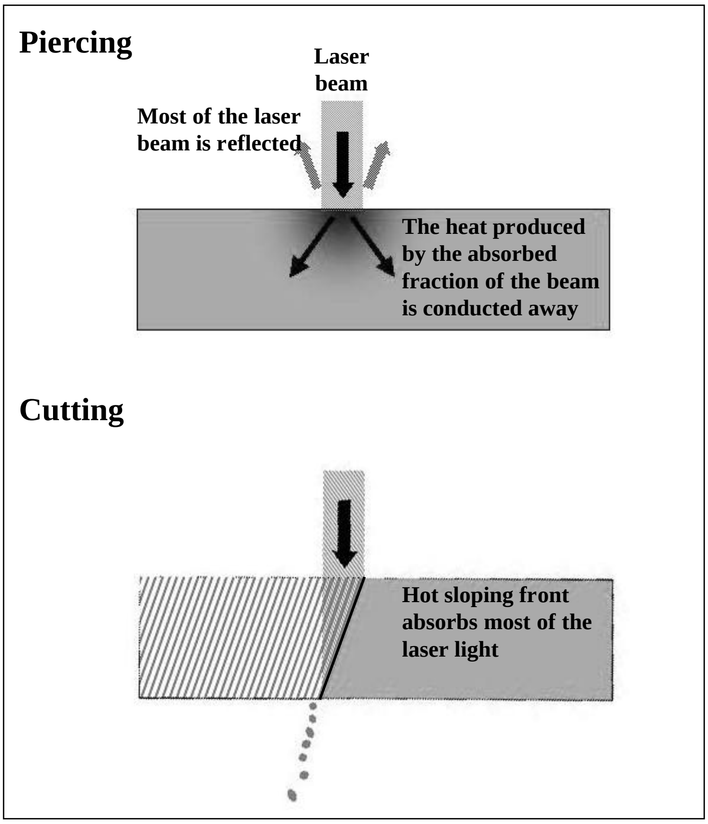

Figure 1. A comparison of laser piercing and cutting.

<u>Reflectivity</u>

The reflectivity of an aluminium alloy sheet is the result of a combination of two factors; the chemical composition of the alloy and, more importantly, the surface finish of the sheet. As far as the chemical composition is concerned, the material will pierce and cut better as more alloying ingredients are added i.e. as the aluminium content becomes less. For example, the 1050A grade (or S1B) is 99.5% pure aluminium and can be very difficult to cut or pierce. 1080A (S1A) at 99.8% is even worse. The 5251 grade (or NS4) has an aluminium content of approximately 95% and, although this seems like a small reduction, it can have a significant effect on piercing and cutting.

The surface finish of the sheet can have a dramatic influence on the surface reflectivity of the material and this is extremely important to the piercing process. A polished surface is the most reflective and will be the hardest pierce and cut. However, one cannot always tell by eye how absorptive a surface will be at the far infrared wavelength of the laser. Some surface finishes which appear visually more reflective turn out to be more absorptive.

Conductivity

The thermal conductivity of an aluminium alloy is purely determined by its chemical make up. As mentioned above, the alloys with less aluminium in them cut better. This is because the thermal conductivity is reduced and more of the laser power stays in the cut zone to carry out the cutting process.

Summary

Points to bear in mind for cutting aluminium alloys:

1. Piercing is more difficult than cutting.
2. The purer the aluminium alloy the more difficult it will be to pierce and cut.
3. Batches of the same material from different sources may have different surface finishes and this can significantly affect piercing and cutting.
4. Higher laser powers and tighter focusing (lower F-number) lenses make cutting and piercing easier.
5. Anodised surfaces assist cutting and piercing but make the finished product very difficult to weld or bend.

COMMENT

Laser feedback problems

Chris Williams

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We most certainly endorse all that John has to say in his article, but would like to add a few related observations that may be of interest to readers.

The back-reflection problem

The basic CO_2 laser cavity comprises two mirrors, one a nominally 100% reflector and the other, known as the output window or output coupler, is partially transmitting at the CO_2 laser wavelength. In normal operation a 3kW laser, say, has about 3.6kW of laser power continuously circulating to and fro between the cavity mirrors and 3kW is ‘emptying out’ of the output window. If, by placing an additional reflector behind and facing the output window, the power ‘emptying out’ is returned, then the circulating power grows rapidly to much higher levels, leading to laser instability and damage to the cavity mirrors.

A sheet of aluminium at normal incidence to the focused laser beam acts as such an additional reflector, and unless steps are taken to prevent the reflected CO_2 laser light from returning to the laser then damage may result to the cavity mirrors. Failure to pierce and initiate cutting is therefore a potentially serious problem.

Minimising back reflections

The most straightforward way to avoid back reflection problems is to use a laser and lens focal length combination that generates sufficient intensity to rapidly initiate cutting for the aluminium alloy of interest. Two suggestions are offered:

1) Pierce using oxygen and cut using high pressure air. Note that the focusing head must not move off from the pierce until the hole is large enough to allow good coupling of the assist gas.
2) Test unknown alloys for reliable piercing times and cutting feed-rates and stick to these parameters. A laser power in the 3kW range and a 125mm focal length lens should be satisfactory as a starting point.
3) Use real-time monitoring of the plasma above the metal surface to automatically slow the feedrate if the cut deteriorates, thereby (hopefully) re-establishing good cutting. This approach protects against failures to cut or pierce caused by such random effects as a surface irregularity or a sudden deterioration in the beam line optics.

Dealing with back-reflected laser light

Most CO_2 lasers emit linearly polarised light. A circular polariser is normally already in the beam-line to provide uniform cutting in both orthogonal directions, and when the beam reflects off the workpiece, its subsequent reflection off the circular polariser turns it back into linearly polarised light but polarised at right angles to the original beam. It follows that an optical element that transmits one polarisation but blocks the other can be used to prevent the reflected light from reaching the laser.

One such optical device is the Absorbing Thin Film Reflector (ATFR) from II-VI. They offer good protection, but the reflected power that the ATFR might have to absorb is high and so if routine care is not taken the ATFR mirror itself may overheat and be damaged. Alternatively, V&S offer a Brewster plate assembly, in which the plates reflect the power to one side where it is absorbed in a water-cooled beam dump. In not having to absorb the power, the beamline optic is less likely to become damaged*.

Safety matters

Moving from cutting steel to cutting aluminium, it is a good idea for the user to re-evaluate the company risk assessment strategy, particularly if cutting the material for the first time. Safety considerations include:

The use of oxygen for cutting aluminium can increase cutting speeds. However the presence of small particles of aluminium in an oxygen atmosphere is potentially explosive and for this reason we generally advise the use of high pressure nitrogen as an assist gas.

Since aluminium is highly reflective, scrap material should not be allowed to build up in the cutting bed where it may cause an additional reflection hazard.

Strong reflections from the aluminium may undermine the effectiveness of the safety enclosure, including laser damage to the guarding.

** A full discussion of this subject can be found in ‘Reducing workpiece back reflections’ Issue 7 (May 1997) pp20, including both the II-VI ATFR and the V&S Brewster Window Attenuator. Back issues are available from the members’ area of our web site at www.ailu.org.uk., or from the AILU office.*

Successful applications for high power diode lasers

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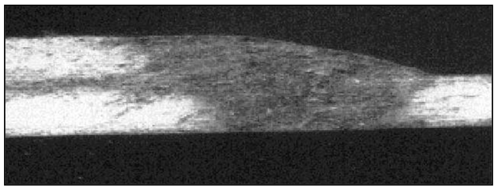
High power diode lasers with a powers in the range of a few ten watts up to several kilowatts are available for industrial materials processing. The beam quality of state-of-the-art high power diode lasers remains inferior to that of conventional lasers but their high efficiency, low running costs, small size, low weight and virtually service-free operation, makes them extremely attractive for applications where moderate beam qualities are acceptable or even advantageous.

Figure 2. Cross section of an edge fillet weld at a lap joint on 1mm stainless steel , produced by a 2 kW diode laser.



With current beam sources, the beam forming technologies and beam combination methods, diode laser systems from 30 W up to 8 kW are commercially available with free space and fibre delivery. The higher power are achieved by coupling the output of more individual diodes, so higher power comes at the expense of reduced beam quality. Schemes for stacks of diode laser bars involving interleaving and combination techniques based on different polarisation and wavelengths can allow coupling into a single optical path, with theoretically no decrease in beam quality. However, as shown in Figure 1, today's state of the art systems provide a beam parameter product increasing with beam power, from 10 to 1000 mm mrad. At first glance this excludes traditional applications such as deep penetration welding, cutting or marking or at least makes them difficult. however, it is evident from this figure that high power diode lasers are well suited to heat conduction welding, brazing and surface treatment (hardening, remelting and cladding).

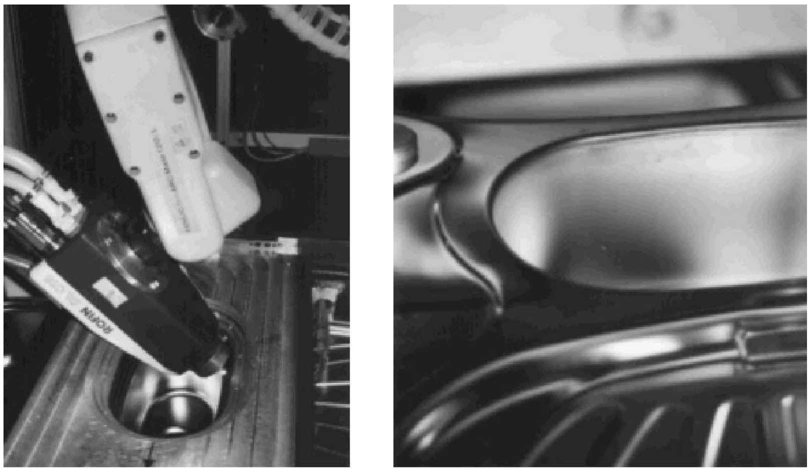


Figure 3. Welding a kitchen sink with a high power diode laser.
(left) positioning the laser head in a robot, (right) kitchen sink after welding.

Metal welding

Considerable speeds can be reached for heat conduction welding of thin foils. Foils with a thickness of 150 µm have been welded with only 500 W of diode laser power at a speed of 6 m/min with a diode laser. However, heat conduction welding requires careful gas protection even downstream of the welding zone in order to avoid oxidation and a carefully designed clamping tool must be used. Heat load requirements are higher for conduction welding than for deep penetration welding and if thicker material is conduction welded then welding speeds are rather slow by comparison. Figure 2 shows a cross section of a fillet weld at a lap joint, performed with a 2 kW diode laser on 1 mm thick stainless steel (1.4301) at a welding speed of approximately 0.5m/min max. Although slow, there is a considerable advantage for the heat conduction welding, including the excellent optical quality/smoothness of the seam, as can be seen in figure 2. Indeed, the possibility of producing optically perfect seams led to the very first industrial application of high power diode lasers, the welding of kitchen sinks in figure 3. The use of the diode laser to replace conventional TIG welding in this application led to a considerable reduction of after-work since only polishing (no grinding or repair) was necessary.

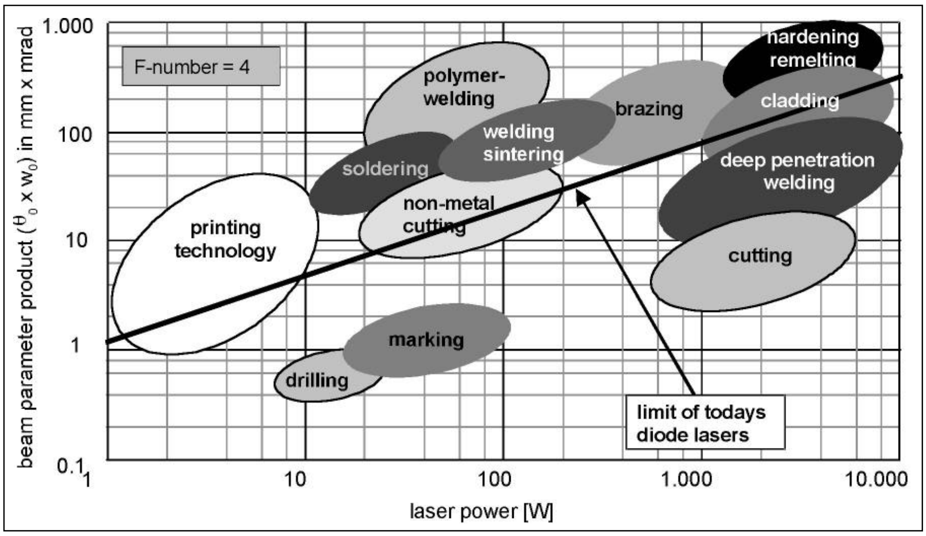


Figure 1. Plot showing the line of beam quality vs. CW diode laser power output together with the parameter ranges of laser processes for focusing with a F-number of 4.
(data provided by P.Loosen, Fraunhofer-Institut für Lasertechnik, Aachen, Germany)

As reported in *The Industrial Laser User (*Issue 18, p17), deep penetration diode-laser bead-on-plate welding of stainless steel sheets

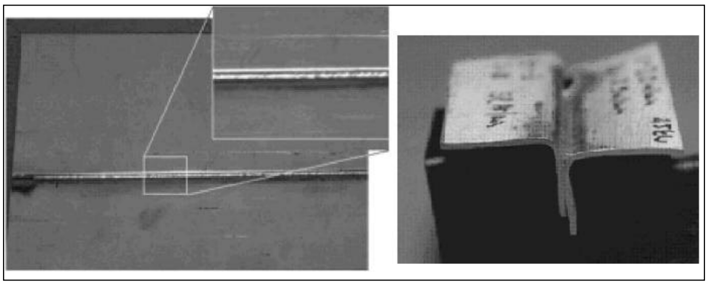


Figure 4. Brazing Zinc-coated steel sheets with a 2.5 kW diode laser. *The 0.9 mm sheets were joined with CuSi hard solder (1 mm dia. wire) at speeds of 2-4 m/min. Samples are seen to have a smooth, visually perfect joint.*

with a thickness between 2 and 6 mm has been demonstrated. The result do not contradict the predictions of figure 1, since the diode laser used had a smaller F-number and a shorter wavelength. Even if the working distance (30-80 mm) and welding speed (0.2 mm/min for 6 mm thick, 1.4 mm/min for 2 mm thick material) are not ideal for large scale industrial implementation, the results nevertheless show the potential and the high rate of development in this technology.

Brazing

For car bodies as well as for RF-sealing of electronic cabinets brazing is becoming increasingly interesting. Experiments in our applications laboratory have demonstrated the feasibility of diode lasers for this application, with visually perfect hard solder joints being produced, see figure 4. Note that the speed quoted in the figure caption depends on the gap filling requirements.

Hardening

Because of the rectangular beam with a 'top hat' intensity distribution in one axis (the "slow-axis") and a Gaussian in the other (the "fast-axis") the diode laser is especially well suited for surface treatment applications. Because of its relatively short wavelength (808 nm or/and 940 nm), there is no need to blacken the surface of parts to improve absorption, as is often the case when a CO_2 laser is used. This, together with its high efficiency and reliable and its unique beam profile makes the high power diode laser an ideal and cost efficient tool for surface hardening.

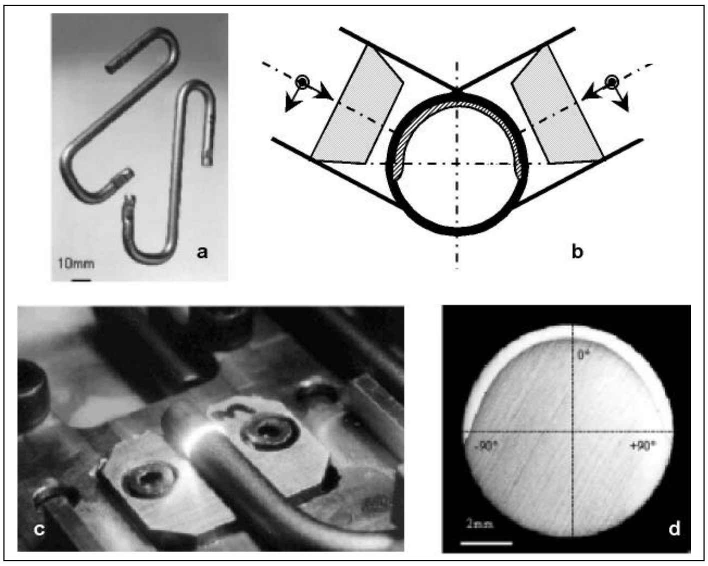


Figure 5. Hardening of tortion springs with a high power diode laser. *(a) tortion springs; (b) beam configuration scheme; (c) the laser hardening process in action and (d) cross section of a hardened spring.*

Pictures courtesy of Fraunhofer-Institut für Lasertechnik, Aachen, Germany

A prominent example of an application is the hardening of torsion springs, which are used in the hinges of car doors. In this case the diode laser not only provides the ideal beam geometry, but also has been proven to be by far the most cost-effective way for the transformation hardening process.

The torsion springs shown in figure 5a must be hardened over an angle of 170° and a length of 10 mm at a hardening depth of 0.2-0.4 mm. In the setup illustrated in figure 5b, two diode lasers simultaneously scan a 10 mm band of the spring, generating the required hardening geometry without difficulty. An active process control with two pyrometers for measuring and registration of the surface temperature assures the quality of each individual part. By October 2000 the system had been running for more than 18 months without any failure and more than 12 million parts had been produced.

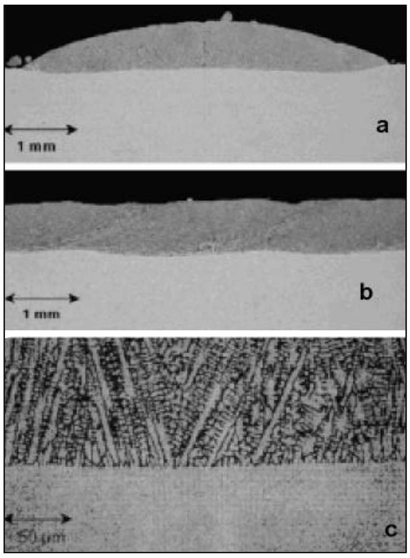


Figure 6.
Deposition of Stellite F from powder.
(a) Cross section of deposition achieved with a power density of 2 x 10^4 W/cm^2 and a spot of 2 x 4 mm. Layers with a thickness of about 0.5 mm could be deposited with a speed of ~ 400 mm/min.
(b) The overlap region of the diode laser deposited tracks, seen to be dense and smooth
(c) The thin re-melting area in the base material, demonstrating the good joint of the deposited material.

Results provided by S.Nowotny, Fraunhofer-Institut für Werkstoff- und Strahltechnik, Dresden, Germany.

Cladding

Another important surface-related application for diode laser processing is cladding with wear-resistant or repair layers. Often Stellite is deposited as powder, fed into the laser-heated zone by a special nozzle. As with laser hardening, this application is currently dominated by the CO_2 laser, yet the diode laser is an ideal tool. The results shown in figure 6, a laser spot of 2 x 4 mm depositing 0.5 mm thick layers at a speed of ~ 400 mm/min, is more than twice the speed of that achieved with a CO_2 laser with the same output power and a comparable setup. Taken with the higher efficiency of the diode laser, the running-cost advantage is clear.

Laser soldering

The contactless deposition and excellent control of power makes lasers attractive for soldering of sensitive and/or hard-to-access electronic parts. Laser soldering with Nd:YAG lasers has been well known for many years, but this application has only become economically attractive since the advent of high power diode lasers, because of their high efficiency and long (>10,000 hr) lifetime.

Polymer welding

As with soldering applications, polymer welding with CO_2 and Nd:YAG lasers has been investigated for many years yet the breakthrough seems to have come with the arrival of diode lasers. In the case of overlap welding, the upper layer needs to be transparent to the laser while the lower or intermediate layer must absorb the laser power (see, for example, *The Industrial Laser User Issue* 23, pp 28). First applications are already in manufacturing but questions of the polymer material itself, pigmentation and clamping have still to be investigated and answered in order for large market penetration.

Conclusion

High power diode lasers with output powers up to several kilowatt have passed the threshold of industrial applications. These state-of-the-art laser systems provide high power at high efficiency for applications where a moderate power density of 10^4 to 5×10^5 Wcm^{-2} is sufficient. The small size of these laser sources makes them easy to integrate in manufacturing lines; the long lifetime of more than 10,000 hours and the fact, that they are almost service-free over the lifetime of the diodes are other attractive features of these lasers.

A number of current commercial applications in welding, brazing, hardening and cladding have been illustrated, in which the diode laser is the source of choice. Looking to the future, lifetimes will be further increased, prices may eventually be reduced and beam quality may be improved further. Nevertheless, high power diode lasers will remain a system of a high number of incoherently-coupled lasers and thus will not really compete with ‘traditional’ lasers in those applications that require very high beam quality. But even with moderate beam quality, a steadily growing market and a widening range of applications is anticipated.

A more complete article by the author on this subject can be found in the proceedings of the ICALEO 2000 conference (Dearborn, MI USA 2-5 October 2000) , which is available from the Laser Institute of America.

Comment

In our laser hardening business at this point in time, high power diode lasers are attractive for dedicated applications particularly for small high volume parts. Their higher wallplug electrical efficiency and compact size are a big plus over CO_2 lasers but it is my assessment that beam handling capabilities are still a limitation for jobbing work. We use raster scanning methods with CO_2 lasers and this gives us a large depth of focus and active beam shaping, thereby allowing us to treat 3D shapes effectively.

However for energy efficiency and higher power applications, induction heating still wins if there is enough parts to justify tooling up. Even very small parts such as in textile equipment or fine saw blades are commercially treated in quantity by induction heating by using very high frequency (27 MHz) with pulse shaping, giving results similar to those obtained by laser.

Ian Hawkes
Inductoheat (Tewkesbury) Ltd

If you found the range of applications covered in Friedrich Bachmann’s paper of interest, you may like to download papers from back issues of the magazine, available for member to download at http://www.ailu.org.uk/membersonly.

These include:

Industrial applications of high power diode lasers
O Freneaux, 14, 24, Nov 99

Deep penetration welding with diode lasers
Dirk Petring, 18, 17, Feb 00

Hybrid welding with a CO2 and diode laser
Steffan Bonß et. al. 21, 26, Nov 00

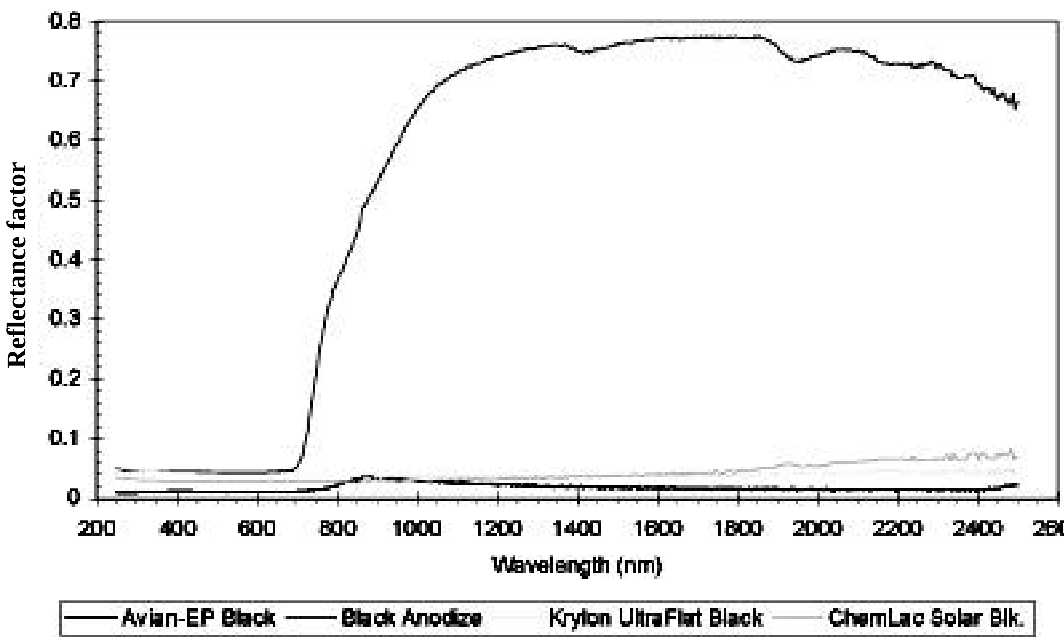
Diode laser transmission welding of nylon
Ian Pashby et al, 23, 28, June 01

As well as Ian Hawkes paper *Laser hardening in practice* (Issue 17, 20, Nov 99) and many other general application papers.

How absorbing is black anodised metal?

Thanks to Martin Sharp for pointing out that black anodised surfaces are not as black in the infrared as they appear to be at shorter wavelengths.

Anodisation does not provide very good absorption. A recent review article (*Review of black surfaces for space-borne infrared systems* by M. J. Persky (MIT Lincoln Labs Bob Kane Philips Research USA) in Review of Scientific Instruments vol 70 no 5 May 1999 page 2193) has summarised the performance of many black surface treatments.



For spectral reflectance data (UV-Vis-NIR) on anodised aluminum and a few other things, check out *www.aviantechnologies.com/avianblack-graphs.pdf*

Conduction welding with diode lasers for the aerospace industry

Stewart Williams[1], Graeme Scott[1] and Neil Calder[2]

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Although keyhole welding is the preferred mode for joining with high power lasers, problems remain with keyhole stability, which can limit the quality of welds in materials such as aluminium alloys. An alternative approach is to weld in the conduction limited regime, the only option with high power diode lasers, where poor beam quality limits the available spot sizes.

Introduction

Whilst power levels available from High Power Diode Lasers (HPDLs) have been steadily increasing, this has not been matched by improved beam quality. As a result, current HPDL outputs can typically only be focused down to spot sizes of a millimetre or more and so they usually weld in a heat conduction limited mode. However, in certain applications conduction welding actually offers advantages over the deep penetration keyhole welding associated with CO_2 and Nd:YAG lasers. Table 1 compares the merits of the two processes.

Slow speeds and large beam sizes are required to obtain significant penetration depths for conduction welding. For example, Figure 1 shows the penetration depths obtained for 1.6mm thick 8090 aluminium alloy, surface treated to enhance the absorption, as a function of beam size measured using 1300W of CO_2 laser power. The keyhole and conduction welding regimes can be readily identified and full penetration is seen to be obtained in both cases. Unexpected perhaps is the observation that, at constant beam power, penetration in the conduction welding regime increases with increasing beam diameter/ decreasing intensity. Clearly the large beam diameters required for the conduction welding process are ideally suited to the lower beam quality of the HPDL.

Two HPDL lasers were used in this investigation. One was a DILAS 015, providing a maximum power of 1.5kW at 808nm. The laser was used exclusively with a 50mm focal length processing lens, providing a smallest spot size of 3x1.5 mm. The other laser was an experimental DILAS laser with an average power of up to 3kW with two wavelengths of 808 and 920nm. The smallest beam diameter possible with this laser was similar to that of the 1.5kW laser. To obtain the large beam sizes required for conduction welding the distance between the laser focussing lens and the sample was varied.

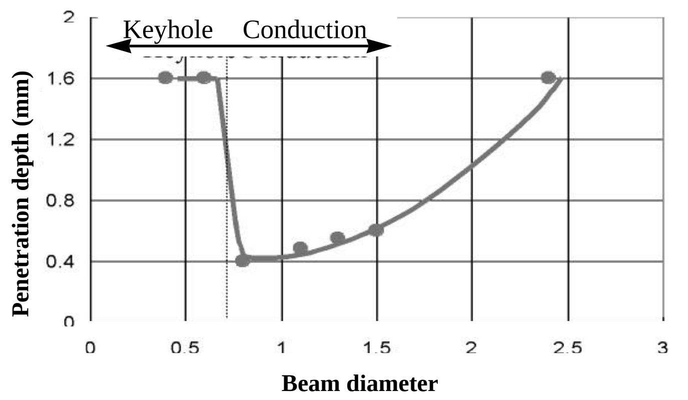


Figure 1. Penetration depths obtained for 1300W of CO_2 laser power in 1.6mm thick 8090 aluminium alloy as function of beam diameter
ref: DUWALP Final Report. BRITE EURAM Project BE- 4370, 19

Thin sprayed graphite coatings were applied to the aluminium alloys (which had been scraped clean, rendering the surface mirror smooth) to improve the coupling of the laser beam. In both cases, inert gas shielding of the top and bottom of the weld was required to prevent oxidation.

Aluminium welding

Bead on plate

The main process parameters varied were beam focal position (spot size on plate) and travel speed. Their effect on penetration depth is shown in figure 2, for 3 mm and 7mm thick AA2024 alloy. These results, including the curve cross-overs, were successfully modelled using the steady-state heat conduction equation with the added boundary condition that the maximum surface temperature is the metal's vapourisation temperature. The model also aids interpretation of the observation of an optimum beam diameter for a given penetration depth, one that increases with laser power.

Table 1. Comparison of keyhole and conduction welding processes

Process	Advantages	Disadvantages
Keyhole Welding	Low heat input per unit length and small weld bead - low distortion	Tends to be unstable - collapses to form pores and spatters
	Deep penetration - high aspect ratio welds	Requires good 'fit up' of parts
	Very fast weld speeds >> m/min	Requires laser with reasonable beam profile
Conduction Welding	Can be carried out with a laser with a very poor beam profile	High heat input per unit length and large bead - higher distortion
	Very stable process	Relatively slow < 1 m/min

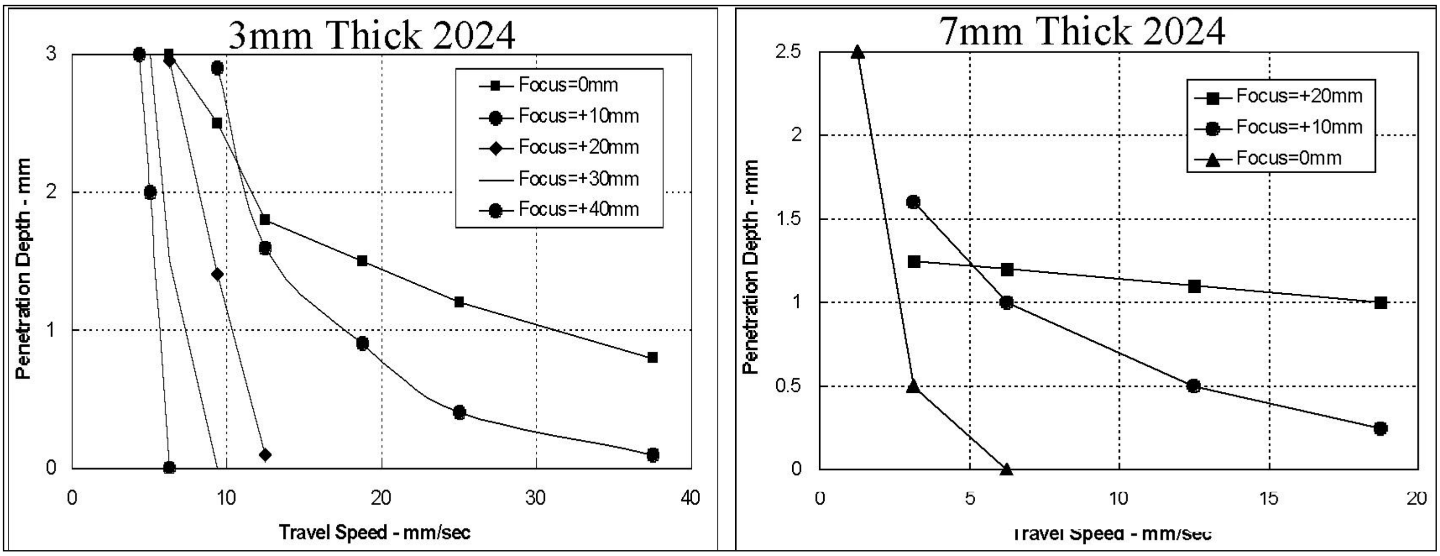


Figure 2. Variation of penetration depth with travel speed for different focus positions in 2024 alloy.
Note that full penetration can be obtained for the 3mm thick material for almost all beam sizes. In both cases some of the curves cross over. For example, for the 3mm material full penetration can be achieved at higher travel speeds with a defocused beam than can be achieved with a focused beam. For the 7mm material almost double the penetration is achieved with the defocused beam compared to the focused beam.

The presence of an optimum beam diameter indicates the limiting mechanism for conduction welding i.e. that the maximum surface temperature is the vapourisation temperature (boiling point) of the material. As the travel speed decreases a larger beam diameter will be required to maintain the weld pool temperature at the vapourisation temperature or just below it. Under these conditions the penetration depth is independent of the incident intensity (i.e. tighter focussing simply leads to loss of penetration) but increases with beam radius. In practice when decreasing the radius below this size the penetration depth would start to increase again at some point as keyhole welding commences (see Figure 1).

Figure 3 shows the results of a simple analytical solutions for the heat conduction equation and provides a semi-quantitative explanation for the influence of beam radius on penetration depth. In this model the penetration depth for a given beam radius depends on the ratio of the vapourisation temperature to the melting temperature, T_v/T_m. On this basis, aluminium (T_v/T_m = 2.94) is better suited to conduction welding than either titanium (T_v/T_m = 1.84) or steel (T_v/T_m = 1.67).

The modelling predicted that for the 3kW laser a full penetration weld should be possible at a travel speed of 0.2m/min if at least 1600W of laser power were absorbed. Figure 4 shows a cross section of such a butt weld in 6.35mm 2024, believed to be a world record for the thickness of aluminium direct diode welded.

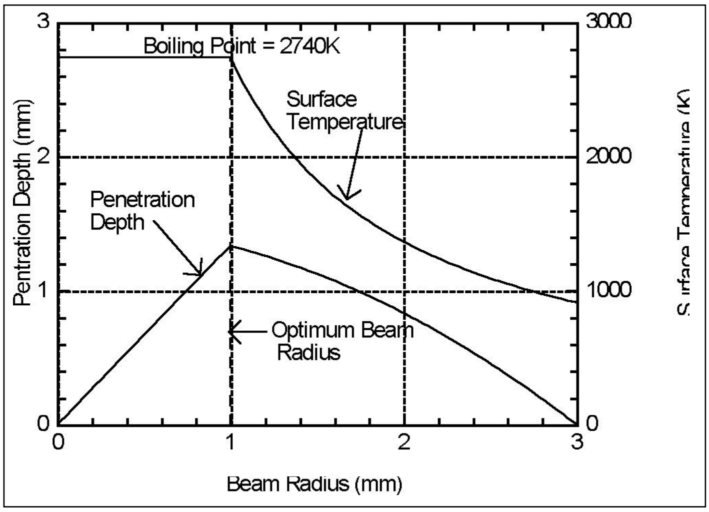


Figure 3. Analytical solution of the heat conduction equations, giving surface temperature and penetration depth for aluminium.
At large beam diameters the model predicts penetration with weld pool temperatures not much above the melting temperature of aluminium (~ 930C). As the beam diameter falls, the laser power density increases and the weld pool temperature and penetration also increase. At the optimum beam diameter the weld pool temperature just reaches the vapourisation temperature of the material (2740K for 2014/2024). Further reduction in the beam diameter results in 'over heating' and energy loss by vapourisation of material from the weld pool surface rather than more melting; thus the penetration depth falls.

Butt Welding

The initial parameters chosen for butt welding were those developed for the penetration depth studies. However, as filler wire was required to produce high quality welds the weld speed was reduced slightly. The filler wire used, 5356, was added at 30^{o} to the sample surface at a rate of $3cms^{-1}$. The travel speed was initially set at 0.6m/min but there was incomplete mixing of the filler wire as shown by the swirling patterns in the left picture of Figure 5. This was improved by reducing the speed further to 0.4m/min.

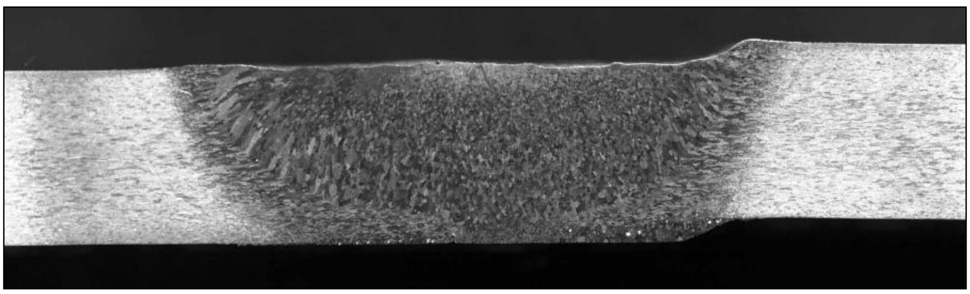


Figure 4. World record! The greatest weld depth in aluminium using a direct diode laser.
The photograph shows the cross section of a butt weld made in 6.35mm 2024 using the 3kW HPDL at a speed of 0.2m/min

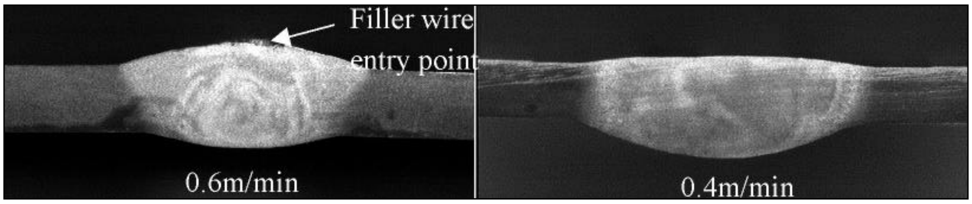


Figure 5. Cross sections of butt welds made in 1.6mm 2014 with 5356 filler wire at travel speed of 0.6 and 0.4m/min.

A study was carried out on the effect of the size and the position of the laser relative to the TIG torch. The experimental arrangement used is shown in Figure 6a. The TIG torch was operated with a current of 100A and produced a penetration depth of 1.3mm in 3mm thick 8090AlLi alloy. The result of the effect of the laser beam size and position on the penetration depth is shown in Figure 6b and 6c.

Hybrid TIG-Laser Conduction Welding

One major problem limiting the possible application of conduction welding for aluminium is the low absorptivity for some alloys after preparation, even at 808nm. A possible solution is to use a hybrid process whereby an arc is used to initiate the process and the laser is then efficiently coupled into the workpiece. The same conditions will apply in that for efficient operation it is necessary to avoid any losses through vapourisation.

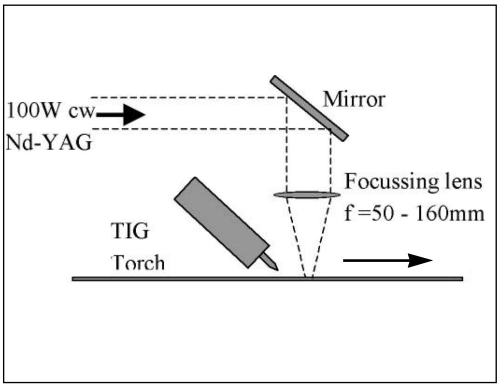
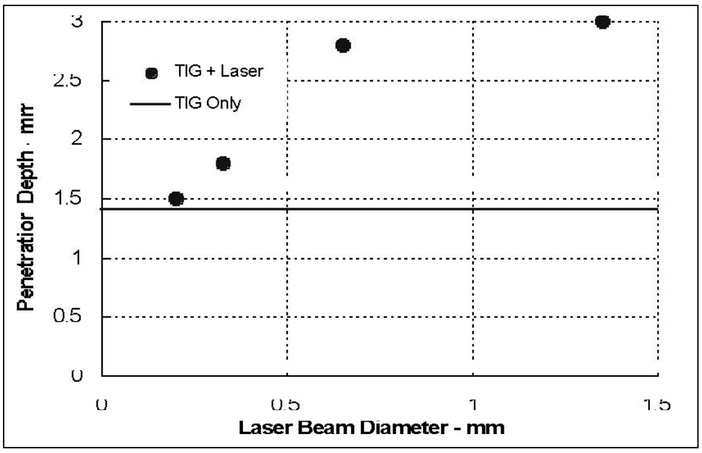
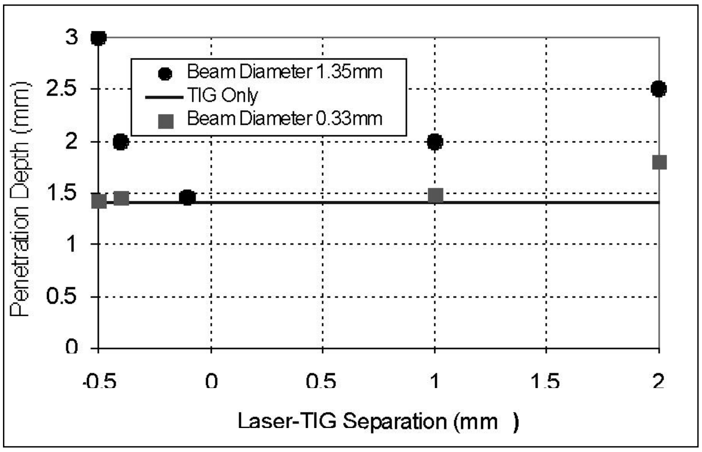


Figure 6. (a) Experimental set up for hybrid TIG-laser conduction welding and (b and c) results showing the effect of size and position of 100W of cw laser power when added to the TIG welding of 3mm thick 8090ALLi alloy.





With the addition of only 100W of cw laser power full penetration could be achieved. Figure 6b and 6c show the thermal efficiency to be very low with small beam sizes. For efficient welding it was necessary to use a sufficiently large beam size and to position the laser spot away from the centre of the arc. Note that the same increase in penetration could be achieved by increasing the TIG current by 10A, corresponding to an increase in TIG power of about 100W. This demonstrates how efficient the conduction welding process can be under optimised conditions and also shows how using the heating of the TIG arc provides good coupling between the laser radiation and the aluminium. In our most recent work we have now obtained a 12mm butt weld in aluminium by combining the 3kW HPDL with a TIG torch.

Conclusions

We have shown that conduction welding can provide high quality welds in a variety of aerospace materials and is an attractive alternative to other welding processes. It provides advantages of easy fit up, good mechanical properties and high stability of the process. The large beam sizes needed mean that the HPDL is the optimum laser source for conduction welding. Indeed the beam sizes can be many millimetres in size and it may be that for this application the current commercial HPDLs optical systems could be greatly simplified, reducing cost and easing their practical use. By optimising the process we have been able to weld aluminium 6.35mm thick with only 3kW of laser power. We have demonstrated that laser conduction welding is a very suitable way of carrying out hybrid processing leading to almost full use of the available laser energy.

Acknowledgement

Part of this work was carried out under the BRITE EURAM project DILAMP (Project No. BE-5060). The authors gratefully acknowledge funding from the CEC.

Stewart Williams spent five years at Edinburgh Instruments developing lasers and laser systems. For the last twelve years he has worked at BAE SYSTEMS investigating the use of lasers for aerospace manufacturing. This has included studies of welding, cutting, surface treatment and drilling of a wide range of aerospace materials.

This paper was presented at the WLT Meeting "Lasers in Manufacturing" at Laser 2001, Munich, June 18th 2001. A more complete version will be in the published in LaserOpto 33(4), 50-54 (2001).

Some useful calculations for laser users

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FREE estimation routines from Laser Beam Products

The perversity of lasers and optics seems to be endless. Over the years we have often been asked to comment on ‘strange’ behaviour from a laser or optical. At first the observations usually suggest that something is very wrong, but a brief analysis can often show the situation to be entirely normal. Some insight on problems or other oddities can be found from some simple rules-of-thumb, or estimate calculations.

A little arithmetic and some simple formulas will often shed some light. The main time consumer is searching reference books for the physical constants of various materials (density, heat capacity or whatever) which, when found, are of course always given in inconvenient units.

For our own use we have developed a simple range of Calculators, easy-to-use programmes that prompt the user for data to be entered and then calculate an answer. These Calculators are really too simple to be classed as software, just quick routines for making estimates with the relevant physical constants pre-programmed in. The routines are small ‘.exe’ files that will run on any PC using the Windows operating system, and they are all similar in that they ask for information and then return some answers to the user.

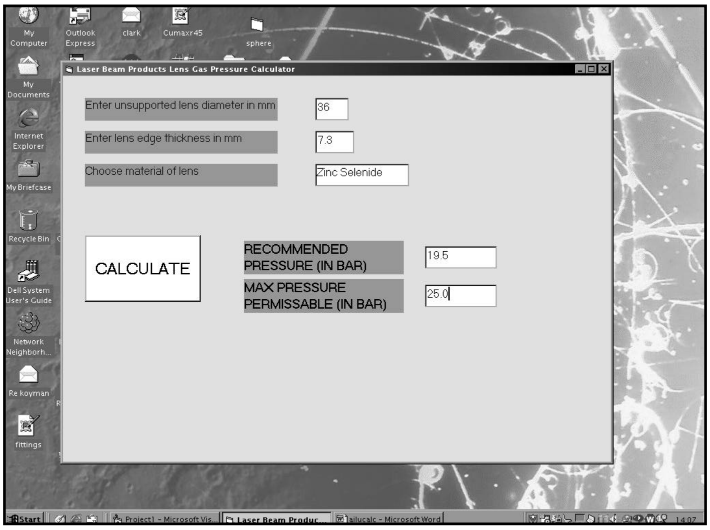
Example

Lets look at the calculator that answers the question ‘My lens has just shattered. Was this due to the high cutting-gas pressure?’

Double clicking the Calculator icon launches the calculator window and the user is prompted to enter the lens diameter, and lens thickness. Several options of standard lens materials are suggested. Pressing the ‘calculate’ button gives as an answer a recommended pressure and the absolute maximum pressure that should be used. To save confusion a ‘mouse tip’ explains that the thickness value to be entered refers to the edge thickness of the lens and that the diameter value refers to the unsupported diameter of the lens when mounted, typically a few mm less than the lens diameter itself.

If the pressure being used is substantially more than the maximum pressure then the answer to the question is probably ‘Yes the gas pressure was too high,’ in which case the user could input a few different lens thickness values and in this way can home in on the appropriate thickness of lens for the desired gas pressure.

The help option with the Calculator explain what estimates or assumptions have been made. In this example, lens heating has been ignored and it has been assumed that the lens is not over-tightened and that there are no pressure surges. General points about this area of technology are given on the help screen too, for example for a given thickness a Germanium lens will be found better able to withstand high pressures, but it has other properties that make it unsuitable for high power lasers.



A LBP Calculator in action

Other Calculators

Below is a description of other Calculators that may be of use to laser users and system integrators. We have found all of them useful at one time or another.

Laser spot size

The user enters the lens details and the laser beam diameter and divergence. The calculator returns an estimate for the focused spot size. Inputing various values for the focal length can show how the spot size changes with this parameter. Questions that this Calculator can answer include “Is it really worth buying that 10" f.l lens?” and “Is there a performance difference between a plano-convex and a meniscus lens?”

Heating of a mirror

Many customers touch the back of mirrors to see if they are hot. This Calculator estimates how fast a mirror will heat up if it is not cooled. Just because a mirror feels hot does not necessarily mean that it has a poor reflectivity.

Cooling of a mirror

Just how much cooling water is needed to keep a mirror cool? Are a few litres a minute sufficient? Should the cooling water be noticeably hotter coming out of the mirror mount?

Using a beam splitter

Mounting a window at 45 degrees to a laser beam will displace the beam path even if the window is flat and the surfaces parallel. This Calculator shows by how much the beam is offset.

<u>Using a protective window</u>

A sealing window or protective window placed after a lens will cause a shift in the position of the focus. This Calculator shows the new focal position of the lens/window combination.

<u>Radius of Curvature tolerance</u>

We are all familiar with long radius of curvature output windows and rear mirrors where values of 20 or 30 metre are common. Is an output window of specification 30m acceptable if the actual value is 32m? This Calculator converts Radius of Curvature to the 'surface form errors' which optical manufacturers specify, as well as explaining how components are toleranced.

Free copies!

All these and other Calculators are available on a single floppy disc or as an e-mail attachment to AILU readers and others free of charge. Please contact Laser Beam Products for your copy.

Any suggestions for other simple problems that could be solved by a Calculator are always welcome.

? QUESTION AND ANSWER

How safe should laser safety shutters be?

We recently had a situation with our flatbed CO_2 cutting machine where the safety shutter failed to danger. The shutter jammed open yet the laser remained on. Just how fail-safe do these safety shutters have to be?

To maintain output power, beam quality and pointing stability, it is common practice to leave lasers running and instead to close a safety shutter, for example when gaining access to the process zone of a laser processing machines for piece-part loading or unloading. In such situations the shutter is surely required to provide the same level of safety as would the process zone guard during laser processing.

The scope of the Machinery Directive includes safety components introduced by a manufacturer for the purpose of guaranteeing a safety function. The Directive requires that if they fail or do not function correctly, the safety or health of persons in the working area or around the machinery should not be compromised. To meet this requirement, the shutter must be required:

• to tolerate the full laser beam radiation without deterioration or damage during periods when laser radiation is not intended to be emitted into the laser process zone;

• to have an adequate lifetime of operation considering the anticipated cycle time and life expectation when use in an industrial application;

• to be monitored to ensure there is no mechanical or optical deterioration or damage that would allow laser radiation to inadvertently enter the laser process zone when the shutter is closed;

• to be monitored to ensure that the shutter is in its intended state, in particular to ensure that the shutter is actually closed when it is intended or commanded to be closed. The monitoring should supplement a design which uses 'basic safety principles' and 'components which are well-tried with respect to safety', being preferably fail-safe;

• to be monitored to ensure that the speed of operation especially during the closing process is adequate, to ensure that the laser process performance can be met and that closure of the shutter is achieved in a shorter time than the anticipated human access time which may be dependant on the process zone guarding design.

• to be controlled by safety-related control circuits which themselves are designed and monitored to ensure that foreseeable faults do not compromise the safety function and meet the requirements determined by the Safety Category selected from the risk assessment process according to IEC 13849-1 (EN954-1). It should be noted that a single channel software controlled shutter control system is unlikely to meet the requirements for safety-related controls.

Many high power CO_2 and Nd:YAG lasers will incorporate beam attenuators or shutters which have these features. However, a surprisingly large number of lower power CO_2, Nd:YAG and Excimer lasers and others appear to have totally inadequate shutter systems. Many lasers originally intended for use in the laboratory are fitted with basic beam attenuators (shutters) which only barely meet the requirements stipulated within the relevant laser product standards e.g. a simple cap that is manually placed over the output aperture of the laser. In other cases more sophisticated electrically operated shutters are incorporated, but many have inadequate electrical control, no monitoring of shutter performance and suspect mechanical/optical design to withstand use within an industrial environment.

The basic safety approach for the design of machinery requires the manufacturer to undertake a hazard analysis, in order to determine all the hazards associated with the machinery. System designers and integrators therefore need to be aware of the risks that may be presented by a shutter failure and the consequences of injury that may result. Many laser source manufacturers, especially those from outside Europe, may not have had to consider the safety of this part of their product. Indeed their product may not have been intended for use in these sorts of applications. Thus, additional features may need to be incorporated when the product is integrated into an industrial application.

Isolation of the process zone is generally expected to be achieved by adequate physical guards that, in addition to their other attributes, will tolerate exposure to the laser radiation to the level and duration defined by a risk assessment (see discussion of this in Issue 23, p 30). For guards that can be displaced or removed, their position and state must be monitored and as defined by the risk assessment (using say IEC 13849-1 principles) suitable safety-related controls may require the use of dual channel, cross monitored control circuits with monitor devices being designed using established safety design principles etc.

Operators should be adequately protected from harm and not be expected to "notice" a shutter malfunction because they were subjected to a laser burn. My belief is that this is unacceptable in today's industrial society.

Mike Barrett
Pro Laser Consultants

?

QUESTION AND ANSWER

How do I avoid contamination during laser marking?

We are using a CO_2 laser marker for printing onto a PVC plastic wrapper prior to its use in sealing a pharmaceutical product. Most of the fume can readily be extracted, but we find that there is a residual dust that is not, despite local enclosure, strong suction and a cross flow of air. The pharmaceutical industry in general is highly sensitive to possible downstream product contamination and I would like to know if there in anything we could be doing to improve the efficiency of particulate collection.

Solutions sent in by members fall into two main areas, one focusing on improving the extraction and the other at ways of avoiding or minimising the fume. We take them in turn.

Improving the fume extraction

We recommend a very specific 3 tier filter combination for PVC processes to ensure maximum efficiency and filter life. The size of machine would depend on the service window and 24/7 processes require longer filter life, hence larger equipment to reduce downtime. If you don't have sufficient pull-through, this may be caused by premature filter blockage or even mis-specification.

Graham Mattock
Purex

Polymer fume is notoriously sticky, condensing where ever it meets a surface, so encourage an up-draught into your extraction head and don't extract along a surface.

You can try extracting directly through a concentric ring around the laser-irradiated area, though if you're using a scanning head this might not be practical.

Karen Williams
Loughborough University

This is not a problem that I have come across before, but one that should be solvable. My initial thoughts are to suggest that the following areas are looked at:

1)The design of the extraction head can greatly affect the ability of the extraction unit to collect the dust. Remember that during coding the particles can be ejected from the surface with considerable velocity.

2) If the cross flow of air is from a compressed air system, is the flow too strong and carrying the dust away from the extraction nozzle?

3) If dust is found on the surface of the film is it being attracted back by static charge caused when the film is unwound from the roll? Could a static eliminator be fitted just prior to the marking position?

4) Can the marking be done further downstream after the product is sealed in its packaging, thus eliminating the possibility of contamination

David Miller
Linx Xymark

Minimising the fume

Laser marking with a carbon dioxide laser is a purely thermal process whereby the material is thermally degraded in some way to produce the mark. It can be sometimes possible to adjust operating parameters to change the temperatures reached during the process and thereby to change the nature of the fumes given off. But the long and short is that, if you mark your component by heating up the material with a carbon dioxide laser until it degrades or discolours, then the fumes given off are a function of the material. They probably cannot easily be prevented and the solution is all to do with fume extraction.

An alternative might be to use photochemical "cold marking" of the material using ultra-violet lasers. This process uses a photochemical change of the fillers inside the material and is non-thermal. So, no fumes are given off. Additional benefits come from the improved resolution that can be achieved and the complete absence of any thermal damage to the component which might, for example, compromise sterilisationor mechanical strength.

Coherent has been working on this area through its Dutch subsidiary Lasertec and is finding it extremely suitable for applications in the medical industry where high quality, indelible marks are required onto components whose function cannot be compromised by the coding process.

John Abbott
Coherent UK

Doing anything for medical uses with a laser is problematical, the slightest amount of contamination is a no-no. Ultimately, I don't think that there is any way round this if a CO_2 laser is used. The marking is a thermal process and particulate in the fume will stick to adjacent surfaces no matter how well you fume extract. Best to look at reducing or eliminating the fume in the first place. Options include:

1. Changing to a shorter wavelength laser or a short-pulse laser (e.g. frequency doubled YAG or excimer) or change the target material to one that produces a colour change and no particles when a laser beam hits it (e.g. materials with a titanium dioxide additive), or a combination of both.
2. Mark labels instead of the product directly. The labels could be marked and cleaned before being applied to the packaging.
3. Use a label with a coating transparent to the laser. The coating prevents the laser fume/debris from escaping while the substrate is marked. Laser markable labels based on this principal are commercially available. The Schriener system, for example, allows for the transparent layer to be left in place after marking, to protect the mark until other processes (e.g. painting) are complete.
4. Shield the remainder of the product and only expose the area you want to mark.

Tim Holt
Institute of Photonics

Three dimensional laser micro-patterning: the manufacture of a complex RF antenna

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Patterning and structuring on 3-dimensional shaped surfaces is a critical process when high precision is required. Traditional mechanical methods such as moulding, printing and machining have limited capability to produce very small features together with high positional accuracy. On the other hand, high definition lithographic processes that are widely used in the printed circuit board industry have the capability to deliver the required small feature size and positional accuracy, but the pattern transfer method lacks the ability to be extended to non-flat surfaces. Subsequent shaping of flat, patterned surfaces into the required shape is possible, but this will distort the pattern geometry and can therefore not be used for the production of surfaces with predictable properties.

Laser beams can expose photo resists and several laser-driven reactions such as photo-ablation, material deposition or surface treatment offer direct fabrication routes which are becoming relevant to a growing number of industrial areas. Lasers are attractive because they can be easily and precisely imaged, focused and scanned over large areas that need not be flat. Indeed, there is a particularly strong need to introduce 3-dimensional laser patterning in the printed circuit board industry, widening to applications in aerospace, telecommunications and aviation.

Here we show how laser micro-patterning can be applied in the construction of a prototype conformal microwave antenna, a device comprising several layers of circuitry with an overall cylindrical shape, intended for mounting on the side of an aeroplane for inflight communication through satellites.

The conformal microwave antenna

Figure 1 shows the appearance of the conformal demonstrator antenna. The substrate is a sheet of PEI Ultem 1000 polymer material 3.2 mm thickness, thermally formed into a truncated pseudo-parabolic cylinder, onto which are mounted demonstration circuits representative of a real antenna. Referring to the four layers shown in Figure 1, on the convex side there is a single layer of copper tracks representing the dipole array (TOP) and on the concave side there are 3 layers of circuitry, one for microwave reflection (INT2), one for signal routing (INT3) and one for mounting the dipole driver components (BOTTOM). Through- and blind via interconnect these layers.

To obtain the required patterns while optimising the time required for laser processing, one of two different processes were applied, depending on the area coverage of the copper tracks. For the reflector plane INT2 the process, referred to below as Process 1, was as follows: (i) plasma cleaning and copper metalisation; (ii) electrophoretic resist coating; (iii) laser ablation of the insulating tracks; (iv) chemical etching of copper; (v) resist removal.

The copper tracks of the circuitry in the signal layers (INT3, BOTTOM and TOP) occupy less than 50% of the total area.and conductor formation was achieved by Process 2: (i) plasma cleaning and copper metalisation; (ii) electrophoretic resist coating; (iii) laser ablation of copper tracks and via pads; (iv) electrolytic SnPb coating on exposed copper and inside via holes; (v) resist removal; (vi) chemical etching of copper; and (vii) chemical etching of SnPb.

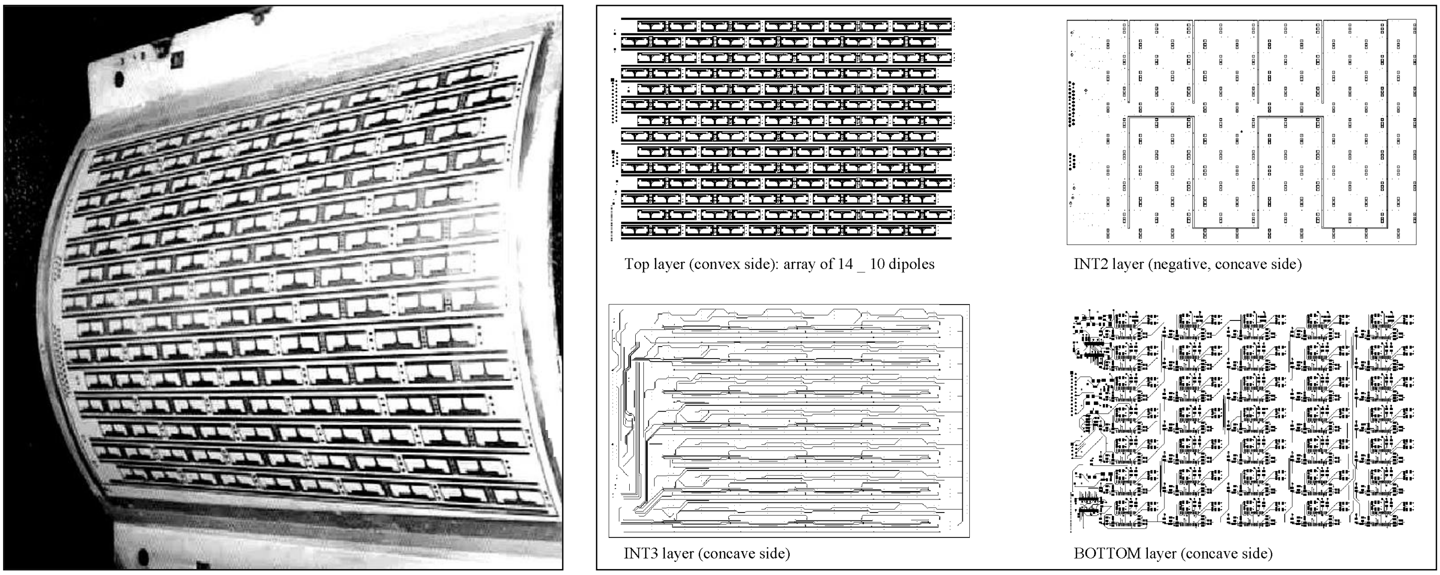


***Figure 1. Demonstrator conformal microwave antenna.** (left) finished product (right) the four conducting layers within the antenna substrate*

The manufacture of the antenna substrate involved the following operations:

1 form the antenna shape by thermal pressing

2 Mechanically drill the through holes from the concave layer INT2 to the convex side layer TOP

3 Copper plate (15µm) both sides and the drilled holes

4 Apply process no 1 to concave layer INT2

5 Apply the first dielectric layer, 50 µm Kapton and 50 µm acrylic, onto layer INT2 by means of a lamination process

6 Apply process no 2 (negative) to concave layer INT3

8 Apply the second dielectric layer (50 µm Kapton and 50 µm acrylic) onto layer INT3

9 Laser drill the required blind via between the concave layers (using copper pads as stops), and mechanically drill through via from the concave to the convex side

10 Apply copper plating to both sides, to form layer BOTTOM on the concave side and layer TOP on the convex side. The plating also effects the connections through the via and holes produced in the previous step.

11 Apply process no 2 to the TOP and BOTTOM layers

Each dielectric layer, applied by means of a novel 3-D lamination process, consisted of a 50 µm acrylic film and 50 µm Kapton film sandwiched together and adhered to the antenna substrate, which had dimensions of 200 by 300 mm before thermal forming. Vias diameters varied between 100 and 200 µm, and through holes had diameters of 1 mm. The corresponding pad sizes were twice the via diameters. Copper and insulating track widths varied from > 200 µm for the signal plane to > 300 µm for the power plane.

Laser selection for ablation and drilling

Ablation process

The ablation process for both conductor processes 1 and 2 were based on mask projection. Excimer and TEA CO_2 lasers have suitable beam shape and size, and pulse energy characteristics commensurate with mask projection. Both lasers gave similar pulse energies (0.5 J) in a similarly sized beam shape (approx. 16 x 24 mm rectangular). No laser beam shaping or homogenisation was required. Table 1 summarises the results.

	KrF excimer laser (0.248 µm wavelength)	TEA CO_2 laser (10.6 µm wavelength)
Ablation conditions	Fluence 1.5 - 4.0 J/cm² 5 - 10 pulses	Fluence 2.0 - 3.0 J/cm² 2 - 3 pulses
Line quality	Good, with excellent width control	Irregular, especially for narrow lines
Accuracy on narrow lines	-1/+3 µm on 60 µm line width	-5/-10 µm on 100 µm line width; irregular
Cleanliness	excellent	post cleaning required (plasma), with effects on final feature size
Process speed	acceptable	2-3 times faster than with KrF excimer laser

Table 1. Excimer laser (KrF) and TEA CO_2 laser processing trial results for electrophoretic resist ablation in conductor processes 1 and 2. *Experiments were carried out using a mask of a square aperture, imaged through a x4 demagnification lens and dragging the work piece under the mask image, producing a line of ablated resist. The ablation conditions as shown in the first row of the table were determined for optimum line quality, accuracy, and cleanliness.*

The table shows how, for this application, the excimer laser gave superior results i.e. better cleanliness, accuracy and line quality. The CO_2 laser ablation process invariably produced residues, both on the exposed copper and on the remaining resist which could only be removed by plasma cleaning. This had the undesirable side-effect of broadening the ablated lines slightly, since the plasma process also removed some of the resist.

Via drilling

Two different types of via are required to be drilled: through holes from the concave side of the antenna substrate to the convex side, and interconnect holes between the layers on the concave side. While the latter requires the drilling through approximately 100 µm or 200 µm of dielectric (Kapton and acrylic), the through holes are of substantial depth (3.2 mm) with a depth-to-diameter aspect ratio of approximately 3.

A comparison of the KrF excimer and the CO_2 laser showed that the former gave superior results. The CO_2 laser produced conical holes and too much debris that stuck to the surface and walls of the hole. The excimer laser produced holes of acceptable quality at a fluence of 1.8 J/cm², but required of the order of 10000 shots to drill a single through hole, and 200 shots to drill a 100 µm interconnect hole. This represents a processing time of approximately 2 seconds for an interconnect hole, and 50 seconds for a through hole. In view of these results it was decided to drill the interconnect holes with the excimer laser but to use a mechanical drill for faster drilling of the through holes, approximately 1 second.

(N.B.: A good quality beam from a Nd:YAG laser in fundamental, frequency doubled or frequency tripled mode, could be used for the drilling operation but this option was not addressed since it was not desired to have more than a single laser source in the laser work station.)

Laser workstation development

Workpiece handling

Micro-machining by mask imaging with an excimer of a curved surface requires the manipulation of the workpiece to keep the laser beam perpendicular to the surface, in order to maintain the image geometry at the correct fluence. The mask imaging lens must also remain a fixed distance away from the antenna surface, which required the workpiece to be translated along x, y and z axes, and rotated around 2 of these three axes; but the additional requirement to keep alignment of the mask image maintained meant that rotation around the third axis was also necessary. In addition to these six axes, a further two linear stages were required to position the metal mask plate in the laser beam, according to the mask shapes needed to produce the desired patterns.

The robot layout chosen was one where all three rotary stages are nested on top of each other since this yields the best mechanical stability, compactness and precision. Various commercial manipulators are available based on this design, and the

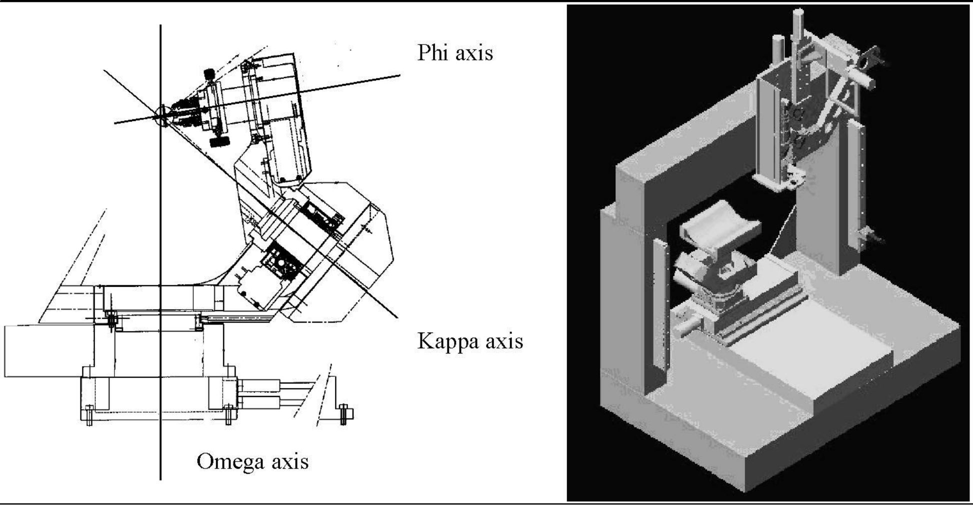


Figure 4 Schematic of the Kappa Goniometer and the workstation lay-out. *The Goniometer consists of three rotary stages connected to each other by means of two precisely machined brackets such that the angles between omega and kappa, and kappa and phi, are precisely known (approx. 50 °) and these stages are mechanically aligned such that the omega, kappa and phi rotary axes have a common intersection point to within 20 µm. In this configuration, all three axes are dependent and rotations around the three translation axes x, y and z must be facilitated by calculating the rotation angles of each of the three stages by means of an appropriate coordinate transformation.*

Fabrication

The software (not discussed here) and laser workstation hardware proved to be capable of producing complete antenna substrates, manufactured to the required tolerance of ±20 µm over the entire antenna substrate.

The antenna substrate was mounted onto the robot by means of a special bracket that made use of a 30 mm wide flange on either side of the antenna (see figure 6b). The antenna design included approximately 900 interconnect holes between the layers on the concave side and 570 holes that connect the layers on the concave side with the convex side. The latter holes, of 1.0 mm diameter, were made using a miniature mechanical drill attached to the imaging lens mount, and aligned precisely with the optical axis of the imaging lens (which coincided with the z-axis).

manipulator selected was the Kappa Goniometer from Newport Inc. The linear stages that were used are made by Aerotech Inc.

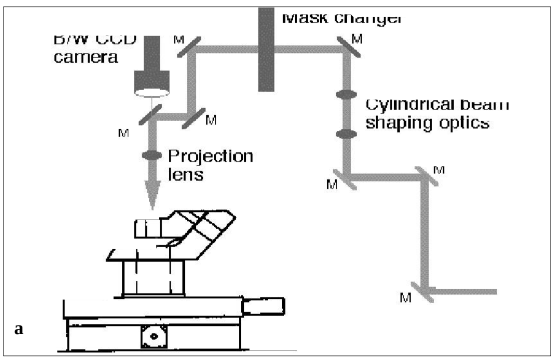
Optics

The circuit patterns on the antenna substrate were produced by imaging a range of different apertures of appropriate shape and size onto the antenna surface. A steel mask plate was fabricated by wire spark erosion to contain a matrix of different apertures and was located in the object plane of the projection lens, the correct aperture selected by control of the vertical x-z linear stage in which the plate was mounted.

Figure 5a shows the optics layout. Two cylindrical lenses transform the laser beam into an approximately square shape for illumination of the aperture plate. The laser ablation of the resist took place a relatively low fluence (2J/cm^2) and was self limiting because once the resists was fully ablated the laser fluence was too low to affect the underlying copper. As a result, beam homogenisers were not required. A video camera was mounted above the final dielectric turning mirror above the imaging lens viewed the antenna surface through the imaging lens. The imaging lens had a magnification of 4x at an object to image distance of 750 mm. This gave a numerical aperture of 0.08, which was adequate for the purpose.

After mounting the antenna substrate onto the robot but before laser machining commenced, any offsets that need to be applied to the 6 axes were measured. A camera with microscope objective, fixed to the optical axis (z), was used to measure precisely two 1 mm diameter alignment holes previously drilled in each substrate. The position of these two holes with respect to the substrate was precisely known. Since the depth of focus of the camera is only a few µm, the camera was able to measure the x, y and z coordinates of the centres of the holes. The same camera was used to measure the heights of the flat flanges either side of the antenna which, together with the alignment holes, fully specified the substrate position.

The laser processing time of a layer depended mostly on the density of the pattern and the maximum speed of the mask stages and the Kappa Goniometer. The time per layer varied between 25 minutes (the first operation, the drilling of through holes) to a few hours (layer INT3). It should be noted that only rudimentary software optimisation has been performed in the sorting algorithm and it is highly likely that significant reductions in these times could be achieved.



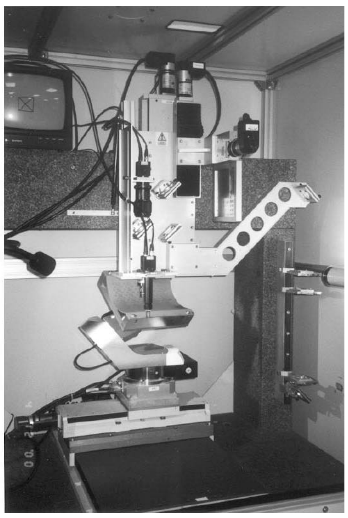


Figure 5 (a) schematic of the optics lay-out (b) antenna substrate during processing (with mask imaging lens and microscope objective are clearly visible), and (c) layout of the motion equipment and optics. *All optical elements, including the aperture plate x-y stages, were located on a 250 mm travel linear stage, mounted vertically. This stage is the z-axis of the system. A second camera with a microscope objective was used for precise measurement of the antenna substrate position, and was mounted under the projection lens, a fixed distance away from the mask image .*

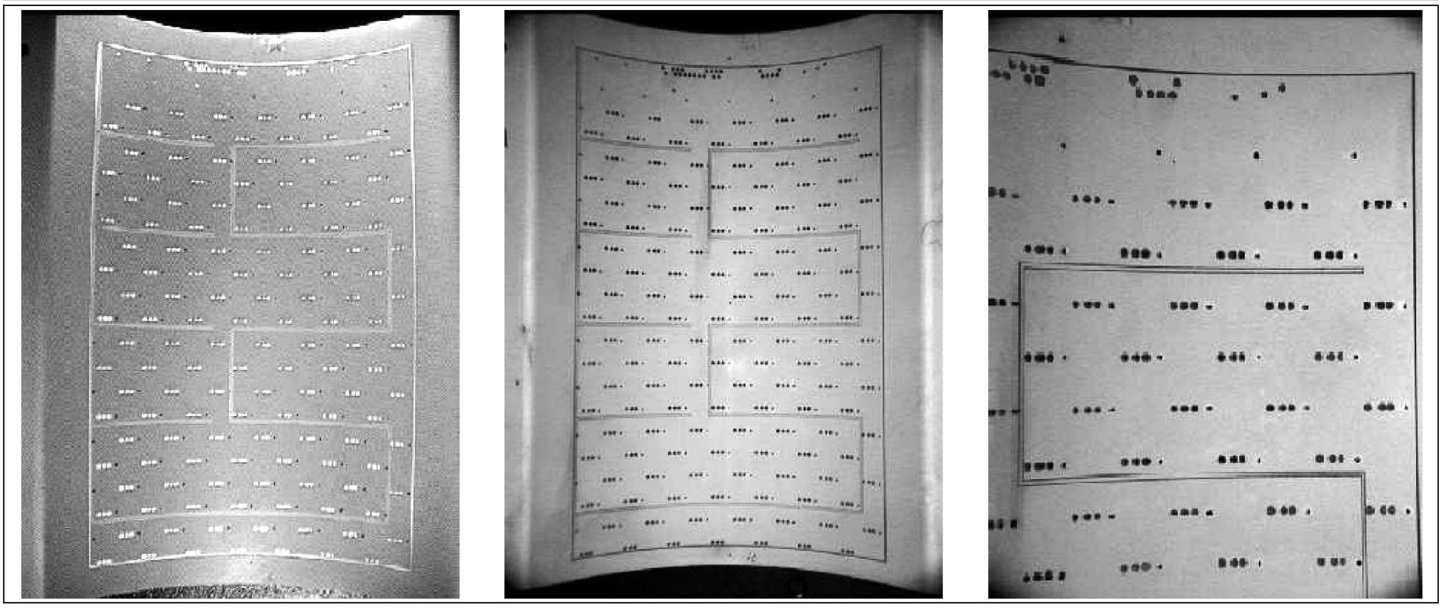
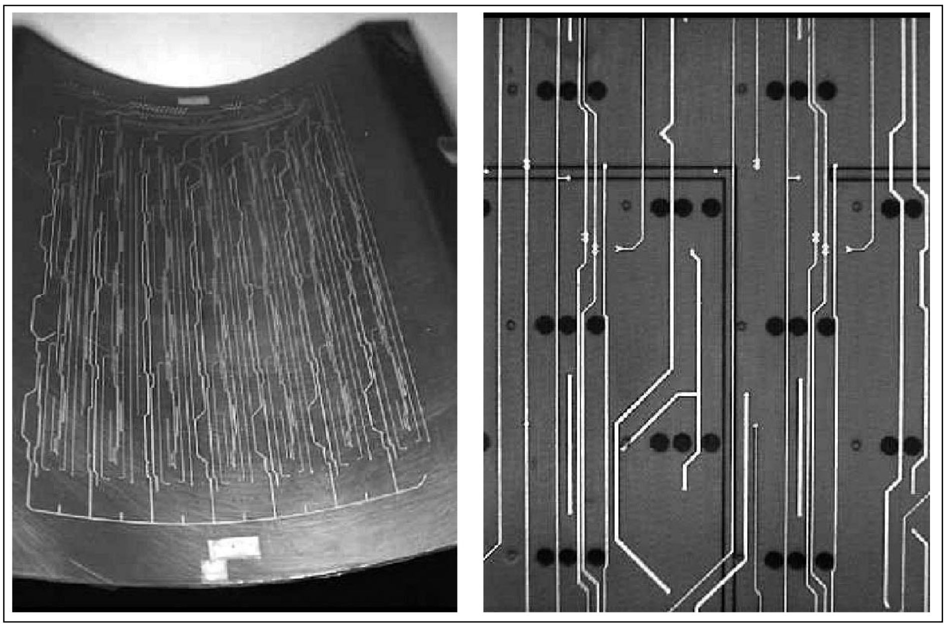


Figure 6. (above) Manufacture of the power/ground plane INT2, showing laser patterning (left), copper etching (middle) and pattern detail (right).

Figure 7. (right) Electrolytic SnPb coating after laser patterning of layer INT3 (right) detail of the layer

Figure 8 (below right) Excimer-laser drilled copper-plated through hole (left) and interconnect via (right)



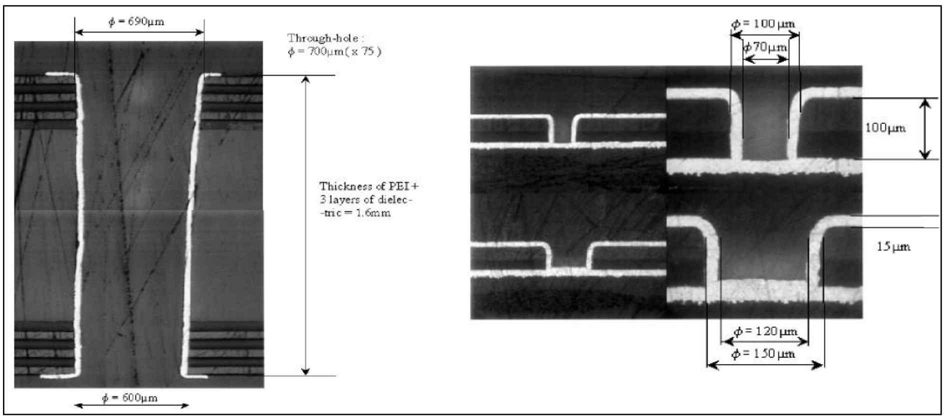


Figure 6 shows the first layer that was produced on the concave side (INT2). The copper was deposited for this layer also metalises the insides of the through holes. This layer carries the power and ground connections of the antenna. The through holes connect the convex side (which carries only one layer (TOP), that hold the active microwave devices) with the power/ground layer.

Figure 7 shows the layer INT3, the layer that is located on top of INT2. The dielectric layer, applied by 3-D lamination technology, is transparent and visible in the photograph, as are some underlying laser-drilled interconnect holes through the substrate, vias between INT3 and INT2 are also shown. Some even smaller features of INT2 are seen as dark features in the close up on the right-hand side of figure 7. As an indication of scale, the large circular insulation areas have a diameter of 2 mm.

Figure 8 shows examples of the via drilling and plating technology developed during this project. Shown are a plated through-hole and an interconnect via between two adjacent layers. The through hole in this figure was not mechanically drilled but was excimer-laser ablated. The slightly tapered profile so produced is advantageous for the plating process. The interconnect vias were also drilled by excimer laser.

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Investigation of multi-wavelength DPSS laser micromachining of stainless steel

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Industrially-rugged diode-pumped solid-state lasers (DPSS) with multi-wavelength capability have become an industrial reality over the last few years. Their capability to micromachine industrially relevant materials such as ceramics, metals, and polymers has resulted in a growth of interest in micromanufacturing with lasers. In particular, DPSS lasers operating at short wavelengths and with excellent beam quality and short pulse length can micromachine with a small kerf width, a small heat effected zone and at an increased machining rate.

This paper reports results of the micromachining of 316L stainless steel and examines the factors that limit DPSS Nd:YAG laser use in ambient air and also under controlled gas environments using directed gas jets. The results reveal that traditional plasma-controlling gases, whilst providing efficiency gains, have a detrimental affect on the surface morphology of micomachined components.

The laser used for these results was a Lambda-Physik Starline™ DPSS Nd:YAG laser. Non-linear crystals enable the fundamental Nd:YAG wavelength (1064nm) to be frequency converted to 532nm and 355nm. The pulse-to-pulse stability quoted for the laser is 1% for 1064nm, 1.5% for 532nm and 2% for 355nm. Maximum average powers of 8 W, 5W and 3W are available at 1064 nm, 532 nm and 355 nm respectively.

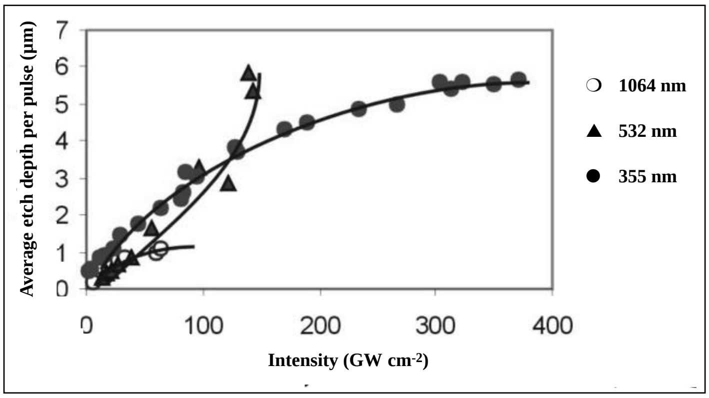

Figure 1. Average etch rate on 316L stainless steel in ambient air as a function of focused beam intensity, at wavelengths of 355nm, 532nm, and 1064nm, estimated from the number of pulses required to drill through a sheet 0.2 mm thick.
N.B. Intensities quoted for 1064 and 532 nm are measured values, whereas values quoted for 355nm were calculated.

Percussion drilling

Figure 1 illustrates how the machining rate in stainless steel varies with focused laser intensity and laser wavelength. The fundamental Nd:YAG wavelength (1064nm) produced a maximum machining rate of 1.2mm per pulse – significantly less than that produced at 532nm and 355nm. At 355nm, the maximum etch rate was similar to that obtained at 532nm, nearly 6mm per pulse. The laser-material interaction depends on a number of factors in addition to wavelength and intensity, including laser pulse duration, laser pulse shape, the temperature of the material, its physical properties, and angle of incidence. Figure 1 is consistent with the wavelength and intensity greatly influencing coupling of laser energy into the material and therefore the etch rate.

The variation in entrance hole diameter as a function of wavelength and intensity has been plotted in Figure 2. The percussion-drilled hole size is influenced by melt erosion of the walls of the hole, the formation of a recast layer and also plasma factors that will effect the path of the incoming beam. Note how the gradient of the graph data changes as the etch depth is increased, particularly for 355nm and 532nm at an approximate etch rate of 1mm per pulse. Above this etch rate the mechanism of ablation changes from an evaporative regime to evaporation and violent melt ejection.

In atmospheric air, the high intensity interaction expels the material through melt ejection, which is generated by increasing recoil forces, the vaporisation of the material and also plasma pressure. At the bottom of the drilled hole, evaporating and

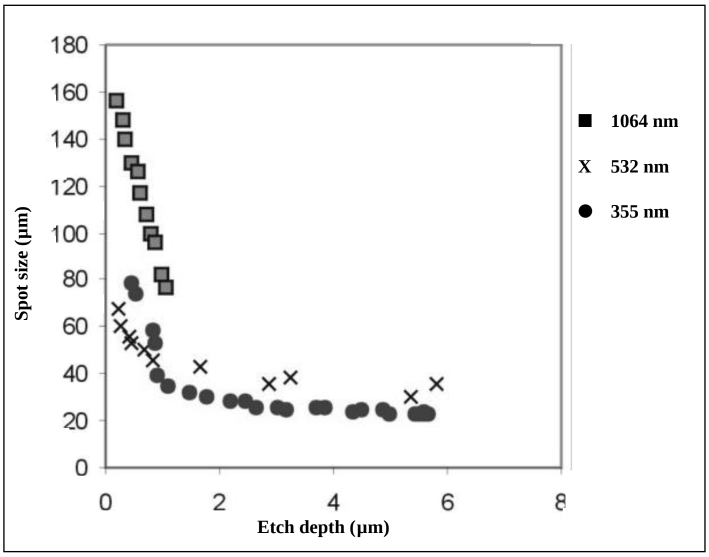

Figure 2. Variation of entrance hole diameter vs. etch depth into 0.2mm 316L stainless steel.

ejected material has such a high vapour pressure that it forces the molten material out of the hole. A characteristic recast layer is formed by the resolidification of the melt on the hole walls. This often has different material and mechanical properties from the bulk of the material.

As can be seen in figure 2, if the intensity of the laser on the surface of the material is increased so that the etch or machining rate is increased above 1mm per pulse, the proportion of explosive vaporisation, and violent expulsion of the molten material from the interaction zone increases. This leads to a decrease in the controllability of the interaction process.

The values for average etch rate shown in Figures 1 and 2 relate to drilling through material 0.2 mm thick. Similar data taken with thicker material show similar etch rates up to an intensity of 10 $GWcm^2$ and then a reduced etch rate. Below 10 $GWcm^2$ the material is ejected through small scale evaporation of the metal, whereas the reduced etch rate with increased material thickness above 10 $GWcm^2$ may be attributed to the thickness influence on vapour expansion out of the percussion drilled hole, the waveguiding of the laser light off the sidewalls of the hole, droplet attachment to the hole walls and plasma attenuation of the incoming beam.

<ins>Using a gas jet.</ins>

Drilling experiments were performed in the same way as the previous set of experiments with the application of a directed gas jet, using a 300 mm convergent – divergent supersonic nozzle supplying 8 bar of pressure to the workpiece, with a standoff between the nozzle exit and the workpiece of 1mm. The gases chosen for the exercise were helium, oxygen, air and argon.

The maximum average etch rate for 1 mm 316L stainless steel in ambient air was 0.4mm per pulse. As shown in Figure 3, each of the gases led to a reduction in machining rate, with the oxygen jet leading to the greatest attenuation in the etch rate. There are a number of possible explanations for this, including the formation of various oxide particulates that attenuate the incoming beam, thereby reducing the etch rate.

Previous experimental work has shown how a gas jet can both help and interrupt the drilling event (see, for example, *The Industrial Laser User* Issue 23, pp23) i.e. the jet impedes the

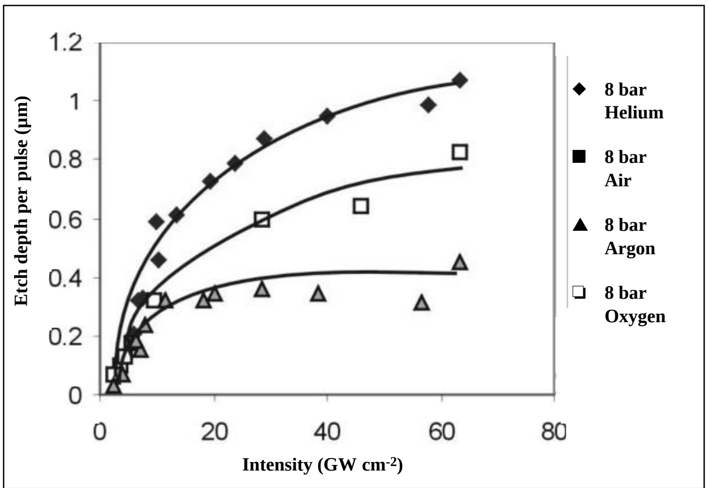

Figure 3 Average etch rate as a function of laser intensity for 1mm 316L stainless @ 1064nm using 8 bar directional gas jet

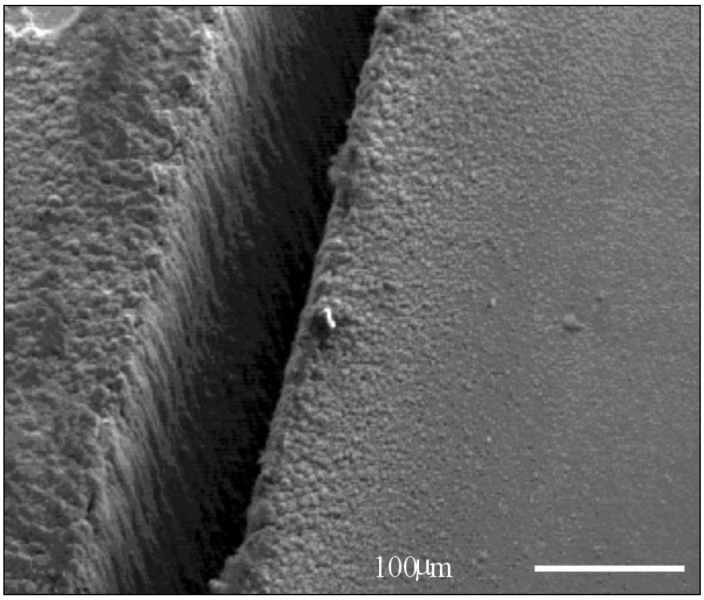

Figure 4. Laser cut in 0.5mm thick 316L stainless steel with a 300 mm conical convergent – divergent nozzle using an 8 bar oxygen jet directed at the surface during the interaction event.
The intensity on the surface was 47GWcm-2 and the cut velocity was 1mm/min. The laser wavelength used here was 1064nm.

ejection of the melt from the hole up until full penetration occurs, at which point the assist gas helps the ejection of the melt and vapour. The acoustic retort associated with the melt and vapour ejection was observed to be significantly louder when processing with 8 bar argon than the retort observed in atmospheric air, whereas when processing in 8 bar helium the retort was significantly quieter. The oxygen retort is significantly less than in argon and becomes quieter as the laser etches through the material, eventually becoming virtually inaudible. Measurements of etch rate as a function of oxygen pressure show that as the pressure is reduced, then the etch rate increases, supporting the explanation of the suppression of the ejection mechanism with the high pressure gas jet.

Cutting

In sharp contrast to the results for percussion drilling, an oxygen jet allows faster cutting rates than those obtained when processing with the other gases used in the exercise, or when cutting in ambient air. The geometry of the interaction in cutting enables the ejection of melt from the bottom of the kerf and the suppression of plasma, thereby allowing cutting to proceed at a faster rate, and when using oxygen the exothermic reaction adds a significant amount of energy to the cutting process.

The predominant alloying element in stainless steel is chromium, which unfortunately inhibits the laser machining process by preferentially migrating to the surface of the melt as a result of its high affinity for oxygen. The chromium initially reacts with the oxygen in the gas jet to produce a surface oxide (Cr_2O_3) layer on the cut front, which forms a semi-impermeable seal over the underlying material, thereby inhibiting the reaction between the oxygen and the melt. However, movement of the melt under the influence of the jet continuously ruptures the outer oxide layer and allow the passage of oxygen.

Cutting experiments involved cutting 0.2mm and 0.5mm thick 316L stainless steel at feed rates varying between 0.1mm/min to 50mm/min. Figure 4 shows a scanning electron micrograph (SEM) of a cut in 0.5mm 316L stainless steel at a wavelength of

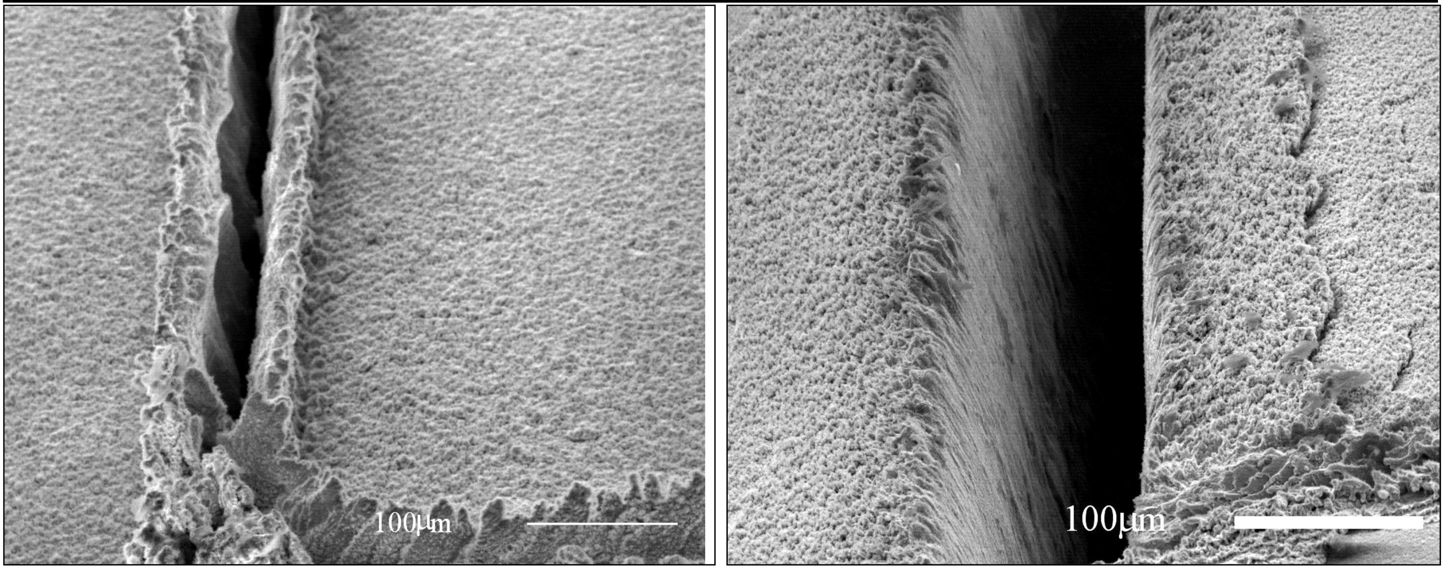

Figure 5. Laser cut in 0.5mm thick 316L stainless steel with a 300 mm conical convergent – divergent nozzle using an 8 bar gas jet directed at the surface during the interaction event; (left) helium, (right) argon.
The intensity on the surface was 47GWcm^{-2} and the cut velocity was 0.5 mm/min. The laser wavelength used was 1064nm.

1064nm radiation at an intensity of 47GW/cm^{-2} and an 8 bar oxygen jet. The cut is surrounded by a powdery black/blue 'soot' that is easily removed with a cloth. The edges left after removal of the powdery residue have different material and mechanical properties from the bulk, necessitating further processing (e.g. etching or plating) if this phenomena is not to affect the manufactured part.

By contrast with oxygen, cutting with an inert gas results in the formation of a pronounced recast layer that sits proud of the surface. This can be seen in Figure 5, which shows laser cuts in 0.5mm 316L stainless at a feed rate of 1mm/min using helium and using argon as the assist gases. Cutting with helium or argon leads to the formation of an oxide-free edge, which when examined shows a considerable recast of high hardness that is difficult to remove.

The cutting experiments involving high pressure helium were very interesting. Examination of the helium-cut samples by optical microscopy and SEM showed that the cut tracks had closed up behind the cut front, unlike cuts made in oxygen. This may be due to insufficient momentum transfer between the incoming jet of helium and the ejected metal particles and vapour, to remove the material from the kerf. Very little plasma is observed during helium processing and the gas has a pronounced cooling effect on the ejected particulates and metal vapour, causing re-solidification of the melt and incomplete ejection of the particulates. Moreover, a considerably reduced retort is heard during helium-assisted cutting, implying that the shock waves are significantly attenuated, thereby reducing the mass ejected during processing. SEM analysis of a helium cut shows the formation of considerably smaller melt droplets due to condensation of the metal vapour and the reduced size of melt particulates ejected due to attenuation of the acoustic retort.

Conclusion

Processing of stainless steel in a controlled gas environment using directed gas jets can result in complex interdependencies associated with the interaction of laser light, plasma plume and normal shock wave formation. Consequently, careful optimisation of the gas jet, laser wavelength, and intensity is required to achieve optimum processing of microparts. In blind drilling experiments with a gas jet, the etch rate is observed to decrease as result of plasma confinement through normal and oblique shock formation above the hole, whereas in a cutting situation, a high pressure gas jet leads to an increase in cutting efficiency. There are problems associated with the use of gas jets leading to post-processing issues which need to be addressed before manufacture of the part can occur. For some manufactured parts, the associated heat affected zone, microcracking and recast when processing with a nanosecond pulsed DPSS results in significant post-processing operations. Further work is in hand to understand the detailed effects of plasma-laser-shock interactions.

Acknowledgments
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Safety in laser machine design

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One of the main strengths of the risk assessment approach of the 'New Approach' Product and Workplace Safety Directives is its flexibility, but this has resulted in some significant differences in opinion by suppliers, test houses and laser users, over the interpretation of directives and the standards that support them. In this narrow context, the situation has not been helped by the excellent safety record of lasers in industry (though we would not want it otherwise): there have been no court rulings on acceptable design requirements for industrial laser equipment.

Whilst most modern laser processing machines are adequately guarded with respect to protecting the operator during normal operation, a closer inspection often reveals short-comings and potential causes of concern. A number of the most common of these, taken from findings during recent safety audits for laser users are listed below, and can be used both to assist users in discussions with manufacturers over the proposed purchase of equipment and as an aid in risk assessments, to help the user identify potential hazards in machine use.

Guard installation

1. non-essential gaps in the guarding that prevent the machine from achieving a Class 1 laser hazard classification (see figure 1);

2. inadequate guarding provision for safe maintenance and servicing;

3. inadequate protection of gas pipes and other service supplies from laser damage (see figure 2);

4. missing guard interlocking or interlocks of an unacceptable design;

5. incorrect or inadequate safety labelling on guards;

Guard construction

6. guarding inadequate to deal with laser exposure under 'worst case reasonably foreseeable conditions';

7. space constrains, resulting in an inadequate 'hazard to guarding' separation;

8. guard construction not 'fit for purpose' e.g. easily damaged by 'wear and tear' in normal use.

Typically, passive machine guarding is of such construction that it provides only a few seconds of protection against a 'raw' high power laser beam (i.e. the material melts or vaporises) which can, of course, be acceptable providing that the laser beam is sufficiently well controlled from source to workpiece. Integrity of the beam path, in turn, raises issues of maintenance and servicing.

The stability of beam delivery is important both for safety and reliability of the machine and the cost of safety can be justified on grounds of increased reliability of performance, yet beam delivery shortcomings are still to be found in modern laser processing machines, including:

Courtesy Corus

Figure 1. An open-topped flatbed CO_2 laser cutting machine with guarding providing full peripheral protection.
Even through the operator and others at ground level may be protected from direct reflections of the laser beam, a machine with an open top must be classified as Class 4. In addition to maintenance and service operations on the machine, the risk assessment by the user will need to deal with the laser hazard in normal operation

Inspection and alignment

9. poor access to optics for inspection and adjustment;

10. optical mounts cannot be removed for inspection without realignment after re-insertion;

11. key optical components (e.g. turning mirrors) are not interlocked in order to prevent emission of the laser beam prior to their replacement;

12. lack of alignment aides (e.g. no co-linear Class 2 laser incorporated, cross-wire jigs not supplied);

13. guarding design does not facilitate safe alignment (e.g. no 'post box' provision or back stops behind turning mirrors).

Protection

14. inadequate protection of optics from laser generated fume, airborne dust and moisture, especially during maintenance or service procedures;

15. insufficiently sturdy mounting of optics from the external influences of an industrial environment (e.g. vibration, temperature cycling, mechanical impact).

The important point to note is that all of the above are 'potential causes for concern', though some are cases of failure to meet the requirements of a relevant standard. Checking for these and other shortcomings in design and construction is a valuable exercise as part of both product compliance and workplace safety checks, though whether or not action need be taken depends on the specific circumstances of use and the assessment of risk.

Safety standards

A list of relevant standards for industrial lasers and laser materials processing was provided in *The Industrial Laser User* Issue 22, pp33. However, in addition to these laser-related standards there are a number of general machine safety standards that are highly relevant to the design of a laser machine and these are listed in Table 1. Below we address some of the key implications of these standards.

Standard	Description	Main relevance to manufacturers of laser processing machines
ISO TR 12100 (EN292)	Safety of machinery Part 1 & 2 Basic concepts, general principles of design	Risk reduction by design. Acceptable safeguarding techniques.
IEC 60204-1 (EN60204-1)	Safety of machinery – Electrical equipment of machines – general requirements	General design requirements. Switching off and protection of equipment. Operator interfaces. Technical documentation. Testing and verification.
ISO 13849-1 (EN954-1)	Safety of machinery – Safety related parts of control systems – Part 1 General principles of design	Safety objectives in design. Design of safety measures. Categories for safety related controls. Fault consideration.
ISO 13850 (EN418)	Safety of machinery – Emergency Stop equipment – Functional aspects	Safety requirements. Requirements for electrical equipment.
ISO 14118 (EN1037)	Safety of machinery – Prevention of unexpected start-up	Isolation and energy dissipation. Devices for isolation and energy dissipation. Measure intended to prevent unexpected start-up
EN1050	Safety of machinery – Principles of risk assessment	Hazard identification. Risk evaluation.
EN1088	Safety of machinery – Interlocking devices associated with guards – Principles for design and selection	Operating principles. Typical forms of interlocking and technological requirements for electrical interlocking. Selection of interlocking devices.
EN981	Safety of machinery – System of auditory and visual danger and information signals	Selection of auditory and visual signals
IEC 73 (EN60073)	Coding of indicating devices and actuators by colour and supplementary means	Selection of colours etc for indicating devices
EN953	Safety of machinery – General requirements for the design and construction of guards	Risk assessment Design and construction of guards Verification of safety requirements
ISO 10218 (EN775)	Manipulating industrial robots – Safety	General design requirements Design and safeguarding of robot systems

Table 1. General machine standards

<u>Design of safety controls</u>

The design of safety controls and circuits should conform to the requirements of IEC 60204-1 (EN60204-1). This standard supports the primary standard giving the principles for the safety of machinery ISO TR 12100 (EN292). A common approach, based on risk assessment principles, to the design of safety-related control circuits is provided in the methodology set out in ISO 13849-1 (EN954-1) in which a classification system is defined which can easily be applied. The five 'safety' categories described are formulated in such a way that they are not specific to a particular technology.

The standard ISO 13849-1 (EN954-1) is particularly helpful in the design of the control system. The main controls are required to include methods to reliably start and stop the machine. As part of the process, the controls must switch off the machine actuators and also either isolate the laser beam or deactivate the laser beam generator. If separate laser-stop controls are incorporated, the beam generator is required to be deactivated, and the standard recommends that separate control devices are provided for both the laser system and the rest of the machine.

The Emergency Stop control must comply with the necessary category as described in IEC60204-1 (EN60204-1) and ISO 13850 (EN418). Both standards define the principles of design and the features that are required to completely terminate operation of the machine, including the laser, in various emergency conditions, and in such a way that there is no increase in hazards caused by the shut-down sequence.

As a minimum requirements, activation of an Emergency Stop must:

• Deactivate the laser beam generation (preferably by switching off the laser power supply and discharging all stored energy sources) and automatically position the laser beam stop mechanism to prevent the further emission of laser radiation;

• Safely deactivate the machine (i.e. remove power and other energy sources from the actuators);

• Comply with IEC 60204-1 (EN 60204-1) with regard to speed of response and degree of actions for switching off the laser power supply and discharging all stored energy sources. Where a laser source is supplying more than one machine, the optical path to the laser beam is required to be isolated.

The safety related control circuits must include means to prevent unexpected start-up, adopting features included in ISO 14118 (EN1037). This prevents any start-up caused by a start command which is the result of a failure or inopportune actions, electrical interference (from external or internal influences) or restoration of a power supply after an interruption.

The design strategy must incorporate isolation and energy dissipation measures appropriate to the equipment and as indicated by the risk assessment. The use of standard EN1050 – Risk Assessment, can prove useful in determining the sources of influences which may effect satisfactory operation of this feature. To maximise effectivity during the Emergency Stop and Shut-down situations, the features of ISO 13850 (EN418) should be incorporated.

Requirements for laser guards are addressed by ISO TR 12100 (EN292) in regard to the general design, by EN953 in regard to general features and by IEC 60825-4 in regard to laser protective properties. The implications of this latter standard have already been addressed in *The Industrial Laser User* Issue 10, pp25 and Issue 22, pp32. In addition, EN292 requires that automatic operation of the machine must be impossible when guards are open or displaced, or safety interlocks are defeated.

The design of interlocks, controls and devices for guards must comply with EN1088. The degree and integrity of the interlocks and the associated safety-related control circuits must be assessed using ISO 13849-1 (EN954-1), based on the appropriate safety category. Many laser processing machines will require the use of dual channel, cross monitored circuits to provide adequate safety integrity considering foreseeable single fault conditions.

An operating mode may be selectable which allows guard interlock override if the design of the machine requires occasional procedures to be carried out with one or more guards removed or displaced but with power maintained to the machine actuators. A lockable mode selector which also automatically isolates the laser beam and prevents automatic operation of the machine for such procedures is then required. The type and status of the mode selector should be clearly and unambiguously shown, referring to EN981 and EN 60073 on the selection and provision of indication aids.

Any discrete deliberate interlock override mechanisms used on removable access panels around the beam path or the process zone are required to meet IEC 60825-1.

Recent developments in safety-related hardware and software

IEC 61508 'Functional safety of electrical/electronic programmable electronic safety-related systems (SRS)' is a new standard that provides significant aid to the development of safety-related systems. This standard takes the approach of determining the Target Failure Measure (TFM), that is, the acceptable likelihood of the SRS failing to danger and then satisfying what this necessitates in terms of the specification, design, installation, operation and maintenance of the SRS, taking into account both random and systematic failures.

Part of the process of defining the TFM is to establish a Safety Integrity Level (SIL). The SIL is somewhat similar to that used to determine the safety category in EN954-1, but the SIL is the probability of an occurrence happening - sometimes referred to as the probability of failure on demand (PFD). The SRS must meet the SIL required, and this is determined by analysing the components and the system configuration to ensure that the PFD for each element is understood and its effect is evaluated and quantified. The standard gives guidance and examples of how this can be done in a systematic and consistent manner. The design also needs to specify the process of installation and maintenance so that the SIL of the system is not compromised during that part of its lifecycle.

Software related to the safety aspects of the system is addressed within the scope of the standard using a similar approach as for hardware. Again, all aspects of the software management and lifecycle are to be considered, and techniques and measures are suggested that allow the SIL to be met. The hardware and software comprising the SRS are regarded as an integrated whole.

The standard is of wide applicability. Of particular relevance to industrial laser processing machines, is the concept that electronics will enter the safety-related controls currently carried out by electromechanical devices. Already some of the major machine control manufacturers (e.g. Siemens) are producing safety-related controls that operate on a network or communication bus (i.e. controllers linked to a distributed intelligence in sensors and actuators) without compromising safety. PC's and PLC's are being used within these systems as the complexity of integrated manufacturing process equipment expands.

Additional features for large machines

For walk-in enclosures (workstations) additional features to detect or control human presence within the danger zone may be necessary, plus the provision of means within the enclosure for immediately stopping both machine motions and laser beam emissions. In addition, a device (e.g. a satellite controller on a flying lead) for activating machine motions or laser beam emission should be provided for the person entering the danger zone to carry with him. Such devices are described in IEC 60204-1 and must be provided with a "hold-to-run" control, which when released terminates the laser hazard. Under the control of this device all machine motion and laser beam emission must only be controllable from this device.

What is Class 1?

Class 1 according to EN 60825-1

EN 60825-1 is first and foremost a standard for the manufacture of laser products. In particular, it sets out how the manufacturer is to assign the laser Class. In the context of laser materials processing, the laser doing the processing will in general be Class 4, the most hazardous class. If the design of the machine allows human access to this radiation, then the machine is a Class 4 laser product and the user will have to incorporate additional measures to address the laser radiation hazard. On the other hand, if the laser radiation is properly guarded to prevent human access then the machine will be Class 1 and the user need not be concerned with the laser radiation hazard during normal use of the machine.

EN 60825-1 defines 'human access' in the form of three 'tests' or conditions: (a) the capability for any part of the human body to meet hazardous laser radiation as emitted from an aperture, (b) the capability for a straight 12 mm probe up to 80 mm long (i.e. a standard finger) to intercept Class 3B or Class 4 laser radiation, and (c) (for Class 3B or 4 laser radiation within a housing) the capability for any part of the human body to meet hazardous laser radiation that can be reflected by any single introduced flat surface from the interior of the product through any opening in its protective housing.

It follows from (c) that the protective housing of a Class 1 laser product incorporating a Class 4 laser cannot possess any significant openings that offer direct line of sight to unenclosed portions of Class 3B or Class 4 laser beams from a distance closer than the Extended Nominal Ocular Hazard Distance.

An informative annex in EN60825-1 entitled 'High power laser considerations particularly appropriate to materials processing laser products' highlights, in particular, the measures available for minimising the likelihood of strong errant laser beams threatening the integrity of the protective housing. These include a number of recommendations identified in the list of common shortcomings, including: protection and isolation of the laser beam path from external influences; protection and stable mounting of beamline optics; minimising the permissible degree of movement of beamline optics; installation of stops and limit switches to prevent collisions during machine motion; installation of proximity switches to ensure presence of critical beamline components; monitoring of overall laser beam transmission.

Class 1 according to EN 60825-4

EN60825-4 ‘Laser Guards’ is risk-based, and Erwin Heberer’s paper in *The Industrial Laser User* Issue 23, pp30 outlines an approach to this subject. In multi-axis processing machines where the laser beam is not constrained to the vertical nor the plane of the workpiece surface to the horizontal, a risk assessment will most probably require guard testing to simulate exposure of the vertical enclosure walls to a misdirected laser beam. Engineered safety features including software and hardwire limits to beam movement.can dramatically reduce the requirements for the guard, or some form of active guarding (e.g. internally coated (smoke generating) surfaces plus smoke detector) can be used

Class 1 according to EN 12626

At the present time EN 12626 is the only standard supporting the Machinery Directive for laser processing machines. It requires, among other things, that the machine be a Class 1 laser product. The conflict between this ‘worst single fault’ condition for Class 1 and the assessment of machine safety under ‘reasonably foreseeable fault conditions’ is the core of much confusion in the industrial laser industry and proposals have been drafted to extend EN12626 to include, for example, open-topped machines (see figure 1), many configurations of which by definition cannot be Class 1. The new proposals would require that human access to laser radiation during normal operation be below the Class 1 AEL only in unrestricted and uncontrolled areas, but that if the laser processing machine is sited in a location with controlled or restricted access (i.e. a location not open to the public, such as industrial and commercial premises, or where access to the protective housing or ENOHD is accessible only to authorised persons who have received adequate training in laser safety and servicing of the machine) then it would be sufficient to incorporate engineering measures or a combination of engineering and administrative controls, selected on the basis of a risk assessment, to ensure that people are not exposed above MPE. Clearly, a risk assessment will often lead to quite different acceptable guarding solutions for equivalent CO_2 and Nd:YAG laser machines.

Summary and Conclusions

Safety standards relevant to laser materials processing machines offer good design advice. A list of common shortcomings in laser machine design point to areas where their requirements are not always followed rigorously.

Lasers were originally designed primarily for operation within a research environment. Operators were highly skilled and trained experimenters. Today, large numbers of lasers are going into industry for use on fully automated machines or to be operated by relatively inexprienced users. Lasers remain one of the safest, as well as the most flexible tools available to today’s engineer, but this is clearly no cause for complacency.

Laser Job Shop 2001

Wednesday 3 October
BOC Gases, Wolverhampton

Our 'Laser Job Shop 2000' in Leeds last year was the first of our business meetings, and this year's programme addresses equally important job shop topics. Moreover, the meeting provides a unique opportunity for laser job shop representatives to meet, to learn and to discuss issues of common interest and concern.

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Tricks and secrets of ...

Design for Manufacture by Laser

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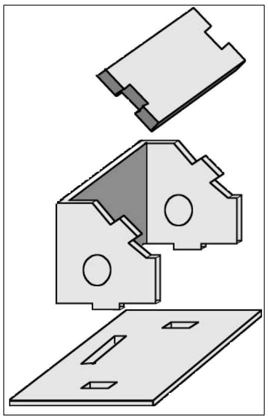
BAWA Centre, BAE SYSTEMS Bristol

Programme includes:



The Practicum of Flexure Design and Application (David Brown, Wave Precision, USA)

"It is a hallmark of the flexure that it (almost) always does the difficult job straight away, and seems so miraculous a device that it's secrets are veiled with a zeal worthy of MI5."

The Laser Cutting Approach to Tubes Fabrication (Lino Grisoni Adige Sala SpA Italy)

"Tube fabrication by laser cutting offers flexibility, manufacturing steps reduction, cost savings, time savings, easier assembling and more freedom in designing new products."

Rapid tooling by selective laser sintering:
(Isaac Chang University of Birmingham)

"Lasers offer the ability to manufacture metal tooling directly from a CAD file, providing opportunities to reduce the time and cost of product development."

Forthcoming Events

October

3 Laser Job Shop 2001

Laser Job Shop Group
Users of Lasers for Profit

Annual meeting for laser job shops
BOC Gases, Wolverhampton
Further info: AILU office *(see adjacent info)*

8 Metals Engineering 2001 (8 - 11)
Including MetFab UK, a new show
NEC, Birmingham
Further info: (Metfab): Kate Hamlin T: +44 (0) 1737 855122

15 ICALEO 2001 (15 - 18)
AILU-supported event
Jacksonville, Florida
Further info: AILU office *(see ad on page 34)*
AILU members can register at LIA-member rates

18 Advances in Laser Technology
Linde Gas AG presentation to Welding and Joining Society (Leeds branch) 7:30 pm start
The Village Hotel, Headington, Leeds
Directions T: 0113 278 1000
Further info: Bob Eden at Linde. T: 0121 500 1000

30 Design for Manufacturing exhibition (30 - 1/11)
NEC, Birmingham
Further info:
T: +44 (0) 20 8910 7979

31 Cost effective laser processing
Joining Forces in conjunction with Make It with Lasers
TWI North, Middlesborough and Caterpillar, Peterlee
Further info: Carol Fielding
T: +44 (0) 1223 891162 F: +44 (0) 1223 892588
E: carol.fielding@twi.co.uk

November

11 FABTECH International exhibition (11 - 14)
Chicago, Illinois, USA
Further info:
T: +1 815 399 8700

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Design for Manufacture by Laser
AILU workshop
BAWA Centre, BAE SYSTEMS, Filton, Bristol
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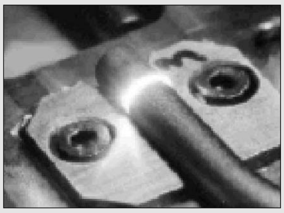

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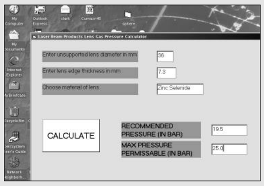

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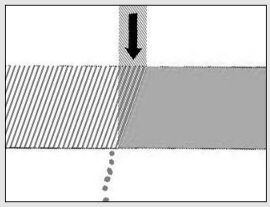

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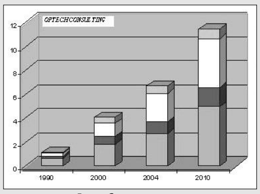

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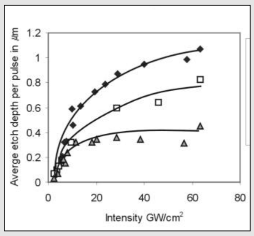

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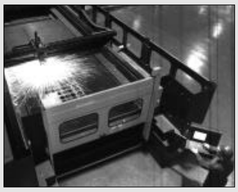

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Editorial Policy

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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