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ABSTRACT

Over 100 firms in the UK are active in laser and related opto-electronic technologies. About one tenth of these are involved in manufacturing complete lasers or laser systems for industrial applications. Published work in materials-processing has primarily involved Nd-YAG and CO_2 lasers; illustrative examples are the trepanning of cooling holes, and the cladding of components, for the aerospace industry. Fibre-optics and data-transmission form another important growth area. Work at Culham has ranged from the single-pass welding of steels having thicknesses up to 25mm to the development of on-line two-dimensional laser beam monitoring (for quality assurance), and computer-controlled equipment. Our own experience, together with that reported elsewhere, is used to essay a 'forward-look' on possible market developments and trends in technology transfer.

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The British Laser Industry

The main specialization of firms tabulated in a selection of trade guides as being actively involved in laser technology are listed in Table 1. Column (i) sums the principle laser-related activity claimed by each company, and column (ii) the number of companies claiming to work (at least to some degree) under each heading.

Table 1 (Principal activities within UK)

	(i)	(ii)
Laser Manufacturer	9	9
Laser Systems Manufacturer	10	15
Optics and Coatings	29	31
Associated Equipment (modulators, detectors etc.)	20	27
Fibre Optics Equipment	18	19
Sales Agents	11	22
	97	-

The list includes three commercial off-shoots from University departments, some foreign-owned subsidiaries (manufacturing in the UK), and various companies specializing in military markets (which will not be discussed in this paper). Total industrial activity is certainly larger than this list suggests (particularly in fibre optics communications): for example firms such as Desitech supplying turn-key laser-based XY tables and FLS (robotic systems) were not included in the tabulations used as the source material for Table 1, and a few contract R&D organisations working in the industrial laser field, (including ourselves) have also been omitted.

Lasers manufactured commercially within the UK span a wavelength range from the ultraviolet to the far infrared. They include excimer; copper vapour; He-Ne; ion; L.E.D.; Nd-YAG; tunable diode; waveguide, TEA, sealed-tube slow/fast axial-flow, and transverse-flow CO_2 systems. (Academic research is also broadly based, and includes work on free electron lasers. The SERC Central Laser Facility at the Rutherford Appleton Laboratory acts as a focal point for Universities interested in very high intensity multiterawatt laser beams, the generation of ultra-dense plasmas, and related studies on non-linear interactions with matter etc.)

Industrial Applications

The lasers listed above are finding an increasing and diverse range of industrial applications which include: alignment, metrology, quality assurance (e.g. detection of surface flaws on paper and similar materials), non-destructive testing, pollution-monitoring and laser Doppler anemometry. However, in market terms perhaps the most significant areas are associated with information technology and laser materials-processing in the electronic, printing, manufacturing/engineering and related industries. The following section concentrates on the last area, and in particular on topics with which we are most familiar at Culham.

Materials Processing at Culham

A range of commercially available axial-flow CO_2 lasers are normally used for machining or welding non-metals and steels up to a few mm thick. For work at higher powers continuously-rated multikilowatt transverse-flow CO_2 lasers have been developed. Four industrially-rated 5kW (CL5) units have been run routinely on a single-shift basis - with a cumulative life exceeding 15,000 hours. At full power, not less than 80% of the beam can be focused into an f/4 spot diameter of 0.3mm. On-line measurements of the (two-dimensional) radial intensity distribution at a range of axial positions are available using a beam-scanning quality assurance unit. This prototype unit has an insertion loss of a few percent and data is available from its pyroelectric detector within 2 secs; a microprocessor then deconvolves and displays this information on a VDU for on-line laser or process control. One of these CL5 lasers has been installed at Springfields Nuclear Laboratory. Two others have recently been combined at Culham to provide an industrially-rated 10kW (CL10) laser. Typical single-pass autogeneous mild-steel welding speeds achieved with the CL5 and CL10 lasers at Culham are shown in Fig. 1. Whilst aerodynamic windows are not always essential on these systems, one has been fully developed for use on CL10. Lasers have proved to be very flexible processing tools. They have been reliably routed by mirrors over distances of tens of metres to a number of separate workstations, on demand. They can weld or cut components whilst others are loaded for an entirely different process at an adjacent workstation. When the inherently high processing speed of the laser is combined with efficient beam utilisation in this way, one achieves the high production capacity required of a fully-automated and flexible manufacturing system (FMS). If the workpiece is three-dimensional it may prove more convenient to couple the stationary laser to the work by means of a flexible beam guide, in which all the mirrors remain automatically in alignment. We have successfully operated such systems with power capacities up to 1kW, with and without robotic control of the head, (Fig. 2). Such systems are scalable to powers of many kW.

Typical sub-kilowatt laser cutting applications include disassembling radio-active fast-reactor fuel subassemblies at Dounreay N.P.D.E.; and the mass production of a novel (contoured) security thread using microprocessor control techniques for the new £50 bank note recently introduced by the Bank of England. For both cutting and welding it is not simply laser power but mode quality and stability which is important. For example, single-pass, autogeneous welds in materials as thick as 25mm steel and 16mm titanium have been made over the past year with the CL10 system. Such welds have low distortion and shrinkage and the process is, of course, achieved out-of-vacuum at high speed. Adequate process control can ensure weld closures on circular components with high integrity and reproducibility. Conventional filler-wire equipment has been used successfully on components having poor fit-up. Multikilowatt systems such as CL5 can also heat-treat at rates of $\sim$ 30-500mm^2 s^{-1}, depending on the case depth and material of interest. Scanning electron micrographs reveal marked differences in wear scars for different treatments. Hard facing has been undertaken using both powder and wire feed. At an incident power of 5kW material wastage during application is low; surface roughness of dense, hard, well-bonded stellite layers on stainless steel is typically $\leq$ 0.1mm about the mean height.

Development of the Laser Market

High technology markets such as this, with a broad range of existing and potential applications, are more difficult to quantify than, for example, the market for soap! However, an indication of possible growth areas can be obtained from a look at products now being sold and developed. We will therefore summarize a few comments from various UK laser manufacturers, in order to provide a 'snap-shot' of current trends.

Ferranti plc. have been working with CO_2 lasers since the early 1960's and have sold several hundred MF400 (400W slow axial flow) lasers throughout the world. The latest additions to the range are their MFK (1kW) laser, plus the fast-transverse flow CL5 (5kW) and CL10 (10kW) lasers developed at Culham. Other possible extensions to this range are being planned, based on work at the UK Welding Institute. On the applications side they are currently engaged on the integration of lasers and robotics in collaboration with the UKAEA.

Control Lasers are manufacturing, and further developing, fast-axial-flow multikilowatt cw CO_2 lasers of a type initially marketed in the UK by British Oxygen. Control Lasers have a track record in the supply of 5-axis systems for cutting 3-D objects, based on their 2kW laser design.

Electrox Ltd have expanded their range of fast-axial-flow CO_2 lasers by the recent introduction of their M1000 1kW laser, a scaled up version of their existing 450W device. Its operation is compatible with computer control and includes full 0-1kW adjustability, and pulsed mode at up to 2.5kHz. The device is packaged within a single integrated unit for easy installation and maintenance. Electrox see applications in both high speed cutting and welding.
JK Lasers have specialised for many years in Nd-YAG-related lasers for scientific applications (e.g. pico-second studies in chemistry and photobiology), and in the provision of automated systems for fine-scale industrial cutting or drilling. A turn-key CNC 5-axis system has, for example, recently been supplied for trepanning cooling holes in aeroengine components. Their merger with Lumonics Ltd of Canada has given both companies access to wider markets and complimentary technologies.

Scientifica-Cook Ltd manufacture a wide range of He-Ne lasers with output powers from 1mW to 40mW. They have recently introduced their latest industrial laser-alignment systems (LM-10 and RB-10) for both linear and plane x-y alignment and also a unique eye-testing instrument (LASERSPEC), based on the speckle effect, suitable for rapid eye test in schools, hospitals and industry etc.

Edinburgh Instruments, who manufacture high-stability low-power cw gas lasers, were started by staff from Heriot-Watt University. They have recently developed a range of radio-frequency excited waveguide CO_2 lasers in a major Scottish collaboration with Ferranti. These compact lasers are sealed devices with guaranteed operating lifetime per gas-fill in excess of 2,500 hours and are already finding numerous applications in industry, medicine and research. The output power range now extends to 15W, with higher power models in an advanced state of pre-production prototype testing.

Laser Applications Ltd, an off-shoot from Hull University, manufacture a range of cw and pulsed gas lasers for both research and industrial applications, including high average power 200Hz devices and single shot systems up to 50J per pulse. Recently developed is a continuously tunable high-pressure CO_2 laser producing single mode, 250mJ, 50ns pulses at 10Hz. They also offer a variety of RF excited waveguide CO_2 lasers and claim the highest powers per unit length available for such devices.

Oxford Lasers, another university associated company, manufactures a range of UV and visible pulsed gas lasers. They have recently announced that, with minor modifications, their Cu25 (5kHz, 25W) copper-vapour laser can be operated as a gold laser giving 9 watts at 627.8nm and that a 20kHz option is also available, giving 10W with Cu-vapour. The output of their rare-gas halide laser KX1 has now been increased to 350mJ pulse energy in KrF and a modified version of this device can now give 30mJ per pulse on the vacuum UV (158nm) transition of F_2 - claimed to be the highest energy available at this wavelength.

Conclusion

Within both the UK and other EEC countries there is now an impressive range of laser technology available. It seems probable that the market will be expanded more by innovative development of novel turn-key industrial systems than by the mere duplication of laser suppliers around Europe.

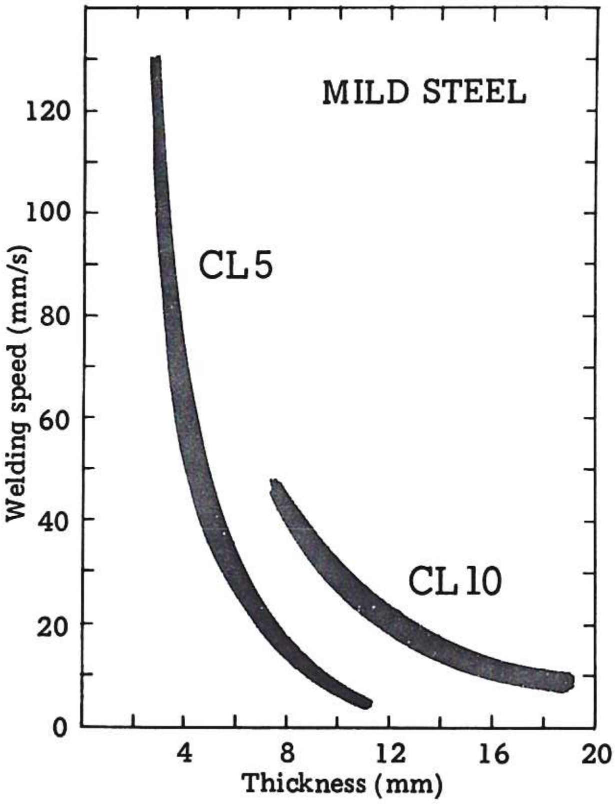

Fig.1 Illustrative welding speeds *vs.* thickness for the Culham 5 & 10kW (modular) laser system.

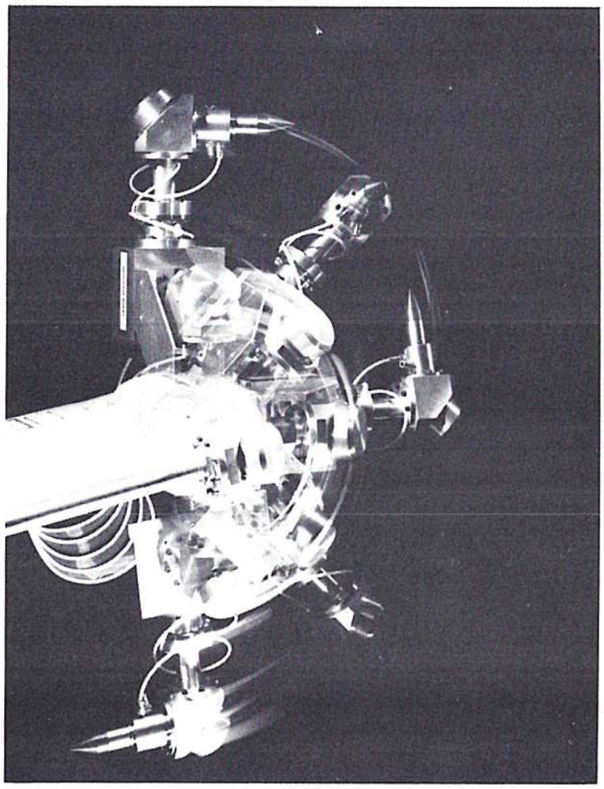

Fig.2 5-axis 1kW laser beam guide, coupled to an ASEA industrial robot. Overlapping camera shots demonstrate the flexibility of the system for 3D machining. (FLS Ltd.).

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