ASSOCIATION OF LASER USERS

STATEMENT OF NEED FOR HIGH POWER LASER PROCESSING FACILITIES FOR THE UK RESEARCH BASES

By

AILU Process and Product Innovations Group

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Introduction

Lasers are currently undergoing step change advances in technology leading to new sources including high power high brightness fibre lasers and high average power ultra-short pulse systems. These new laser sources are revolutionising laser material processing leading to widespread new applications and new scientific challenges. These applications will help the UK address some of its most pressing problems including the carbon challenge and future energy supply. It is imperative that UK academia and industry have access to these new sources in order to help solve these national issues.

The Association of Laser Users (AILU) is a UK-based organisation with members extending across five continents (www.ailu.org.uk). Members include the main UK players in academic research organisations, manufacturing industry, job shops as well as manufacturers and suppliers of lasers and laser-related equipment and services. The Association was formed in 1995 and is recognised worldwide as unique in the high level of practical advice it offers on technical and business matters related to laser applications in manufacturing. Within AILU, the Products and Process Innovation Group. carried out a detailed survey of facilities and research capability in the UK academic research bases and R&D opportunities in laser materials processing research. A competency map of top-level UJK providers of R&D in laser materials processing research is produced and is now available on (http://www.ailu.org.uk/reports/081205%20Report%20v%203.1%20Part%202.pdf). This highlighted that the UK is lacking a number of key state-of-art high power laser facilities that would allow the UK research organisations to carry out world-class research in advanced laser processing and deliver technological solutions to industry. Following the EPSRC call, a new survey was carried out by AILU to identify the need of mid-range facilities for the UK academic and based on this a statement of need is provided here.

1. Type of facility and *brief* description of its function.

Laser materials processing (cutting, welding, drilling, forming, additive manufacturing, surface engineering, micro/nano fabrications) has wide applications in various industrial sectors including the aerospace, automotive, electronic, bio-medical, consumer goods, photonics, chemistry, energy and nuclear industries. The processes enabled by laser based manufacturing rely on

the unique properties of high power lasers (from the traditional CO_2, Nd:YAG and excimer lasers to the modern Diode, diode pumped solid state, fibre and femtosecond Ti-Sapphire lasers). Although the UK research organizations have most basic traditional laser facilities (CO_2, Nd:YAG and excimer), there is lack of state of art high power laser facilities in the UK to enable the UK researchers to carry out leading edge research into next generation laser based rapid and precision manufacturing. The following high power laser facilities have been identified as urgently needed in the UK academic/research bases.

Type 1: Ultrasort pulse, high average power lasers for high throughput micr/nano fabrication. This type includes high power (e.g. 50 W) picosecond lasers at IR, visible and UV wavelengths integrated into precision CNC machining centre; high power (>200 W), high repetition rate (>1 MHz) femtosecond laser material processing systems; high energy (> 100 mJ per pulse) femtosecond laser processing system. These ultra-fast laser facilities that are used for next generation micro/nano fabrication research as they would allow "cold" machining of engineering materials with minimum heat affected zones and processing features at or below the diffraction limits of the lasers. One problem of ultra-fast laser processing is the slow material removal rate, thus there have been very few industrial take-ups in the UK. The listed new lasers are the latest products that have average powers well beyond the common ultra-fast lasers currently used in the UK research communities (<2 W). The high power ultra-fast lasers not only allow advanced research into "clean" and "super-quality" materials processing for a wider range of applications (e.g. solar cells, medical devices, MEMs, plat panel displays, fuel cells), but also would allow more industrial partners to participate in the research and applications, leading to wealth creation.

Type 2: High average power, high brightness lasers for advanced laser materials processing. These include high power (> 20 kW) multi-mode fibre laser material processing system, high power (>4 kW) single mode fibre laser robotic material processing system and high power (>300W), microsecond pulsed fibre laser processing system. These laser systems provide high power, high quality laser beams that would allow research in laser cutting, welding, drilling to go beyond the current limit (in terms of processing speed and material thickness and types). They would also present new opportunities for EU collaboration (These are the laser systems commonly used in Germany, France and some other EU countries for materials processing research). The maximum powered single mode fibre laser available in the UK is 1 kW (The University of Manchester) and the maximum power multi-mode fibre lasers in the UK are 8 kW (Cranfield University, The Welding Institute). Therefore the new laser systems would benefit UK research base and industrial/academic collaborations both in the UK and across EU.

2. Is this an existing UK facility or is it a new facility? If it is a new facility, please explain why this facility is now needed or will be needed in the future.

UK academic/research bases or industry do not have any listed facilities. They are urgently needed to allow the UK research bases to carry out leading edge, world class research that can be competitive internationally and are in common grounds in the EU where many other countries (e.g. Germany and France) have already installed some of the listed facilities in academic/research institutions. The facilities will allow UK academic research bases to collaborate with EU partners in FP7 and FP8. They will support UK research in the next 10 years in the area of laser based manufacturing and materials processing.

3. What facilities of this type already exist (a) at the university level, (b) at the national or regional level and (c) at the international level. How accessible are these existing facilities to UK academics?

The proposed facilities do not exist in the UK but some of them are available in some EU countries, e.g. Germany (Fraunhofer Institutes) and France. Although UK academics can access these facilities by collaboration with EU partners, as these facilities are fully subscribed, it is inconvenient for the UK academics and research students to access these facilities on a regular basis. It is more difficult for the UK industries to access these facilities outside the UK.

4. Please describe who will benefit from the existence of this facility, including the number and type of researchers in the UK who are likely to want to use it and the research disciplines that it will benefit. Please indicate what level of usage such a facility would get in a year.

The listed facilities would be used by UK academic institutions as well as the UK industries for R&D (funded by Research Councils, TSB, regional development agencies, industry and EU) in advanced laser manufacturing research. It is estimated that over 30 UK high educational institutes would have a need to access the facilities and over 500 UK companies would access the facilities over the next 10 years to support over 2000 R&D projects (based on the 2008 AILU survey of UK R&D activities and facilities in laser processing). AILU has proposed a "Virtual UK Laser Processing Laboratory" to allow wider access of university research facilities (see AILU website- PPI group). The facilities will be used in full capacity as most of the currently installed facilities are. The rationale for the listed facilities to be installed in the UK research bases are:

1) To provide a high speed ultrashort processing facility for the medical device industry using the latest laser technology. Results already suggest high speed "clean" cutting is possible, but a UK facility is required to demonstrate and develop innovative products that depend on the clean cutting process and economically viable speeds.

2) The renewable energy and defence/security industries are currently the biggest identified growing market for laser processing and equipment such as that described is essential to economic manufacture. Plastic electronics and displays are likely to provide an ongoing and developing market and a facility is required on which commercially viable manufacturing techniques can be developed and proven.

3) A facility as described will allow the UK research community to continue with heavier engineering sectors such as energy (nuclear, wind, power generation) that urgently require innovative manufacturing and materials routes to face challenges of climate change, light weighting and energy saving. New welding, drilling, sock peening, cladding and heat treatment processes need to be developed and demonstrated with applications in aerospace, ship design and build, pipeline manufacture and to reduce the impact of the necessary new build of fossil fuelled electrical generation plant

As an additional benefit the listed laser facilities will offer significant advantage in energy efficiency (e.g. a fibre laser has an electrical to optical energy conversion efficiency of >20% compared with 1-3% for a traditional arc-lamp pulsed Nd:YAG laser). They represent the future need of the industries as part of clean/green manufacturing initiatives.

5. Please explain why this facility is a "mid range facility" and what the benefits are of EPSRC supporting this facility. That is, why the facility needs to be supported at a national or regional level, rather than at a University or international level.

Each laser system has a price range between £300k - £800k, thus they are in the mid range. The benefit for the EPSRC to support the facilities is to allow the facilities to be used for fundamental and applied world class research by many universities. The facilities will also provide opportunity for training and education ((PhD, EngD, MPhil, MSc and UG and CPD) purpose as well for promoting opportunities for industrial / EU collaborations. The cost of facilities is too high for an individual university to invest in. There is no appropriate funding route for the relatively low budget equipment at international level (unlike nuclear fusion projects).

6. How long should the facility be supported for?

2 years, for preparing specifications, tender documents, procurement (tendering and selection), site/infrastructure preparation, delivery/installation, system integration, testing, staff recruitment/training, safety systems and initial evaluation.

7. Please indicate what the facility should provide to be of maximum benefit to the research community and estimate the likely cost of the facility. For example, indicate what size should it be, what technologies should it have available, how many staff would it need. You should prioritise these requirements in terms of "must have" and "desirable". In addition, please highlight any features that would be detrimental.

System	Lasers	Support	Applications	Cost (£k)	Rating
High Average Power ps laser processing system including the laser and linear motor driven XYZ stages with high speed rotary axis (e.g 300mm x 300mm x 300mm), gas assist nozzle and high speed galvanometer	Picosecond lasers: 50W Av @ 1030nm, <10pS, 200kHz, 250uJ max pulse energy 25W Av @ 515nm, <10pS, 200kHz, 125uJ max pulse energy >15W Av @ 343nm, <10pS, 200kHz, >75uJ max pulse energy	Basic infrastructure (electrical power, water, gas supplies, fume extraction) and estate. 0.5 experimental officer and laser safety officer. Service contract	Micro/nano fabrication or applications in displays, plastic electronics, medical (e.g. stent and implants) and solar cell, composite machining and surface cleaning and drilling (aerospace and automotive industries)	600	Must have (not available in the UK)

High average power femto second laser micro/nano fabrication system	200-300 W average power femtosecond laser system with rep rate > 1 MHz (up to 75MHz)	As above	As above but would include micro-fluidics and photonic industries as well as high quality cutting.	750	Must have (not available in the UK)
High average power CW multi-mode fibre laser materials processing system including large CNC tables and high speed galvo scanning system	20 kW multi mode fibre laser	As above	Cutting and welding thick section materials for the heavy industry including oil/gas, wind and nuclear industries.	800	Must have (not available in the UK)
High average power CW single mode fibre laser with robotic delivery and high speed CNC/Galvo system	5 kW single mode fibre laser	As above	Super-high speed cutting, welding and drilling of reflective and high thermal conductivity materials, remote cutting and welding	800	Must have (not available in the UK)
High average – tasking multi-tasking CW laser (low beam quality) mounted in anaerobic chamber with large working volume e.g. 2m x 2m x 2m minimum, and powder handling / delivery system.	Diode laser (10 kW), multi-mode fibre laser (10 kW)	As above	Welding, deposition, surface hardening	800	Must have (not available in the UK)
High pulse energy femtosecond laser processing systems	85 mJ pulse energy fs laser, peak power 1-2 TW with 80 fs, 10 Hz and a wavelength of 1240 nm.	As above	Shock peening, fundamental research in laser generation of plasma and shock waves	600	Desirable (not available in the UK)
High average power micro-second pulsed fibre laser processing system with 3-axis CNC motion system	1-100 μs pulse length fibre laser with high peak power (>20 kW)	As above	High speed precision drilling and cutting with high throughput and smaller heat affected zone	400	Desirable (not available in the UK)

8. If EPSRC was unable to support this facility, what would the research community do? (for example, in terms of looking for other sources of financial support or seeking access to non-UK facilities)

If the facilities are not available, the UK research community will mainly have to use their existing facilities to continue their current research activities. Facilities available internationally such as in the Fraunhofer institutes could be used assuming suitable agreements could be made. However this has two major drawbacks

- These systems are already heavily subscribed for their own national programmes and access would be very limited
- It would be very difficult to configure the systems in a manner suitable for the work that needs to be carried out for UK national requirements (partly due to the 1st point)

This will lead to the UK losing its competitive edge and current world leading international standing in laser based manufacturing. UK industry would be forced to rely on international input to remain competitive.

9. Please make any other comments that you think are relevant to the statement of need for the facility.

Laser material processing will have a major impact in addressing future UK national challenges. Reduction of carbon levels requires major changes in energy production including renewable sources, nuclear power and increased efficiency conventional power generation. All of these areas require new materials and new and new material processing technologies. The advent of the new laser power sources mean that step changes in laser material processing can be envisaged and these will be a key element of achieving the UK national goals. These changes will only be realised if suitable facilities are provided for the UK academic and industrial laser processing research community.

These facilities will provide further benefit to the UK through increased competitiveness in general manufacturing. High value manufacturing is recognised at government level as being a key element to the future success and growth in the UK economy. Laser processing is a vital part of high value manufacturing and it is essential that the research community has the tools needed to provide

The UK laser materials processing community has an outstanding record of technological developments which have made significant scientific and industrial impact world wide. For example:

1) Laser cutting (oxygen assisted) was invented in the UK (by TWI in late 1960s) which is the now the main method for sheet metal profiling and the sale of laser cutting systems alone is over £2.5b/year and business over £20b/year (estimated). There are over 400 companies using laser cutting machines in the UK.
2) Hybrid laser and arc welding has now been considered world wide as a most suitable method for welding thick section materials. This technique was invented in the UK at Imperial College (Professor W.M.Steen and his colleagues) in late 1970s.
3) Blown powder laser cladding and laser metal deposition by blown powders was invented in the UK (Imperial College, by Professor W.M.Steen and his

colleagues) in early 1980s. It is now the most widely used technique for surface modification and additive manufacturing for both new components and for repairing used components contributing to material re-use and recycling. The additive manufacturing (save up to 70% materials and 60% time in high value components manufacturing) and has a £1b/year business and it grows rapidly as part of clean/green manufacturing drivers.

Provision of the requested mid-range laser facilities will ensure that the currently buoyant and productive UK laser material processing research community will continue to provide world leading research and industrial technological solutions.

Comment from Professor Colin Webb, FRS**.**

Dear Professor Li,

As a former President of the UK Consortium for Photonics and Optics I led UK delegations to California and Germany to investigate how the governments of those states handled the transfer of technology from Universities and Research Institutes into Industry. It became apparent that we in the UK are woefully short of the financial backing - especially in the area of laser machining - that is available to those in our competitor nations. The sort of facility envisaged by the proposal by AILU is just the kind of initiative that will act as a stimulus to UK academe and Industry to collaborate to make best use of the undoubted talents for innovation that we in the UK still possess.

I wish you every success in this endeavour,

Colin Webb

Professor C E Webb MBE FRS

Who was involved in preparing this statement of need? Please list name, institution and research interests.

1. Professor Lin Li, Director, Laser Processing Research Centre (LPRC), Photon Science Institute (PSI), The University of Manchester. Research interests: *laser cutting, welding, drilling, surface engineering (surface cleaning, hardening, shock peening), rapid additive manufacturing and micro/nano fabrication and laser synthesis of nano materials, with applications in the aerospace, medical, renewable energy, automotive, construction and nuclear industries.*
2. Professor Stewart Williams, Director of Welding Research Centre, IMRC, Cranfield University. Research Interest: *laser processing, residual stress control, additive manufacture and armour alloy welding. The laser processing research is focussed on the use of high power and high beam quality fibre lasers in welding applications. These applications include micro welding, dissimilar material welding and hybrid welding where the laser is combined with an arc source.*
3. Professor Ken Watkins, Head of Laser Group, University of Liverpool. Research Interest: *Laser materials processing (cutting, welding, forming, powder deposition), laser ignition, laser direct writing, laser cleaning in microelectronics and art conservation, ultrafast laser processing, micromachining, optical tweezers, biomedical applications of lasers.*

4. Dr. W. O'Neil, Reader, IMRC, Cambridge University, Research Interest: *laser materials processing, ultra-fast laser micro processing*.

5. Professor Malcolm Gower, Imperial College. Research interest: *laser machining of sub-100nm structures*.

6. Dr. Janet Folkes, Senior Lecturer, IMRC, University of Nottingham, *Research interests*: *laser deposition, fibre laser welding, micro-machining*.

7. Professor Duc Pham, OBE, FREng, Director of Manufacturing Engineering Centre, Cardiff University. Relevant research interest: *micro-machining, rapid manufacturing*.

8. Professor Duncan Hand, IMRC, Heriot-Watt University. Research Interest: *laser micro-processing, fibre optics for high power lasers*.

9. Professor Peter Dyer, University of Hull. Research Interest: *ultrafast laser micro/nano fabrication. Fundamental beam/material interactions*.

10. Dr. Martin Sharp, Principal Lecturer, Leader of Photonics in Engineering Research Group, General Engineering Research Institute, Liverpool John Moores University. Research interests: *laser cutting, welding, deposition, micro-machining.*

11. Dr. Richard Hewitt, Warwick Manufacturing Group, University of Warwick. Research Interest: *high volume automotive parts remote laser welding.*

12. Dr. Jonathan Lawrence, Senior Lecturer, IMRC, Loughborough University. Research Interest: laser machining, laser processing of bio-materials.

13. Dr. Liang Hao, Lecturer, School of Engineering, Computing and Mathematics, University of Exeter, Research Interests: *Laser Materials Process, Selective Laser Sintering, Selective Laser Melting, Laser Consolidation*

14. Professor Philip Withers, FREng, School of Materials, The University of Manchester. Research Interest: laser shock peening, laser cutting, laser additive manufacturing.

15. Dr. Zengbo Wang, Lecturer, Laser Processing Research Centre, Photon Science Institute, The University of Manchester. Research interests: *laser micro/nano fabrication*, *far field super-resolution nano-photonics, metamaterials.*

16. Dr. Andrew Pinkerton, Research Fellow, Laser Processing Research Centre, School of Mechanical ,Aerospace and Civil Engineering, The University of Manchester. Research interests: *laser additive manufacturing and welding, modelling of laser processing processes*.

17. Dr. Paul Mativenga, Senior Lecturer, Manufacturing and Laser Processing Research Group, School of Mechanical ,Aerospace and Civil Engineering, The University of Manchester. Research interests: *laser micro/nano fabrication*, *surface cleaning and surface coating, hybrid laser/non-laser processing.*

18. Dr. M. Sheikh, Reader, Manufacturing and Laser Processing Research Group, School of Mechanical, Aerospace and Civil Engineering, The University of Manchester. Research interests: *laser cutting, laser forming, laser drilling, synthesis of nano wires and nano tubes, modelling of laser processing processes .*

19. Dr. Zhu Liu, Senior Lecturer, School of Materials, The University of Manchester. Research interests: *laser surface modification (cladding, alloying, coating), sysnthesis of nano materials (e.g. nano particles) cutting, laser forming, laser drilling, modelling of laser processing processes .*

20. Dr. Henry Tan, Lecturer, Manufacturing and Laser Processing Research Group, School of Mechanical, Aerospace and Civil Engineering, The University of Manchester. Research interests: *multi-scale modelling of ultra-fast laser interaction with materials.*

21. Professor Andrew Gale, Manufacturing and Laser Processing Research Group, School of Mechanical, Aerospace and Civil Engineering, The University of Manchester. Research interests: *applications of high power lasers in the construction industry and creative industry (arts).*

22. Dr. Patricia Scully, Senior Lecturer, Photon Science Institute and School of Chemical Engineering and Analytical Science, The University of Manchester. Research interests: *laser micro/nano fabrication of polymer devices for environmental, chemical and biological monitoring, for applications such as biofouling and scaling, algal growth. pH, particle concentration, turbidity, fluid flow, strain and water toxicity.*

23. Dr. Mark Dickinson, Senior Lecturer, Photon Science Institute and School of Physics and Astronomy, The University of Manchester. Research interests: *laser cavity designs and pumping schemes; laser Photomedicine, involving medical applications of new and established laser sources, from basic laser-tissue interaction science and diagnostics to clinical studies; non-linear optics involving the development of new nonlinear materials and their application on laser science.*

24. Dr. Tao Wang, School of Medicine, The University of Manchester. Relevant research interest: *laser surface engineering for controlled cell response in medical stents.*

25. Dr. Nick Goddard, Manchester Inter-disciplinary Bio-Centre. Research Interests: *laser micro-processing for microfluidic applications. Femtosecond laser machining to produce fine structures in hard materials for injection moulding of polymeric devices. master gratings in steel for moulded spectrometers, Also high rep rate femtosecond laser applications for Two-photon stereolithography, for production of high resolution polymeric devices with applications for direct production of diffractive optical elements.*

26. Dr. Michael Preuss, Senior Lecturer, School of Materials, The University of Manchester. Research Interest*: laser additive manufacturing, materials characterisation.*

27. Professor Hugh Devlin, Dental School, The University of Manchester. Relevant research interests: *laser drilling of teeth.*

28. Dr. Paul Hilton, The Welding Institute (TWI). Research interest*: high power laser welding, cutting and metal deposition (additive manufacturing)*

29. .Dr. Howard Snelling, University of Hull. Research Interest*: laser micro-processing and beam material interactions.*

30. Dr. Geoff Dearden, Reader, Laser Group, Liverpool University. Research interest*: laser micro-fabrication, laser forming and laser ignition.*

31. Dr. Paul French, Senior Lecturer, Photonics in Engineering Research Group, General Engineering Research Institute, Liverpool John Moores

University. Research interests: *laser drilling, metal deposition, micro-machining.*

32. Dr. Mohammed Naeem, GSI group. *Research Interests: laser drilling, laser welding and laser cutting*
33. Alan Boor, Swisstech, Research Interests*: laser manufacturing of medical stents. Laser based surface profiling techniques and drug delivery systems manufacture.*
34. Mr. Paul Glendenning, Micro Systems (UK) Ltd. Research Interest: *Micro-machining and surface nano-texturing of materials for micro moulds*.
35. Dr. K. Voicy, Lecturer, Lecturer, University of Nottingham, *Research interests*: *laser surfaced modification, laser drilling.*
36. Dr. Joel Segar, University of Nottingham, *Research interests*: *laser deposition, fibre laser welding, micro-machining*.
37. Mr. John Comer, Laser Moder Ltd, Research Interests*: high power laser materials processing.*
38. Dr. Jim Fielet, BOC Ltd., Research Interest: *laser micro-machining, welding, cutting and direct laser deposition and 3D component manufacturing.*
39. Dr. Martin Knowles, Oxford Lasers Ltd. Research Interest*: laser micro/nano-machining, system integration.*
40. Dr. Anna O'Neil, Taylor O'Neil Photonics Ltd, Research Interest*: Optics and laser design, laser micro-processing for medical device manufacture.*
41. Dr. John Powell, Laser Expertise Ltd., Research Interest*: high speed laser cutting.*
42. Professor W.M.Steen, Consultant, Research Interest*: lasers for ophthalmology*.
43. Dr. G.Verhoeghe, TWI, Research Interest: *laser micro/nano fabrication*.
44. Mr. Neil Main, Micrometric Ltd., Research Interest: *high power laser materials processing, micro materials processing*.
45. Dr. Albert Demargne, HIFLUX Ltd, Research Interest: *laser materials processing, additive manufacturing and micro-manufacturing*.
46. Mr. Andy Appleyard, SPI Lasers, Research Interest: *development of high power CW and pulsed lasers for industrial applications*.
47. *Mr*. Steve Ingram, TRUMPF (UK) Ltd. Research Interest*: applications of high power lasers in materials processing.*
48. Mr. Wulf Oppenlender, Swisstec Ltd. Research Interest*: Medical stent cutting, micro-machining with short pulse lasers.*
49. Mr. Roger O'Brien, ThyssenKrupp Tallent Ltd. Research Interest*: Automotive applications of lasers including remote laser welding, hybrid laser welding, laser welding of dissimilar materials and UHS steels.*
50. Dr. Chris Sutcliffe, Lecturer, University of Liverpool / MMT Technologies Ltd. Research Interest: *laser based additive manufacture technology and systems development.*
51. Mr. Jim Fife, Attica Components Ltd., Research Interest*: Special micro-cutting of metal tubes for medical applications.*
52. Dr. Sergei Popov, Royal Society Research Fellow, Imperial College and IPG Photonics. Research Interest: *Fibre lasers and systems, applications of*

high power lasers for rail cleaning, nuclear station decontamination/decommissioning, rapid prototyping and solar panel production.

53. Dr. Fuji Wang, Cranfield University. Research Interest*: Additive Manufacturing.*
54. Dr. Robert Scudamore, TWI, Research Interest: *laser materials processing including welding, surface engineering and additive manufacturing for aerospace and mechanical sectors and thick section materials.*
55. Dr. Suproyo Ganguly, Cranfield University, Research Interest*: development of laser welding processes and structural integrity of weldments for safety critical applications.*
56. Mr. Brook Ward, Europtics Ltd., Research Interest*: Use of high energy (>10 J per pulse) lasers for shock peening.*
57. Dr. Steve Curran, Smith and Nephew plc., Research Interest*: Laser applications in healthcare.*
58. Dr. Simon Dixon, Biomer Technology Ltd., Research Interest*: Manufacture of biomedical polymers.*
59. Mr. Paul Corscadden, CML Group Ltd., Research Interest: *laser manufacture of composite components*.
60. Mr. John Adamson, JP Imaging Ltd., Research Interests: *Production and processing of active coated metal sheets*.
61. Dr. Jeff Allen, Process Owner - Near Net Shape Powder Applications, Rolls-Royce plc, Research Interest: *Laser direct metal deposition for repair and rapid manufacturing of aero-engine components*.
62. Mr Steve Beecher, GE Aviation Systems Aerostructures Hamble, Research Interest: laser processing for aerospace applications.
63. Mr. Jean-Paul Gaufillet, Director, Irepa Laser. Research Interest : *laser materials processing*.
64. Dr. Craig Bratt, Manager of Laser Division, Fraunhofer Centre for Coatings and Laser Applications. Research Interest. *Laser surface engineering*.
65. Johannes Ulrich, Manager, Finn-Power Oy, Research Interest: *high speed laser cutting*
66. Mr. John Cocker, Director, Laser Trader Ltd., Research Interest: *high speed laser cutting, laser additive manufacturing and micro-machining*.
67. Mr. Grant Bennett, Electro Scientific Industries Europe Ltd, Research Interest : performance of ultrafast pulsed lasers on a variety of material types. With the information gathered and from our experience of manufacturing high tech laser based systems we could start to produce systems our customer base is beginning to request.
68. Dr. Nadeem Rizvi, Managing Director, Laser Micromachining Ltd. Research Interest: *R&D into materials processing for ultra-high precision material structuring*.
69. Mr R A Ford*,* Integrated Materials Technology Ltd, Research Interest: *Materials and process technology for composite materials and structures manufacturing.*
70. *Mr.* Paul Harrison*,* Powerlase Ltd*,* Research Interest: *High speed thin film selective removal for flat screen display manufacture.*

71. Dr. Alan Thompson, Head of Welding, Swinden Technology Centre, Corus UK, Rotherham, Research Interests: *Laser welding, cutting, surface treatment and cladding*.

72. Mr John Savage, GE Aviation Systems Aerostructures Hamble, Research Interest: *laser processing of composite materials*.

73. Dr Jay Vaja, Head of Joining Processes, AWE, Aldermaston, Research interests: *laser welding, microwelding, surface treatments*

74. Dr Simon Gardiner, Head of Metallic Manufacturing Technology Research, Airbus UK, Filtlon, Bristol, Research Interests: l*aser welding, cutting and shock peening.*

75. Mr. Clive Crafton-Reed, Global Process Owner – Laser Processes, Rolls-Royce plc. Research interest: *laser cleaning, laser cutting, laser welding, laser drilling and powder deposition for aerospace applications*.