



# **R&D in Laser Materials Processing**

## **Part 1**

### **Current UK Research Opportunities**

Compiled by

**Paul Hilton** PhD, MSc, BA, F.Inst.P, C.Phys

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and

**Part 2**

**Competency map of top-level UK providers  
of R&D in laser materials processing  
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## **Introduction**

The information presented here derives from a brainstorming session held in November 2008, to which selected members of the UK laser materials processing academic and industrial research community were invited. Once the results of the work were categorised and condensed to remove repetition, they were placed on the AILU website in an open forum and all AILU members, together with others who had participated in the surveys described in Part 2 of this document, were given the opportunity to comment on, or add to, the results. The listing of current UK research opportunities in laser materials processing presented below is the output of a further round of consolidation.

It should be pointed out that the information and ideas contained in this report are those that the contributors were willing to make public. We believe that the research opportunities are in line with the individual technology roadmaps of the participating organisations; but that other research opportunities exist, which organisations wish to keep confidential.

Attempts were made during the brainstorm session to establish the impacts of successful research in the suggested laser processing themes; however, no ranking of the research opportunities themes was attempted or indeed is appropriate for a process-based, rather than a sector or product based division, and the six major categories of output are therefore presented in no particular order.

## **Current UK research opportunities in laser materials processing**

### **Theme 1: Fine Scale Processing**

#### **1.1 Fundamental requirements**

To-date, there has been no systematic study of the effects of laser source, pulse length, intensity, rep-rate and wavelength, on processing of the majority of important materials in the semiconductor and electronics industry sector – a sector that now includes photonics, and which is projected to have continued strong global growth in the next couple of decades and be a key manufacturing sector for the UK/Europe. Fundamental laser beam/material interactions need to be better understood for these processing regimes on metals, semiconductors and insulators, as multi-photon absorption in the interaction zone can contribute significantly to the processing and visible and UV laser output can be now be easily and efficiently delivered (by harmonic generation), providing high photon energies. Users today have no clear template or model that allows an easy choice of laser tools in this fine processing area. The lack of clear guidance equally impacts equipment suppliers, who still tend to provide ‘technology push’. For example, very short pulse laser systems (delivering pulses with durations in the pico and femto-second range) are promoted by some for clean processing applications, despite the operating regime of these sources being somewhat restricted. However, it would be fortuitous if the parameter set of such sources was an optimum for the majority of production processing. The community (both users and suppliers) need to better understand what will constitute an optimised laser parameter set to allow equipment RTD to move in the right direction, i.e. to give the most useful processing performance in terms of quality, speed, cost, etc for the user. The RTD work requires model development coupled with careful validation, using beams from experimental and commercially available laser sources and with selected key electronics/photonics industry chosen materials. The output required is a usable model/template that points the direction for the future development of optimised solutions. Only with this information can cost effective lasers sources be developed to optimise the required manufacturing processes.

## **1.2 Photovoltaic cell production**

Pollution free electricity generation using solar cells is becoming one of the main methods of reducing CO<sub>2</sub> emissions. Two main photovoltaic (PV) cell types exist. Currently over 90% of PV production is based on crystalline silicon cells. New designs are being developed to improve efficiency and which require high speed, low cost drilling and scribing of silicon. Thin film (e.g. CdTe, amorphous Silicon, CIGS) cells currently account for less than 10% of PV production, but this is expected to grow more rapidly than crystalline silicon due to lower manufacturing costs. Laser ablation is a very cost effective method of producing the thin layer sandwiches used in photovoltaic cells. It has already been identified that laser ablation is cheaper than lithography. However a considerable amount of research is necessary to improve the industrial uptake of this technique.

IMPACTS: Research of this type will provide financial and environmental benefits as photocells are a potential major source of renewable energy.

## **1.3 Optimising OLED production**

Organic light emitting diodes (OLEDs) can be used in television screens, computer displays, cell phone displays and for general space illumination. A significant benefit of OLED displays over traditional liquid crystal displays (LCDs), is that OLEDs do not require a backlight to function. As a result they require far less power and can be more effectively manufactured than LCDs and plasma displays. The technology depends on a series of layers, often only 100nm thick and new laser processes are required with the control necessary to manufacture the required structures while avoiding damage to underlying layers. This is an area which requires research in order that the production and performance of these devices is optimised.

IMPACTS: The optimisation of OLED production will increase their level of utilisation - with obvious benefits in reduced energy consumption for displays and lighting etc.

## **1.4 Laser cleaning**

Laser cleaning has a range of diverse application – from paint stripping on aircraft to the removal of microscopic debris from electronic components. In many industrial applications, removal of contaminants by laser cleaning can reduce the environmental burden by replacing the use of ozone destroying organic solvents. Recent environmental legislation is severely limiting the use of such solvents and hence the take up of new means of cleaning, such as use of lasers, is an important driver. Improved functionality may be delivered as a result of laser cleaning of surfaces prior to adhesive bonding (for example in the automobile industry). A little noticed but burgeoning application area for laser cleaning is in the area of art conservation and cleaning building interiors where water based techniques would be damaging.

IMPACTS: Improvements in aerospace and medical device production as well as the development of the next generation of electronics will have obvious widespread benefits.

## **1.5 Laser patterning**

Many emerging high volume, mass-reproduced devices for the displays, photonics and optical sectors require high quality master surfaces with 3D features and direct laser structuring will be an important, rapid and cost-effective alternative to existing methods such

as diamond turning. In addition, another important growth area is the direct structuring of micro-features on metal or ceramic cylinders for direct roller replication. Laser ablation of patterns on the surfaces of rollers and dies can have a tremendous effect on the tribological and other surface properties of the items produced by these tools. For example, ink adhesion or lubrication characteristics of the product can be greatly enhanced. In addition, a large research area is open for exploration in the production of hydrophilic and hydrophobic surfaces for the micro-control of fluid flow and capability for wetting, for example, the manufacture of fluidic devices.

**IMPACTS:** Improved wear characteristics and corrosion protection of processed products will have commercial and environmental benefits as we move towards a reduced waste – improved product life cycle ethic. New concepts will become available in material structures using hydrophilic and hydrophobic materials.

## **Theme 2: Materials Joining**

### **2.1 Fundamental requirements - high brightness laser beams**

Modern disc and fibre lasers have many well-understood attributes that make them attractive to laser materials processing applications, in particular their high electrical to optical energy conversion efficiencies. However, the brightness offered by these lasers is sometimes difficult to control and affects the quality of resultant welds. Research is needed to understand better the way high brightness laser beams interact with a range of materials during welding. Only with this information will it be possible to combine the beam quality of the laser source with the correct method of beam delivery and focussing, to produce the highest quality welds with the highest efficiencies. Linked to this is the currently unresolved problem of transferability of laser welding results from development lasers to production laser systems. Research is needed with the ultimate goal of being able to develop a laser process with one laser system, with sufficient knowledge about the process and equipment so that the process can be reproduced on a different laser system. Such differences might include the beam parameter product of the laser, the diameter of the optical fibre delivering the power and the beam focussing system.

**IMPACTS:** Only with fundamental work in this area will the full potential of the new, high efficiency laser sources be realised.

### **2.2 Joining of mixed materials**

In many applications, the joining of dissimilar or ‘mixed’ materials is needed, either for performance, in for example the aero-engine sector, or for weight reduction in automotive applications. The laser is seen as a potential tool for the joining of such materials, either by welding, brazing or by introduction of other innovative techniques. Research is needed to develop laser beam techniques for joining dissimilar materials, particularly sheet steel to aluminium.

**IMPACTS:** Mainly weight reduction in automotive applications, and strength/weight considerations in aerospace applications.

### **2.3 Joining of coated and ultra high strength steels**

The automotive industry will benefit from the introduction of new high strength and ultra high strength steel sheet for body in white applications. Laser welding is a potential joining technique for these steels, but research is needed to be able to weld these materials and still maintain the required joint properties. In addition, there are still problems when laser welding zinc coated steel sheet (and many other coated materials) in the overlap condition in body in white applications. Current engineering solutions to this problem are complicated and expensive to implement. Research is needed to resolve this problem in a simple to implement and cost effective way.

IMPACTS: Weight reduction, less carbon dioxide emissions and improved crash worthiness; increased process efficiency due to fewer failures during welding.

### **2.4 Linking laser weld quality to mechanical property data**

Currently there are insufficient links between laser weld quality data and weld mechanical performance data, to be able to introduce laser welding in many possible applications. Research is needed to alleviate this problem for a range of materials and joint geometries.

IMPACT: More take up of cost effective laser welding by industry.

### **2.5 Weld repair**

Repair of high value components is becoming increasingly the alternative to replacement. The flexibility of current laser sources and the growing potential for remote operation offer advantages for weld repair in the areas of underwater welding and repair in difficult to access areas, such as those found in the nuclear industry.

IMPACT: Significant potential impact on cost reduction and reduced environmental impact.

### **2.6 Micro-joining**

The world is increasingly moving to a range of more miniature products or products that involve miniature components. To produce such components needs a range of joining technologies, some of these operating at a micron scale. Research is needed to investigate the use of lasers to achieve joining at this scale of feature.

IMPACT: Implementation of cost effective laser technology in this rapidly developing product market.

### **2.7 Joining of non-metallic materials**

The majority of laser welding applications are currently centred on metallic components. The laser has much potential for the joining of polymers, technical textiles, ceramics and composites. More research is needed to understand the basic beam/material interactions in these materials, and combinations of these materials, both with themselves and with metallic materials.

IMPACT: The introduction of energy efficient laser sources for the high speed joining of non-metallic materials. Development of novel manufacturing routes for fabric and ceramic based industries.

### **Theme 3: Additive Manufacturing**

Laser based additive manufacturing techniques use either wire or powder to produce either solid metal or polymer near net shapes or to effect repair to damaged or worn components. When using powder this can either be blown into the laser beam/material interaction point or a rapidly scanning laser beam can be used to fuse metal (or polymer) powders to form a complex 3D structure.

#### **3.1 Laser direct metal deposition using blown powder and solid wire**

- Improvements in wire feed technology to better engineer the directionality of this form of delivery and maximisation of wire deposition efficiency, balancing required component quality and properties to deposition rate.
- Development of hybrid wire/powder feed for making single pass compositional graded surfaces.
- Improvement in energy and powder utilisation efficiencies.
- Development of control sensors and logic for speed, height, structure and dimensions of clad or weld build constructions.
- Improvements to net shape accuracy of form and in particular, surface finish.
- Modelling and validation of the laser direct metal deposition process in order to predict deposition characteristics (microstructure, residual stress, deposit quality, fatigue properties etc). These models should be user friendly and work quickly. This will greatly reduce the empirical work needed to establish optimised deposition procedures for a range of materials and applications.
- Determination of the properties of laser deposited materials (fatigue, creep, tensile, microstructure etc) and comparisons with the equivalent properties of cast and wrought materials.
- Investigation of graded surface layers, e.g. Steel to Cu or ceramics to metal, and manufacture of components with functionally graded properties by the use of more than one material in the deposition process
- Methods of coating with ceramics, in particular turbine blade technology and medical prosthesis.
- Development of unusual surfaces such as structured piezo-electric surfaces, e.g. PZT crystals mounted on an LCD board and thus capable of reproducing surface waves to aid fluid flow – similar to the surface contours found on the skin of a dolphin.
- Development of meta-stable surfaces that would weld at very low temperatures.
- Development of techniques to coat plastics.
- Study low temperature cladding routes using such materials as sol gel.
- Development of new alloys specifically for laser cladding.

**IMPACTS:** Improved process efficiency and hence greater savings in material. The ability to recycle high value damaged or worn parts. Predictive capability to minimise procedure development and reduce machine time.

### 3.2 Selective laser melting using powder bed technology

- Improvements to net shape accuracy of form and in particular, surface finish.
- Faster deposition rates by optimizing applied laser power density and beam scan speed.
- Determination of the properties of laser deposited materials (fatigue, creep, tensile, microstructure etc) and comparisons with the equivalent properties of cast and wrought materials.

### 3.3 Micro/nano additive manufacturing

There is also a need to consider the potential of laser based additive manufacture at the micro scale (for example building items <1mm in size and with feature size down to 1micron).

## Theme 4: Surfacing technologies

### 4.1 Heat treatment

- Some fundamental research into absorption and penetration depth of powerful laser radiation in continuous or pulsed delivery. This is particularly so for medical applications.
- The curing of conductive inks for high speed flexible manufacture of electronic circuits.
- The transformation hardening of steels with minimal distortion in the manufacture of engine blocks and the development of adaptive control systems for laser transformation hardening.
- Techniques for improving absorption of radiation need further study.
- Micro manipulation via the laser bending processes has hardly been addressed except by one or two manufacturers of hard drives. This is an area ripe for research exploration.

IMPACTS: Swifter and cheaper manufacturing processes of higher quality which would give UK industry a competitive edge. Micro manipulators would be a new concept within manufacturing.

### 4.2 Laser melting

- Fundamental studies in flow and mixing within a laser generated melt pool and the resulting stress patterns.
- Applied research into the tailoring of tribological surfaces by surface shaping, structured hardness profiles or surface patterns, for example nano pits. The laser is one of the few tools capable of micro-surface melting or ablating and hence making detailed structural surfaces.

IMPACTS: Superior surfaces could lead to longer life, greater reliability and lighter structures. Better tribological surfaces could save energy.

### 4.3 Laser cladding

- The development of rubbing surfaces to create better wear properties or less friction. To achieve this research is needed into the development of new alloys (particularly for Ti), the patterning of alloys over a surface to create regions of harder or softer surfaces (as in the tread on a tyre).

- Erosion and corrosion are both big problems in most machinery. It is a feature of such problems that they occur at specified and highly localised areas. This is precisely where the laser can have an impact. Research is needed to establish better alloys and techniques for micro-coating by laser.

IMPACTS: Improved machinery and longer lasting manufactured goods. This should give a competitive edge to UK manufacturing.

#### **4.4 Laser marking**

Notwithstanding the existing huge market in laser marking, a process which is both quick effective and which can be applied to most materials, there is a need to understand and develop solutions to the slight micro-structural damage around a laser mark on, for example, medical prosthesis, which can affect the corrosion properties.

IMPACTS: Enlargement of the market for marking and the resulting security of products.

### **Theme 5: Cutting and Drilling**

#### **5.1 Improving the overall efficiency of the laser cutting process**

The main consumables of the laser cutting process are; energy, gasses and sheet metals. In the past, the overall efficiency of the process (expressed as a ratio of consumables used to the amount of cut products produced) has been high enough to allow the industry to thrive. However, it is now time to improve efficiencies in order to reduce the costs to the user and to the environment. The strategy for carrying this out requires a re-examination of established research areas from the point of view of overall efficiency. For example, in the past a considerable amount of research into the correct nozzles to use to transport the gas jet into the cut zone was carried out. This research was always focused at improvements in cut quality or speed. However, this area of research needs to be reopened with the aim of reducing gas and energy consumption per unit cut length. Similar areas of interest exist in optimising the focusing optics, laser type and design and material utilisation.

IMPACTS: Research of this type will provide immediately actionable financial and environmental improvements. Less energy, gas and metal will be employed to provide the same number of goods. There will also be secondary benefits such as reduced delivery costs of gas etc.

#### **5.2 Optimising fibre and disc laser cutting and drilling**

The new generation of high brightness fibre lasers are approximately three times as efficient as the established CO<sub>2</sub> lasers if we compare electrical energy consumed to laser energy produced. However, the uptake of these new lasers by industry is being hampered by a lack of reliable information about their performance characteristics. At the moment, the majority of the process information relevant to these lasers is being generated by the machine suppliers and a lot of this information is misleading in one way or another. This situation has led to a considerable amount of caution within industry, which has undoubtedly suppressed the sales and application of this new technology and hindered the uptake of more energy efficient products. The whole area of fibre laser cutting and drilling needs much more research effort than it is presently receiving.

**IMPACTS:** The increased utilisation of these efficient new lasers will provide cost and environmental benefits.

### **5.3 Micro and nano laser cutting and drilling**

Laser cutting and drilling of components on the micro and nano scale is an obvious area for future research. The applications of this technology include aerospace, medical applications, ceramics, polymer based and other electronics, composite processing and many others.

**IMPACTS:** Improvements in aerospace and medical devices as well as the development of the next generation of electronics will have obvious widespread benefits.

Equipment for Laser Materials Processing

## **Theme 6: Laser beam and component manipulation**

### **6.1 High speed machinery**

Research is needed on the equipment required to manipulate either the laser beam or the sample material at the very high speeds, large component size and small process scale required by tomorrow's technologies. This is particularly true in the areas of material removal in the fields of photovoltaic's, production of flat panels and large displays, and in the field of organic light emitting diodes (OLED's). The same applies for areas of sub-micron size laser processing, including the development of near field processing concepts. In addition, research into the area of systems integration for such equipment developments is required.

**IMPACTS:** The processes mentioned above are a high growth area, with application on a global scale, with the laser as a key enabling technology.

### **6.2 Monitoring and control of laser materials processing**

Research is needed in the general area of monitoring and control of laser materials processing. The control should extend to adaptive systems where the process monitoring provides information in real time for feedback to a controlling parameter. This topic is applicable to all the laser processes. Linked to this is a need for more research to be implemented in the areas of systems integration, extending the concepts of process control to the whole production cell and the flow of information on part geometry and process parameters. For example, one of the most important factors in process control is the real-time measurement and assessment of a part being laser machined, i.e. what has been machined so far in terms of form, depth and quality. This assessment then needs to be fed back into the process control function to optimise how the processing continues.

**IMPACTS:** Implementation of better process monitoring systems and the introduction of adaptive control would greatly increase production efficiency and reduce wastage in terms of scrapped parts. The resulting processes will be greener, more energy efficient and more competitive.

### **6.3 Nozzles for gas assisted laser cutting**

Much research has been undertaken in the area of gas assisted laser cutting. The high pressure inert gas technique for laser cutting is becoming more and more popular because of the quality of cut which can be achieved with this technique and a lack of oxidation of the part. However, the amount of gas used is very high. Research is needed to investigate laser cutting

nozzle designs for reducing gas consumption while maintaining cut quality. Modeling is expected to contribute significantly in this area.

IMPACTS: Reduced operating costs, less environmental impact and greener production.

#### **6.4 Optics for tailored energy distributions**

Currently the majority of laser processing takes place using a laser beam focused by a simple lens. Research is required in the area of enhanced beam forming and beam shaping systems to further increase the flexibility and productivity of laser materials processing. This can be done in a variety of ways ranging from the use of diffractive optics, spatial light modulators, to metal optics for very high powers.

The affect of spatial intensity profile at the focus needs to be investigated now that new, very high beam quality, high power lasers are available. A Gaussian profile from a single mode laser appears good for some applications but there is empirical evidence that better and faster processing can be performed with alternative energy distributions.

IMPACTS: New processes, increased competitiveness and high added value products.

#### **6.5 High efficiency laser sources**

With today's energy costs spiraling, the need to improve the efficiency of transferring electrical power to optical power needs further research. For high power materials processing applications the most likely candidate laser in this respect is the diode laser. However, its beam quality is currently lacks that available from other laser sources such as the disc of fibre laser. Research is needed to increase the available beam quality of high powered diode lasers.

The impact of IR fibre lasers has been spectacular in industrial cutting and welding applications, particularly on thin materials for precision applications, with the main attractions being simplicity, ease-of-use and efficiency. It would be an obvious extension to develop fibre lasers into the visible and UV regions, with the potential to bring the benefits of this technology to the micro and nanotechnology sectors. Potential problems with damage and UV transmission obviously need to be overcome and there are already some streams of research into coupling fibre lasers to photonic crystal fibres. Other options need to be researched since achieving a true visible/UV fibre laser source would be a major advance and bring huge benefits to the entire industrial user community.

IMPACTS: More efficient laser sources, less equivalent CO<sub>2</sub> emissions than other currently employed laser sources. Potentially cheaper laser sources.