Lasers at the cutting edge

Roy Szweda

Diode lasers are undoubtedly the strongest market segment in optoelectronics. Expansion is occurring not only via new applications such as DVD but also by capturing market share from non-diode lasers and even LEDs. The field is diverse and growing all the time so this article has to pick from the spectrum highlighting the commercial prospects in such areas as high power lasers, VCSELs and blue lasers.

The pace of development of diode lasers is such that one could possibly devote an entire magazine specifically to the subject. Herein, key technologies having strongest commercial importance are covered. According to the Reed Electronics Research report, *Strategic Study of the Worldwide Semiconductor Optoelectronic Components Industry*, the market for diode lasers has already eclipsed that for all other types of laser combined. As we reported last year *(III-Vs Review, Vol. 11, No. 6)* high power diode lasers (HPDL) are progressively supplanting traditional gas lasers, to the tune of $382 million to $330 million respectively, see Figure 1. Typifying the market evolution of laser diodes overall, these devices are also forging new applications.

HPDLs

Initially, HPDLs achieved market success in the diode pumping of solid state lasers (SSLs) and also in surgery. There is an important distinction here - the market is divided between "direct diode" lasers and "diode pumped" lasers. Direct diode HPDLs are rapidly penetrating other areas and creating new applications in their own right. The HPDL marketplace has steadily broadened as the cost per watt/cm^2 has come down from around $2000 per watt under a decade ago. As a result of the growing marketplace coupled with further investment by major players, HPDLs are now being mass produced, leading to further price erosion. At present, the price per watt is of the order of $100 for some applications or even below $30 for volume orders.

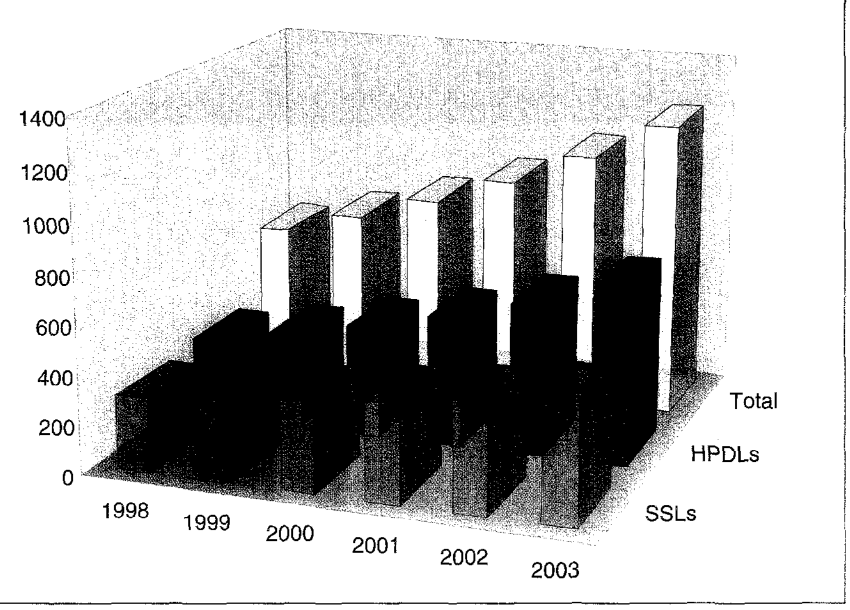

Figure 1. High power diode lasers are progressively supplanting traditional gas lasers, to the tune of $382 million to $330 million, respectively (Reed Electronics Research, see: www.rer.co.uk).

The market is growing strongly but this is due in large part to being only a few years old. Basically, there are two directions: the replacement of traditional process such as those based on SSLs and gas welding and the many new applications opening up where an SSL would be less convenient and too costly. These applications include PCB soldering and dentistry, etc.

Roland Diehl of the Freiburg Fraunhofer Institute is project coordinator for the NOVALAS program. He puts it this way: "SSL diode pumping used to be costly but has fallen to 1.5 times the price of a flash-lamp. Users are coming around to thinking less of the capital investment and more of the cost-of-ownership. The key factor is the lower maintenance over the expected life of the laser unit. Moreover, beam quality from a diode pumped laser is better than that from a flash-lamp pumped laser. There is much less of a thermal lens effect: only a fraction of the light from the flash lamp is absorbed, the rest is heating up of the laser rod generating a thermal, and hence a refractive index, gradient that forms a lens causing distortion in laser output which deteriorates the beam quality. Moreover, it is possible to match the absorption lines of the SSL material with a diode pump which cannot be achieved with a flash-lamp".

For the majority of HPDL applications the most popular wavelength region is 810 nm but other wavelengths are now becoming important with the rise of ophthalmic and cosmetic/aesthetic applications together with photo-

0961-1290/99/$ - see front matter

dynamic therapy (PDT). According to Cambridge, UK, based company Diomed Ltd., PDT is a relatively new area which was created by SSLs and is now moving over to the convenience of HPDL. "This application is not using the diodes for their power but rather for their precision of wavelength control. It is a question of stability of power. For example, at 630 nm this must hold 3 W over +/- 3 nm for maximum coupling with the chemical agent."

Overall, the HPDL device leaders are in the US: Opto Power Corp., for example, specialises in fibre-coupled laser modules and open arrays. "With these products we have entered a new era", says Opto Power Corp. "We have demonstrated surface hardening and drilling of stainless steel ribbon, for example, as well as solid freeform fabrications via sintering with metal and ceramic powders using fibre-delivered diode power". These demonstrations indicate that many additional applications including cutting, soldering, marking, printing, welding and coating can be performed by currently available commercial diode lasers when energy is coupled to achieve high brightness spots.

In Europe, the leading manufacturer of laser die is Osram Optoelectronics (formerly Siemens). Development is focused on the "standard" wavelengths 810 nm and 940 nm with provisions to be made for large-volume production. This will cut the watt price of diode laser power photons even further. The long-lifetime HPDL (20 kh @ 810 nm and more than 40 kh @ 940 nm, both @ 40 W CW per 1 cm bar @ 22°C) are purchased by many systems companies worldwide. One company working with Osram is DILAS which builds high output, ca. 4 kW, laser stacks. These are used by, for example, machining systems companies for welding and hardening in car factories and elsewhere. Most recently, DILAS and the Fraunhofer Institute of Laser Technology (ILT) of Aachen have demonstrated deep penetration welding with a multi-kW diode laser (see Figure 2). So far only heat conduction welding of metal sheets was feasible with direct diode radiation. This opens up new horizons for direct diode applications in materials processing.

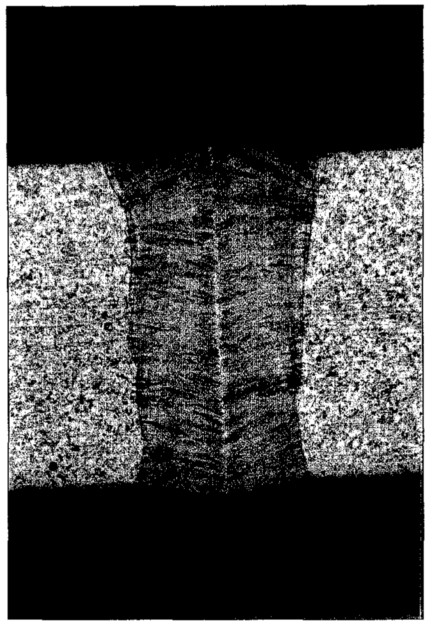

Figure 2. DILAS and the Fraunhofer Institute of Laser Technology (ILT) of Aachen have demonstrated deep penetration welding with a multi-kW diode laser.

And the race is on for even higher direct diode power. The 240 W of CW optical power from a 1 cm diode laser bar at a drive current of 240 A (930 nm, 70% fill factor, 20°C) achieved by Opto Power Corp. was recently surpassed by 267 W CW, also obtained from a 1 cm bar, at a drive current of 280 A (980 nm, 50% fill factor, 22°C) demonstrated by the Freiburg Fraunhofer Institute of Applied Solid-State physics (IAF). Although lifetime is reduced at such high laser powers the results nevertheless show what can be expected from the tiny laser chips.

As these high output powers are emitted from broad-area diode lasers, the respective beam quality of the bars and stacks is low thus making high power densities difficult to achieve. To generate near diffraction-limited high-brightness laser beams diode laser geometries have to be modified. One possibility is to use tapered amplifiers. Fraunhofer IAF is following this route having developed a monolithic bar of 25 tapered diode lasers emitting 28 W @ 940 nm with a 2.7 times diffraction-limited beam with an electro-optical efficiency of 35%. Stacks made of such bars are expected to deliver very high power densities in conjunction with simple micro-optics.

It is something of an over-generalisation that Japan, long a leader in laser diode technology and products, has fallen behind in the HPDL arena. However, one company which already has product on the market is Sony with a range of stand-alones spanning 1 to 6 W plus arrays capable of 20 W.

VCSELs

The VCSEL business has become established in an unusually short time for an optoelectronic component. Honeywell was the first to introduce a commercial VCSEL product in 1997 but the first demonstration of a VCSEL, albeit an electrically-pumped variant, was in 1989 at AT&T Bell Labs. Interestingly, it was Professor Iga, a Japanese scientist, who first predicted the theoretical basis of the VCSEL even though the Japanese companies which are leaders in other laser diode commercialisation are not as yet the leaders in the VCSEL area.

The popular edge emitting laser requires the manufacturer to cleave the process wafer into chips and then package the chip before testing. Conversely, the VCSEL can be tested on-wafer prior to chipping and packaging. This means lower costs and better understanding of device manufacture by virtue of the compatibility with standard automated silicon equipment and practices which are relatively inexpensive. VCSELs have come along way in only a short time, which means that they are by no means mature devices;

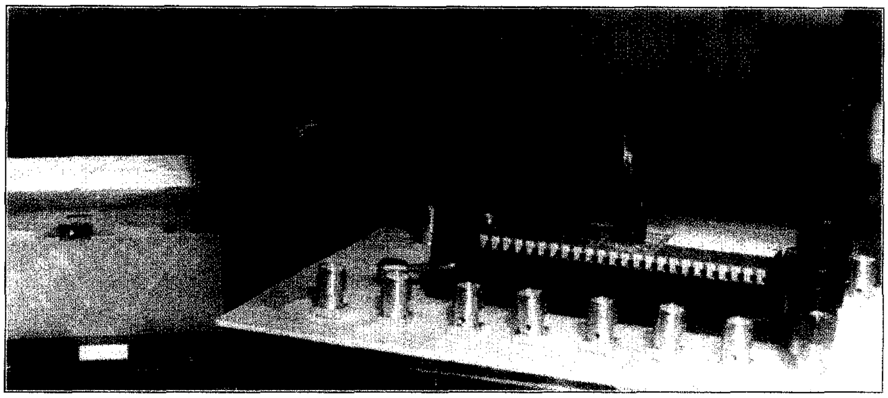

Figure 3. The BREDSELS VCSEL module which will become the basis of a cheap, rugged and high data-rate optical interconnect system designed to operate at the attenuation minimum of low cost plastic fibre.

challenges still lie ahead but the consensus is that these are largely technical in nature and therefore deemed to be soluble.

There are two distinct market application sectors for VCSELs: high speed data communication and a wide variety of sensor applications. The latter topic is included in the article on sensors also featured in this issue (pages 38-41). VCSELs are already big business; their simplicity allied to good performance threatens not only edge-emitting LDs but also LEDs. The simplicity of VCSELs, however, is dependent on major R&D investment, particularly in MOVPE.

Mike Scott, Technical Director of IQE plc points out "MOVPE production of VCSELs relies on precise layer thickness control. As an example, an AlGaAs edge-emitter requires a precision of +/-10%. VCSELs on the other hand need much better than 1%. An 840 nm VCSEL therefore requires a precision of +/-8 nm in the lasing wavelength. We are now able to specify down to +/-3 nm, in other words, +/- 0.3%. We have achieved this only after some pretty intensive R&D. As a result, VCSELs now make up about 15% of our business plus we have been able to improve our capabilities in other areas of devices such as LEDs and detectors."

The more straightforward processes of VCSEL lasers mean that 2D arrays can also be made. Applications for 2D VCSEL arrays include printers, datacomms and even for diode pumping of SSLs. In the UK, a project called BREDSELs standing for "Bright-RED Surface Emitting Lasers", has been underway in order to capitalise on the intrinsic high speed, planar geometry and almost ideal beam profile of the VCSEL coupled with the low cost of plastic fibre to produce a very low cost, high data rate (> 1 Gbit/s) distribution system.

Jon Woodhead of the SERC III-V Facility at the University of Sheffield, one of the partners in the BREDSEL programme told TFR: "Our program has aimed to solve the technological difficulties preventing the fabrication of efficient, high power AlGaInP-based visible VCSEL arrays. We have made a 1 × 8 VCSEL array lasing at 650 nm which is coupled, in a self-aligning fashion, to a multimode plastic-fibre ribbon" (see Figure 3).

"Recently, our understanding of what is limiting the thermal properties of the devices has greatly improved and we now have a new batch of designs being grown. Also, we have begun device lifetime tests at Uniphase: already we have achieved 1000 hours with minimal degradation".

IQE plc has been responsible for the growth of the epiwafers showing that the extra uniformity and reproducibility of multi-wafer reactors is crucial to getting high quality growth. "Although this can makes the research expensive," comments Jon, "it means that when the design is correct there is an immediate route to commercial quantities of material."

Another very interesting development area which exploits some of the special characteristics of the VCSEL is the monolithic integration of this type of laser with microelectronic circuitry. This includes not only compound semiconductors but also silicon circuits such as logic and analog. For instance, Sandia NL has been prototyping monolithically integrated VCSELs and microelectromechanical structures (MEMS) to create a "lab on a chip". CoreTek, a Massachusetts based company, recently announced the prototype of a tunable 1.55 micron laser for dense wavelength division multiplex (DWDM), said to be the first commercial device of this kind. It combines a MEMS top mirror which can be moved and thereby change the cavity length and thereby the emitted wavelength. Moreover, it uses a single, simple voltage tuning circuit with virtually no power consumption, making it continuously tunable over 30 nm. These devices are targeted at the metropolitan and long-haul DWDM and other telecom applications such as optical cross-connect and test and measurement and measurement.

VCSELs have now also entered the arena of high-power applications. Researchers at the University of Ulm have demonstrated output powers in excess of 100 mW per single device. By the end of 2000 they will have achieved 300 mW from one VCSEL and 2 W from a VCSEL array. However, this radiation is multimode and and hence of low beam quality. Far higher beam qualities are expected from coherent coupling of single-mode VCSELs that emit 1 to 2 mW per device. Researchers of the Laser Centre of Stuttgart have successfully developed the coupling technology for large arrays and are now aiming at coupling several thousand VCSELs to a single beam with a diffraction-limited Gaussian profile.

Blue lasers

No LD overview would be complete without an update on blue lasers. This year will be remembered for the debut of commercial samples of blue LDs.

It has been a pair of German companies, PicoQuant GmbH of Berlin and TuiOptics GmbH of Martinsried/Munich, which have announced the first products based on the Nichia blue LDs.

Time-resolved fluorescence spectroscopy is based on nanosecond timeframe fluorescent decay processes, requiring a light source capable of providing 100 ps pulses. These were previously reliant on traditional lasers such as frequency-doubled dye lasers, which are not only inefficient and bulky but also very costly. At first PicoQuant adapted blue/green Nichia LEDs and these worked fairly well but had limited capability as regards pulse generation. Switching to the Nichia blue LD enabled PicoQuant to create an instrument that is both economic and compact with a pulse peak power of up to 400 mW.

On the other hand TuiOptics had a need for a tunable blue laser for applications in plasma physics such as monitoring fusion experiments. With the help of the Nichia blue LD it has built an instrument which is lower-cost and more compact than earlier models. The DL-100 shows short pulse duration at a high repetition rate with high pulse power or true single frequency, and tunable or frequency-stabilized performance with an unmatched amplitude stability. There are many other less exotic applications for such an instrument, according to TuiOptics. Examples include trace analysis and atomic absorption spectroscopy.

It is likely that other companies will soon be looking to utilise the particular advantages of semiconductor blue LDs and we will see a steady replacement of existing sources such as HeNe gas lasers. LDs feature highly stable amplitude unmatched by conventional light sources, making blue LDs attractive for use in imaging, microscopy and printing.

Laser Futures

Whilst the blue laser has the highest media profile, its commercial impact seems to be over a longer term compared to other types. VCSEL, visible-blue and HP diode lasers are amongst the top runners as regards today's commercially significant devices. Collectively, these represent over one-half of the $2.3 bn laser diode market in 1999 - the other half comprises mainly IRLDs for fibre optics and CDROMs, etc. According to Reed Electronics Research, the market will have grown to over US$4 bn by 2004. Diode lasers will achieve this success by edging out existing technologies but most importantly through innovative new designs.