e-Newsletter n°5

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Available at http://www.ist-brighter.eu

WWW.BRIGHTER.EU

World Wide Welfare: High-Brightness Semiconductor Lasers for Generic Use

WWW.BRIGHTER.EU is an integrated project supported by the European Commission's Information Society Technologies programme

CONTENT

EDITORIAL

Welcome to the 5th e-Newsletter of the 3 year integrated project WWW.BRIGHTER.EU, which began in October 2006. This integrated project builds upon the earlier WWW.BRIGHT.EU project, in which we published our first series of e-Newsletters.

If you missed either of the previous four editions of our e-Newsletter, then please visit our website to download your copy. The next e-Newsletter will be published in September 2009.

We hope you will enjoy reading this e-Newsletter and learning about the latest developments in our project.

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GREETINGS FROM THE PROJECT COORDINATOR

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Dear Reader,

Welcome to the fifth e-Newsletter of our EC-IST Project ***World Wide Welfare: High-Brightness Semiconductor Lasers for Generic Use (WWW.BRIGHTER.EU)***, an Integrated Project on high-brightness laser diode technologies and applications, which began in October 2006.

Since our last e-Newsletter, we've again been making great strides forward towards our final project objectives and the time ahead promises to be an exciting one. Our recent highlights include: a 12 W narrow linewidth 1060 nm tapered laser with an internal distributed Bragg reflector; 1.5 W of green emission from a frequency-doubled infrared laser diode; 0.5 W red-emitting tapered lasers with twin-contacts suitable for direct modulation in laser displays; 1060 nm tapered lasers operating at 1 Gbps with 0.95 W of modulated power, and a very low current drive of 68 mA; and 975 nm telecom pump modules with coupled output powers of 50 W and 12 W in 50 micron fibres with numerical apertures of 0.22 and 0.13, respectively.

Inside this e-Newsletter, you will find an update on some of our latest achievements followed by profiles of four more of our project partners. There are also four extended articles in this e-Newsletter. Two applications articles cover the topics of cladding-pumped WDM amplification and single mode and multimode fibre coupled high-brightness laser diode modules. Technical papers are presented on wavelength tuning of laser diodes by pressure and temperature and also on red lasers for medical applications. There is also a report on the Consortiums' involvement in the European Commissions' ICT Event, which was held in Lyon in November. Details are also given about our Project Film Clip, which is now available to view on our website. At the end of this edition, you can find details of some of our recent publications, a calendar of forthcoming events, a preview of the next e-Newsletter and details of some events organised or supported by our Consortium. These include the 4th International Graduate Summer School, Biophotonics '09, which is to be held in June and is organised by our partners from the Technical University of Denmark and Lund University, Sweden and a meeting dedicated to High Power Diode Lasers and Systems, which is to be held during the Photonex '09 exhibition in October in Coventry, U.K.

Michel Krakowski

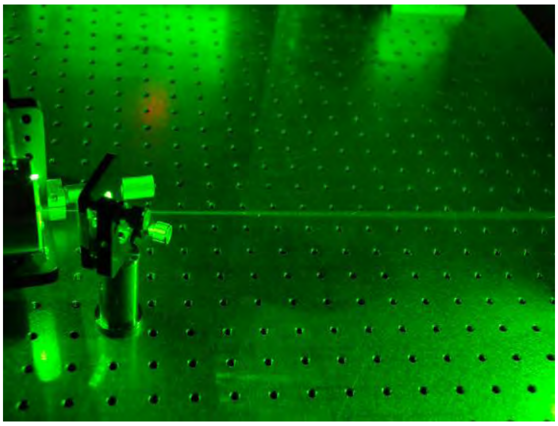
TECHNICAL ACHIEVEMENTS

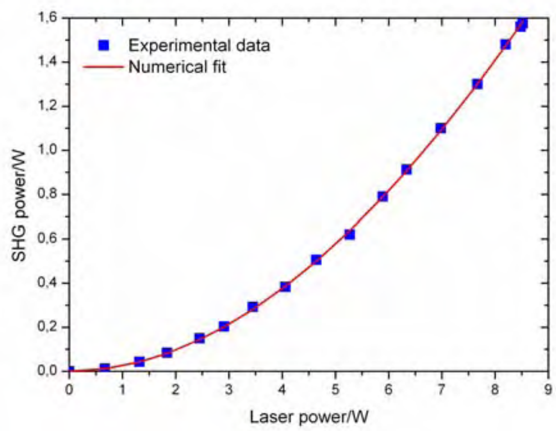
Towards the Project Objectives

The BRIGHTER Project Consortium continues to be successful across the broad range of areas in the project. Here, we present the latest news and briefly review some of the highlights of our recent results.

More than 1.5 W SHG output at 531 nm

DTU Fotonik has demonstrated a compact and robust high-power green laser system based on an infrared diode laser and second harmonic generation (SHG). More than 1.5 W of output power at a wavelength of 531 nm has been achieved by single-pass SHG of a 1062 nm high power multi-section DBR tapered diode laser from the Ferdinand Braun Institute. By modulating the current to the ridge section of the laser, it is possible to modulate the green light at high speed making it ideal as a compact, robust and efficient green light source for display applications.

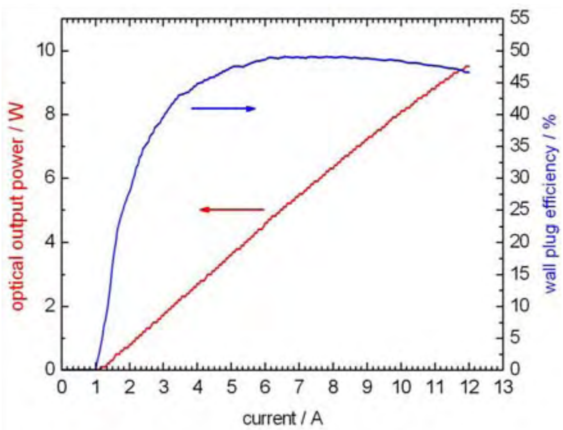




O.B. Jensen et al., Opt. Express Vol. 17, pp. 6532-39, April 2009.

1064 nm frequency stabilised amplifier

The realisation of a compact green-emitting solid state laser source is still a challenging task. One way to generate green light with a solid state laser source is the frequency-doubling of light at 1064 nm to 532 nm. In order to achieve good conversion efficiencies, tunable laser sources with output powers of several watts, narrow bandwidth and good beam quality are required. At the Fraunhofer IAF, tapered laser diodes, emitting at a central wavelength of 1064 nm, have been realised. These devices have an AR-coating on the front facet as well as on the ridge facet. Therefore, these laser diodes can be frequency stabilised in an external cavity setup consisting either of a grating in the Littrow configuration on the rear side or by an integrated Fibre Bragg Grating (FBG). The latter configuration allows the low footprint integration of the laser diodes into compact laser modules. The optical output power of these devices, frequency stabilised at 1064 nm, exceeds 4 W with beam qualities suitable for frequency doubling ($M^2 < 2$) and a tuning range from 1030 nm to 1070 nm. For laser diodes with a HR coating on the ridge facet, even higher output powers of more than 10 W have been achieved. The ridge and tapered section of the devices are contacted separately, so that the light source can be modulated by relatively small variations of the ridge current.



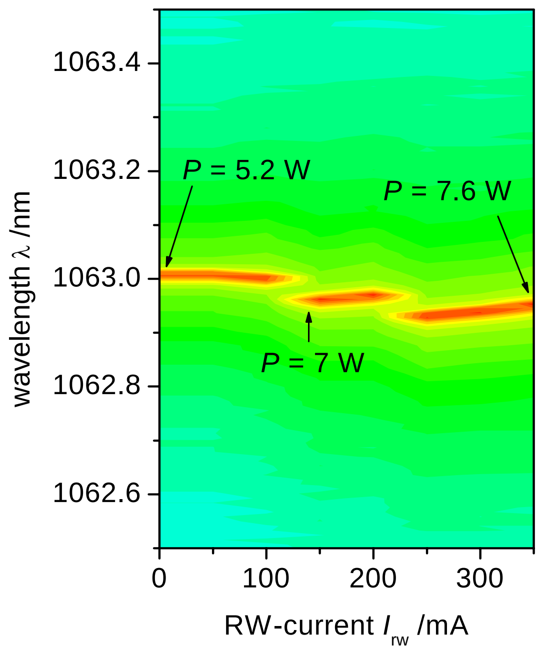
Output characteristics of a tapered laser emitting at a central wavelength of 1064 nm. The taper and RW sections are 3.0 mm & 0.5 mm, respectively. The M² value is 2.2 at a power of 9 W.

R. Ostendorf et al., Proc. SPIE Vol. 7198, February 2009.

TECHNICAL ACHIEVEMENTS
Towards the Project Objectives

12 W narrow linewidth 1060 nm tapered lasers

The Ferdinand-Braun-Institut für Höchstfrequenztechnik have realised high-brightness narrow linewidth 1060 nm tapered lasers with an internal distributed Bragg reflector. The vertical structure of this laser is based on an InGaAs triple quantum well active region embedded in an AlGaAs super large optical cavity and leads to a narrow FWHM vertical divergence of 15º. Tapered devices with a total length of 6 mm (consisting of 2 mm long ridge waveguide including a 1 mm DBR mirror and a 4 mm tapered section) and a full taper angle of 6º have been fabricated, where the input currents to both sections can be independently controlled. The devices have achieved a maximum output power of 12 W with a narrow spectral linewidth of below 40 pm. A nearly diffraction limited beam quality was measured up to a power of 10 W. These devices had a conversion efficiency of about 50% and a first reliability test showed failure-free operation at 5 W without any deterioration of the beam quality and spectral properties.

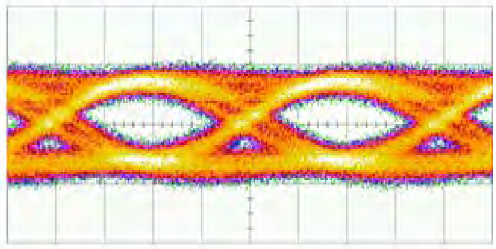


Spectral map of the 1060 nm DBR tapered laser at constant taper current I = 12 A and T = 25°C when changing the ridge waveguide current from 0 mA to 350 mA. As the output power changes, the wavelength remains stable within 0.1 nm. The small shift can be attributed to the decreased self-heating of the laser due to the increase of the optical output power. The colour scale ranges from blue (lowest intensity) to red (highest intensity).

B. Sumpf et al., Proc. SPIE Vol. 7230, February 2009.

High modulation efficiency and high-power 1060 nm tapered lasers

High-brightness diode lasers at 1060 nm with separate electrodes have been realised by III-V Lab, in which the ridge and tapered sections are biased separately. In this configuration, the current through the ridge section is only a few tens of mA, while the current on the tapered section is kept constant at several Amps. By moving the ridge current by only a few tens tens of mA, it is possible to obtain a high modulation of the output power. This is very useful in applications such as free space optical communications and display applications, where a high-power (>1 W) needs to be modulated at high-speed with a low current drive (<100 mA). In the last e-Newsletter (November 2008), high speed operation at 700 Mbps was reported. More recently, operation at 1 Gbps was demonstrated by the University of Cambridge, with 0.95 W of modulated power and a very low current drive of 68 mA. This will be presented by the III-V Lab and University of Cambridge teams at the next CLEO Conference, to be held in Baltimore, Maryland, USA, from 31st May to 6th June. New geometries are also under evaluation in order to achieve a higher modulated power (>1 W) at 1 Gbps with an extinction ratio of 5 to 10 dB.



Open eye diagram at 1 Gbps, 0.95 W modulated power with 68 mA drive current amplitude (measured at the University of Cambridge).

N. Michel et al., Electron. Lett. 45, p. 103, Jan. 2009.
M. Ruiz et al., Proc. SPIE Vol. 7230, February 2009.

<u>To be presented at CLEO Conference 2009</u>
M. Ruiz et al., presentation CWF4, 3rd June 2009.
C.H. Kwok et al., presentation CThB2, 4th June 2009.

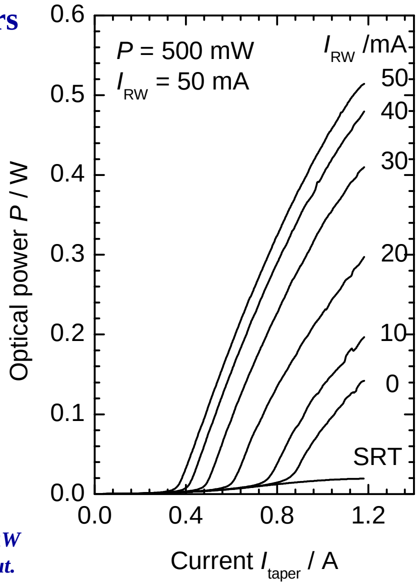
TECHNICAL ACHIEVEMENTS

Towards the Project Objectives

High-brightness twin-contact red-emitting tapered lasers

High-brightness red-emitting tapered lasers are being developed at the Ferdinand-Braun-Institut für Höchstfrequenztechnik. Tapered lasers have been fabricated with a total cavity length of 2 mm (750 µm ridge waveguide section, 1250 µm tapered section) and a 4 degree taper angle. The devices were mounted on AlN submounts with structured contacts, which allow independent control of the ridge waveguide and tapered sections. The laser reached an output power of 500 mW in continuous-wave operation with a nearly diffraction-limited beam quality of $M^2 < 1.1$. It was shown that a shorted ridge waveguide section leads to an almost vanishing output power, even for large bias currents applied to the tapered section. Using this separate contact for the ridge waveguide section, a modulation efficiency of 7.5 W/A was achieved.

P. Adamiec et al., Photon. Technol. Lett. Vol. 21, pp. 236-238, February 2009.

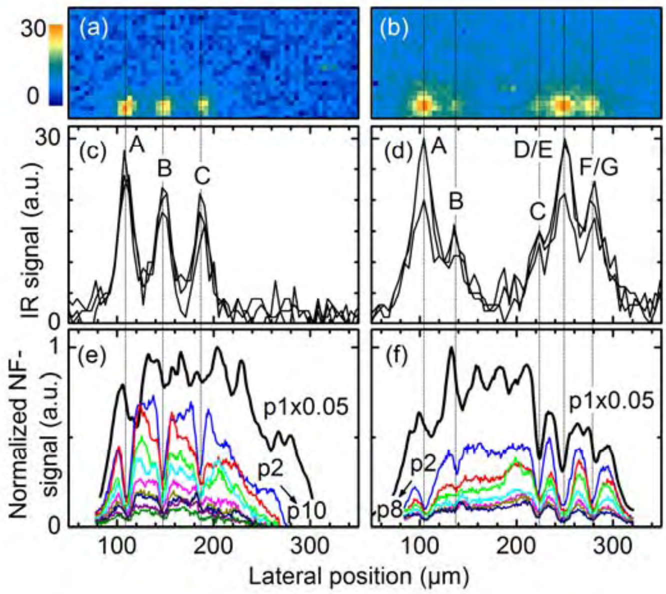


Left: Output power versus taper current for a 650 nm tapered laser with different RW currents. The abbreviation SRT denotes that the contacts of RW section are shorted out.

Catastrophic optical mirror damage (COMD) monitored during single pulse operation

Catastrophic optical mirror damage during single-pulse operation of 808 nm diode lasers has been analysed in a recent collaboration between the Max-Born-Institute and DTU-Fotonik. After the pulsed tests, the lasers were investigated by SEM and cathodoluminescence at the Ferdinand-Braun-Institute. During each pulse, both near-field and thermal images are captured. The thermal runaway process is unambiguously related to the occurrence of a ‘thermal flash’. A temporal resolution of <7 µs has been achieved, which is more than two orders faster than previously reported. A one-to-one correlation between near-field, ‘thermal flash’, thermal runaway and structural damage is observed. As a consequence of the single-pulse-excitation technique, the propagation of ‘dark bands’ into the cavity is halted after the first pulse. Thus, the single-pulse-excitation technique allows the propagation of structural damage to be controlled and we therefore propose this technique for the preparation of devices in the early stages of catastrophic optical mirror damage, even for diode lasers that regularly fail by other mechanisms.

J.W. Tomm et al., Proc. SPIE Vol. 7230, February 2009.

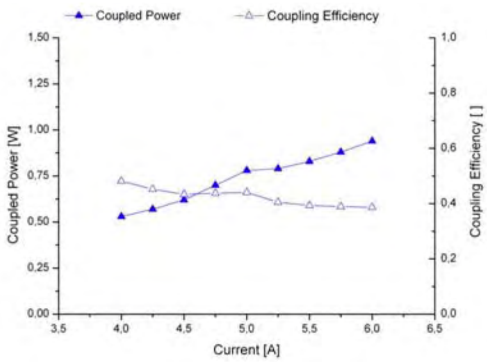


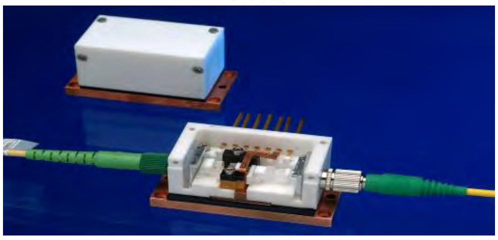
Data shown for 2 µs long, 35 A current pulses. (a,b) Thermal images and (c,d) corresponding lateral cuts through the three lines with maximal signal. (e,f) Normalised near-field profiles (lateral). Profiles for the first current pulse (thick black lines) are scaled by 0.05 relative to the subsequent pulses (thin coloured lines). Left panels display results for device A and right panels for device B. The positions of the peaks in the thermal data and deep minima in the NF data agree well (marked by dotted vertical lines and capital letters). The active stripe is located between 100 and 300 µm.

TECHNICAL ACHIEVEMENTS
Towards the Project Objectives

Fibre coupled laser diode modules for telecommunications applications

A range of fibre coupled modules for telecom applications are being developed within the BRIGHTER project at Fraunhofer ILT. The first is a 975 nm telecom pump module with a coupled power of 50 W in a 50 µm fibre (NA = 0.22). In this module, 16 collimated single emitter tapered lasers are aligned in 4 groups of 4. These are then combined by mirrors and a polarising beam splitter before coupling into the fibre. In a variant of this, 4 emitters are fibre coupled into a 50 µm fibre (NA = 0.13). Here, a coupled power of more than 12 W has been achieved. A single mode fibre coupled module with a maximum output power of 1 W has also been developed. This module is based on a tapered DFB laser at a wavelength of 1060 nm and is for use in free space optical communications. However, the module can be easily equipped with a 975 nm tapered laser and in this case the module serves as a high power pump source for Raman amplification. Read more about modules being developed at the Fraunhofer ILT in the article on page 15.



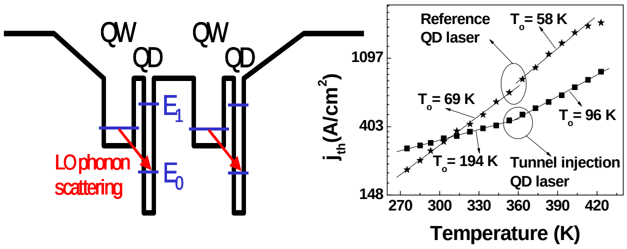


Coupled power & efficiency of the 1 W 1060 nm module (top) and photograph of the assembled module (bottom).

G. Kochem et al., Proc. SPIE Vol. 7198, February 2009.

Tunnelling-injection high-power quantum dot lasers with improved temperature stability

In collaboration with the modelling team at the University of Madrid, the University of Kassel have developed high power 1060 nm $In_{0.575}Ga_{0.425}As$ / (Al)GaAs quantum dot laser material with an integrated $In_{0.25}Ga_{0.75}As$ quantum film acting as a phonon-assisted injector for electrons. The laser uses a GRINSCH structure consisting of a large optical cavity approach for the core waveguide, composed of GaAs / $Al_{0.33}Ga_{0.67}As$ short period superlattices, and $Al_{0.33}Ga_{0.67}As$ cladding layers. In comparison to a QD laser without tunnel injection, these new lasers exhibit a strongly improved temperature stability of the threshold current and internal quantum efficiency.



Accepted for publication in IEEE Photonics Technology Letters, 2009.

The 4th International Graduate Summer School Biophotonics ’09

In terms of research activities, biophotonics is a hot topic and education in this field is also booming. The graduate summer school Biophotonics ’09 has received support and co-sponsorships from several institutions and organisations across Europe, including WWW.BRIGHTER.EU, and the US, which clearly indicates the relevance of education in this area. Also commercial companies co-sponsor the school and, for example, Thorlabs Sweden AB sponsors the best poster award. Please visit the school web site for the full list of sponsors and to sign up to our e-newsletter. More details can be found on page 41 of this edition.

Visit our website at: www.biop.dk/biophotonics09

BRIGHTER at the ICT Event 2008

Towards the end of 2008, the BRIGHTER Consortium took part in Europe’s biggest ICT research event, with a booth at ICT 2008. We would like to thank all who visited us at ICT 2008. For more, read our full report on page 36.

PARTNER PRESENTATIONS

In this section of the e-Newsletter, we introduce some more of the partners in our Consortium. In this edition, profiles are presented for the Institute of High Pressure Physics (UNIPRESS), Tyndall National Institute, Thales Research & Technology and biolitec AG.
Don't miss the profiles of partners Alcatel-Thales III-V Lab, Alcatel-Lucent Bell-Labs (France), the Institute of Communication and Computer Systems (ICCS) of the National Technical University of Athens and the Lund Laser Centre, which will appear in our next e-Newsletter in September 2009.

Institute of High Pressure Physics UNIPRESS

UNIPRESS (created in 1972, within the Polish Academy of Sciences) specialises in the application of high-pressure techniques to various areas of material science. The different materials studied include semiconductors, superconductors, metals, ceramics as well as biological materials. Research in semiconductors involves optical and transport experiments in both gas and liquid cells (up to 3 GPa) and in diamond anvils (up to 50 GPa).

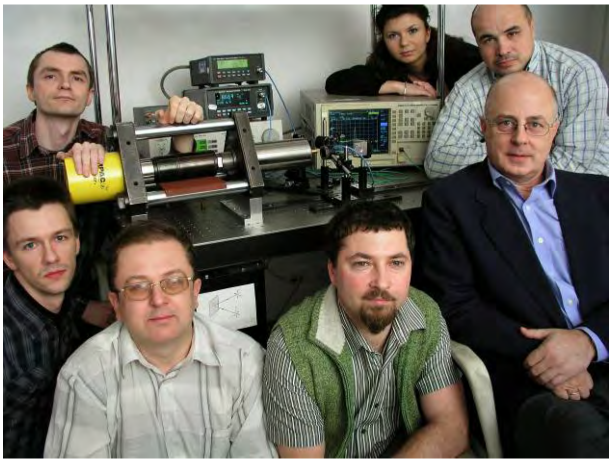
Our semiconductor research also includes crystal growth under high pressure. The UNIPRESS team was the first in the world to obtain dislocation-free bulk monocrystals of GaN, which is an important material for both optical devices emitting in the blue spectral region and also for high-temperature electronics. Using both MOCVD and MBE epitaxial methods on GaN substrates, pulsed and CW InGaN/GaN lasers have been developed by the team at the institute.

UNIPRESS manufactures high-pressure lab equipment and is recognised by the high-pressure community across the world. The director of UNIPRESS has been elected the President of AIRAPT (the International Association for the Advancement of High Pressure Science and Technology). Over the course of its history, UNIPRESS has spun off several companies, the most recent being TopGaN Ltd (http://www.topgan.fr.pl), founded in 2001, as a manufacturer of violet lasers.

UNIPRESS has also been recognised by the award of two Centre of Excellence grants from the European Commission (http://www.unipress.waw.pl/CE). Various teams have been engaged in many 5th and 6th Framework EU Projects, NATO projects and other international collaborations. The institute also has a "twinning agreement" with Montpellier University in France.

The scientific staff of the UNIPRESS Institute includes 10 professors and 27 research associates and post-doctoral fellows as well as 14 Ph.D. students.

Our main location is at Sokołowska 29/37, 01-142 Warsaw, Poland, but UNIPRESS has another building at Prymasa Tysiąclecia 98 and a villa in the small town of Celestynów (40 km South-East of Warsaw).



The BRIGHTER Project Team at UNIPRESS

Activities within WWW.BRIGHTER.EU

Within the project, the team at UNIPRESS develops wavelength tuning of laser diodes using high hydrostatic pressures and low temperatures. This tuning is also combined with external resonator methods (WP3). Using these techniques, we have achieved wavelength ranges previously inaccessible with laser diodes, for example the yellow-orange (570-630 nm) range. Tuning in the visible has been demonstrated in a short video which can be found on our webpage (click on the photo gallery) at http://www.unipress.waw.pl/~wtlab.

We also use pressure and temperature for characterising recombination mechanisms in laser diodes. In short wavelength lasers, we determine the barriers for leakage since they are very sensitive to pressure. In other lasers, we examine axial strains due to mounting (WP2).

Finally, we study laser diode reliability after multiple pressure cycles (WP5). This is important for pressure-tuning methods and also for studying strain-induced degradation mechanisms.

Further Information

Further information can be obtained from:
Prof. Witold A. Trzeciakowski
Tel: +48 22 876 03 46
Email: wt@unipress.waw.pl
Web: http://www.unipress.waw.pl

Tyndall National Institute

The Tyndall National Institute was established in 2004 as an amalgamation of the NMRC (National Micro-electronics Research Centre) with other Information and Communication Technology (ICT) based scientific activities in the Cork region. The fundamental mission of Tyndall is to develop new scientific knowledge and key technological capabilities in ICT-related fields to fuel the evolution of core technology platforms that will in turn enable Irish and European industry to develop next-generation products and applications.

There are presently 350 researchers (Staff and PhD students) at Tyndall with core competencies in Photonics, Nanotechnologies, Micro-technologies and ICT-Biotechnologies. The Photonics activities at Tyndall encompass basic physics to communication systems with research teams working in quantum optics, theory, nanostructures, non-linear dynamics, sources and photonic systems. The work is supported by 6000m^2 of state-of-the-art laboratory space including device fabrication facilities in III-V and silicon materials. A major expansion of these facilities is almost complete.

Tyndall is located on the grounds of University College Cork

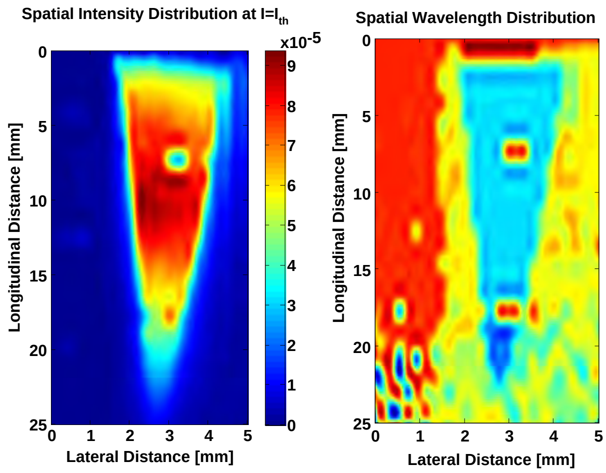
The III-V materials and devices group are investigating advanced devices based on quantum wells and dots at wavelengths from the UV to the IR with applications in:

- High-power pump lasers
- Telecommunications
- Sensors
- Lighting

Achievements include: watt level diffraction-limited power from curved facet lasers; a patented approach to low-cost, tuneable single frequency lasers; red-emitting VCSELs with high single mode power and temperature stability; and high extraction efficiency LEDs. A number of spin-out companies have been established as a result of the photonics activities.

Activities within WWW.BRIGHTER.EU

Tyndall contributes to BRIGHTER in two aspects. The first is in the development of high power 1060 nm lasers with low transverse beam divergence. As is often the case in edge emitting lasers, the transverse divergence of the laser is considerably higher that that of the lateral divergence. This complicates the requirements on the optics for the collection of the emitted light. By using a unique SMILE (Single Mode Intense Light Emitter) waveguide design in both quantum dot and quantum well based materials, grown by our partners at Kassel University and III-V Lab, the divergence is significantly reduced. Tyndall has developed experimental techniques for the analysis of the cavity in tapered lasers during operation by imaging the spontaneous emission through the substrate. This data feeds into simulation tools for modelling laser structures to understand the devices in greater detail and to develop improved cavity designs.



Spatio-spectral analysis of the spontaneous emission from a flared high power quantum dot laser

The second aspect being investigated at Tyndall is the development of non-absorbing mirrors for red lasers using quantum well intermixing (QWI) technology. QWI permits spatial control of the bandgap of the QW active material. By creating regions of a higher bandgap at the facets of the laser, the emitting mirrors become non-absorbing. This in turn reduces self absorption of the laser light at the facet, thereby reducing heating at the laser facet and increasing the reliability and the maximum power achievable from the laser.

Further Information

Further information can be obtained from:

Brian Corbett
Tel: +353 21 4904380
E-mail: brian.corbett@tyndall.ie
Web: http://www.tyndall.ie

Thales Research & Technology

With operations in 50 countries and 68,000 employees, Thales is a world leader in mission-critical information systems for the aerospace, defence and security markets.

Thales annually invests around 20% of consolidated revenues in R&D, including a significant part dedicated to fundamental research and advanced studies, which are a primary source of technological innovation today.

Thales operates a policy of research and technology partnerships with the local industrial and scientific ecosystem in each country where it has major operations. As well as prestigious research institutes and universities, this knowledge network also includes Thales' technology providers and customers, in particular, in North America, Australia, Singapore, South Korea, France, the United Kingdom and the Netherlands.

In practice, this translates into a wide range of public-private cooperative research initiatives, such as the Mobile Virtual Centre of Excellence programme in the UK, the competitiveness clusters ("pôles de compétitivité") supported by the French authorities and various European technology platforms (ACARE, ARTEMIS, ENIAC, NESSI, etc.).

Thales Research & Technology France

Activities within WWW.BRIGHTER.EU

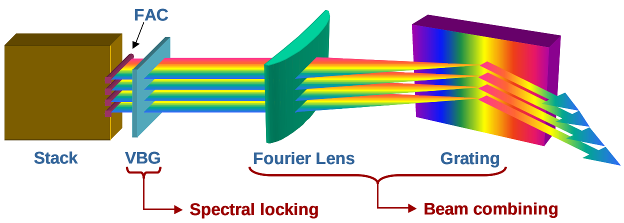
Diode Laser Modelling and Analysis

Thales R&T has more than 20 years experience in the field of modelling of optoelectronic devices. It has developed full simulators involving complex coupling schemes for devices such as quantum well lasers, quantum well infrared detectors, and quantum cascade lasers. Thales R&T has developed a range of advanced analytical techniques for the study of nanotechnology-based products. These skills are used in the project to better understand the degradation mechanisms and underlying defects that control the aging properties of high-brightness single emitters and laser bars.

Spectral Beam Combining (SBC)

Multiple emitter laser diode bars can emit tens of watts but with a very low beam quality, leading to a low brightness. One way to enhance this beam quality is to superimpose the beam of each individual diode. The only possible means for incoherent beams is spectral combining where each diode is operated at a different wavelength and the beams are superimposed with a dispersive optical component.

Thales R&T is exploring such SBC systems. A first experiment was performed with a tapered laser diode bar of 30 emitters from the partner Alcatel-Thales III-V Lab. 9W of locked power has been demonstrated. A new experiment is now in progress following the scheme shown in the figure below. A stack of collimated laser diode bars will be spectrally locked to the targeted wavelengths with a chirped Volume Bragg Grating then combined with a grating.



Spectral beam combining of a stack of diode laser bars

Dissemination with RichMedia

The RichMedia format has been developed at Thales to facilitate knowledge sharing for workshops and training courses. The content can be put onto a website for distribution to a wider audience, as well as on CD (e.g. 1 single CD for a 1-day workshop). This approach relies on the Thales RichMedia Workbench, a dedicated RichMedia editing tool. The RichMedia product is an excellent way of distributing presentations, such as the technical training tutorials in the BRIGHTER project.

This approach of combining video and audio (i.e. a real presenter), together with the PowerPoint presentation and simple navigation on demand is more attractive than the presentation slides alone because of the inclusion of the speaker's comments and their emphasis of pertinent points. Self-paced, on-demand and asynchronous participation to workshops and tutorials are made possible by the Thales RichMedia Workbench.

Further Information

More information is available at www.thalesgroup.com or by contacting one of the following:

Diode Analysis: julien.nagle@thalesgroup.com

SBC: christian.larat@thalesgroup.com

RichMedia: jean-christophe.mielnik@thalesgroup.com

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biolitec AG

biolitec AG has a long-standing experience in the development and production of medical laser systems as well as optical fibres. We combine marketing know-how of our innovative methods of laser medicine with the established expertise in photodynamic therapy. This competency forms the basis of our leading position as a manufacturer of new and innovative treatment methods for a wide range of therapies.

In many areas, laser medicine has established new methods and procedures. biolitec AG and its subsidiaries have been providing a crucial impetus for nearly twenty years: innovations are translated into breakthroughs that have simplified therapy for doctors and patients. We conduct intensive research on how laser and photodynamic substances can be used to make further improvements in traditional processes and methods. These innovations clearly symbolise progress in medicine.

biolitec AG was founded in 1986, in Bonn, Germany, and today is the world leader in specialty fibre and fibre optic-based products for medical, dental and industrial applications. Based on our roots as a specialty fibre optics manufacturer (as CeramOptec GmbH), we continue to evolve everyday in a concerted effort to realise our vision – to innovate unique medical treatments, methods and products that will have a positive impact on the well-being of people worldwide.

Optical application fibre with cylindrical light diffuser

From the launch of our comprehensive line of advanced diode laser systems in 1996 to the establishment of our own biotechnology centre in Jena, Germany, in 2000, biolitec continues to demonstrate its commitment to enhance the research and development of innovative techniques for the advancement of medical science.

Of particular importance to biolitec is the study of photosensitizers and their use in Photodynamic Therapy (PDT) applications. In addition to introducing products specifically designed for this, we are continually conducting several clinical trials and studies dedicated to the advancement of this exciting field.

biolitec is an international corporation with facilities in several countries around the world. As a vertically integrated corporation, we are unique in that we make our own fibre optic preforms and manufacture the most advanced medical lasers on the market. We combine innovation with cost effectiveness to create the highest quality products for our customers.

Photosensitiser Foscan®

In addition, under the CeramOptec brand, we are the leading manufacturer of specialty fibre optics for industrial and scientific applications – setting the highest standards in the industry. For more information visit us at www.biolitec.com and www.ceramoptec.de.

Medical laser system

Activities within WWW.BRIGHTER.EU

Within the BRIGHTER project, biolitec is developing new laser systems for PDT based on the high power diodes developed by the partners in the project. With the project coming to its end, PDT lasers with several watts output power at 635nm and 652nm have become technically feasible. In addition to the fact that they now supply sufficient power for new PDT systems, the new diodes also exhibit much higher reliability and lifetimes.

Further Information

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Cladding-Pumped WDM Amplification

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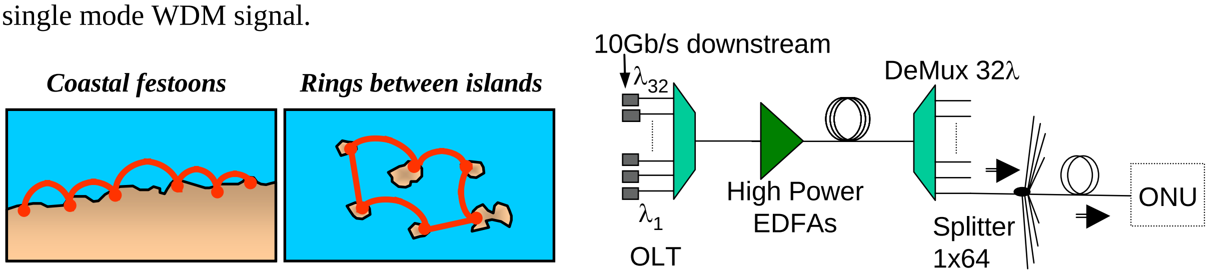
Applications of High Power EDFAs

Erbium-doped fibre amplifiers (EDFA) are the pillars of current and future generations of WDM networks. They remain the most cost-effective amplification solution for both metropolitan core networks and long-haul backbone networks. Some specific applications require a very high output power up to 33dBm. The main applications for such high power amplifiers are amplification in repeater-less transmission systems (see Fig. 1a) and EDFAs for the next generation WDM-TDM Passive Optical Network (WDM-TDM PON) with very high splitting ratio (see Fig.1b). For repeater-less systems, the goal is to have as long a reach as possible and therefore it is necessary to have high per-channel power to compensate for the loss of the transmission line. In WDM-TDM PON, the principle is to connect a high number of subscribers with a single fibre (which is also as long as possible). A high power EDFA is needed to compensate for the high splitting ratio (32*64 = 2048 in the example shown in Fig. 1b). In order to reach high output powers, cladding-pumping is the preferred technology. This has the benefit of being able to use high power multimode pump sources to amplify a single mode WDM signal.



(a) **(b)**

Figure 1: Example of applications for high power EDFAs: (a) repeater-less systems and (b) next generation long-reach WDM-TDM PON with high spitting ratio (64*32 = 2048 in the example shown).

Characteristics of CP-EDFAs

Cladding-pumped EDFAs comprise of a multimode pump (such as those developed within the BRIGHTER project), a double-clad fibre and a multiplexer, which enables the coupling of the single mode signal and the multimode pump into the double-clad fibre as shown in Fig. 2.

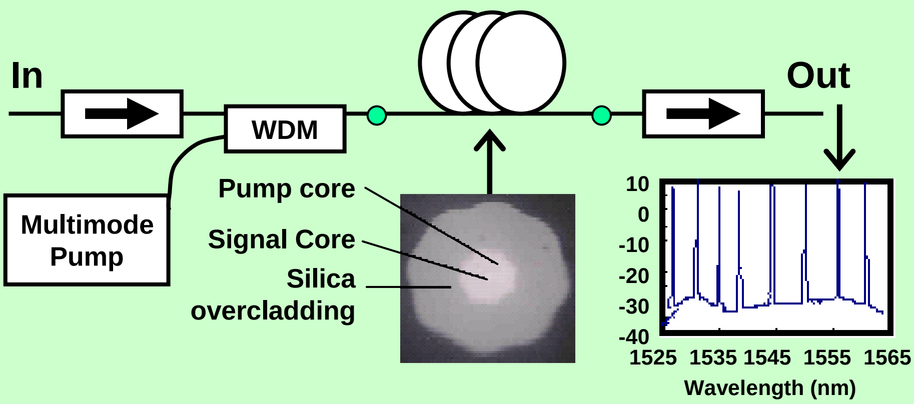


Figure 2: Basic cladding-pumped EDFA architecture.

Double-Clad Fibres

One of the major problems in cladding-pumped technology is the pump absorption. Indeed, the pump is fed into a multimode core (with a diameter of between 50µm and 100µm), whereas the signal is fed into a single mode core (with a diameter of around 6 µm) doped with erbium ions. Therefore, the cross-sectional area of the multimode pump core is 70 times (for a 50µm diameter core) to 210 times (for a 100µm diameter core) larger than the single mode core area. The pump modes propagating in the multimode core have a very low overlap with the signal core. Various techniques are therefore used to increase the pump absorption. For C-Band amplification, a pump core with a circular shape should be avoided. Indeed, in a multimode pump core, many modes are propagating so the pump power is shared among all of these modes. For a multimode core with a circular shape (see Fig. 3a), many pump modes have no overlap with the single mode core doped with the erbium ions. The pump power injected in these modes (skew modes) is not absorbed and therefore this power is lost for the amplification. To minimise the number of these skew modes, which have no overlap with the core, a very efficient technique is to break the circular symmetry of the multimode pump core by using, for example, a D-shaped core (see Fig. 3b) [1]. However, this D-shaped fibre is difficult to fusion splice with the other conventional fibre components that have a circular shape. A good compromise is the fibre geometry in Fig. 3c, which has only a few skew modes and is easy to splice with conventional circular fibre.

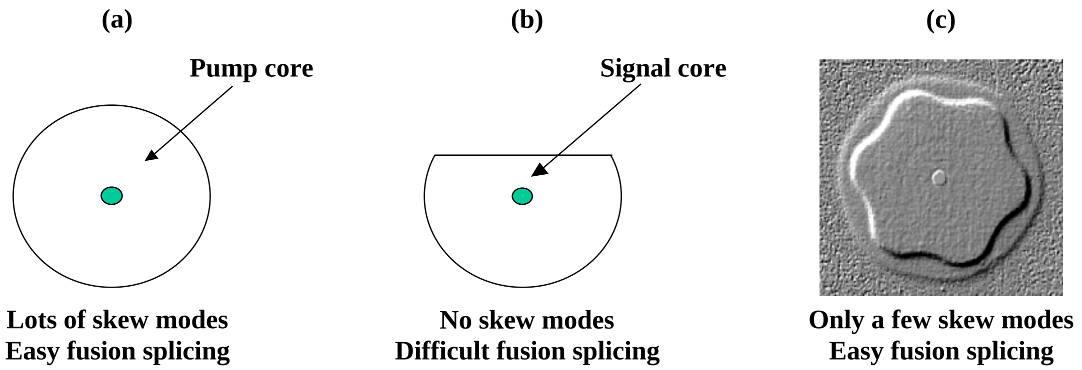


Figure 3: Examples of double-clad fibre geometries.

As well as the use of a non-circular core, additional techniques to increase the efficiency of the pump absorption are still needed. One of these techniques consists of increasing the likelihood of interaction with ions by using high erbium (Er) concentration and Ytterbium (Yb) co-doping in order to have a high absorption coefficient for the single mode core. Co-doping with Phosphorous (P) is then required to ease the incorporation of Yb in the silica glass host and to favour interaction between Yb and Er through a closer arrangement of the ions (see Fig. 4). With this technique, the pump absorption is so efficient that double-clad fibre with a 100µm pump core diameter can easily be used.

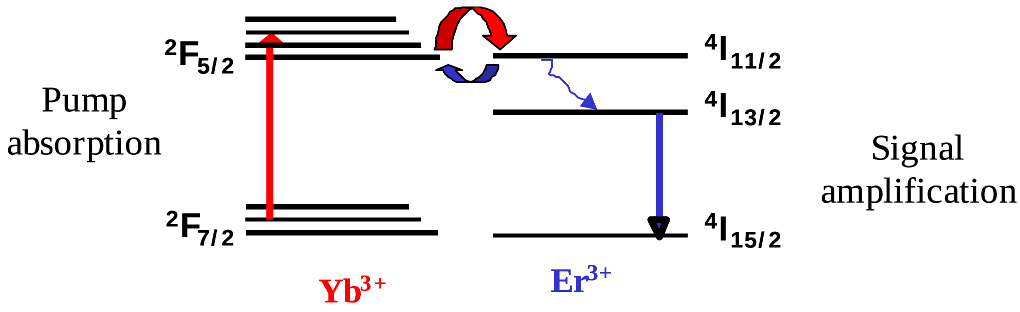


Figure 4: Pumping scheme with Er-Yb co-doping.

The drawback of the Er-Yb co-doping technique is that P-doping makes Yb/Er fibres unsuitable for WDM applications due to the amplification band narrowing at short wavelengths (see Fig. 5). Therefore, in spite of its efficiency, Yb co-doping is not suitable for telecom applications, where full C-Band (1529nm to 1561nm) amplification is required.

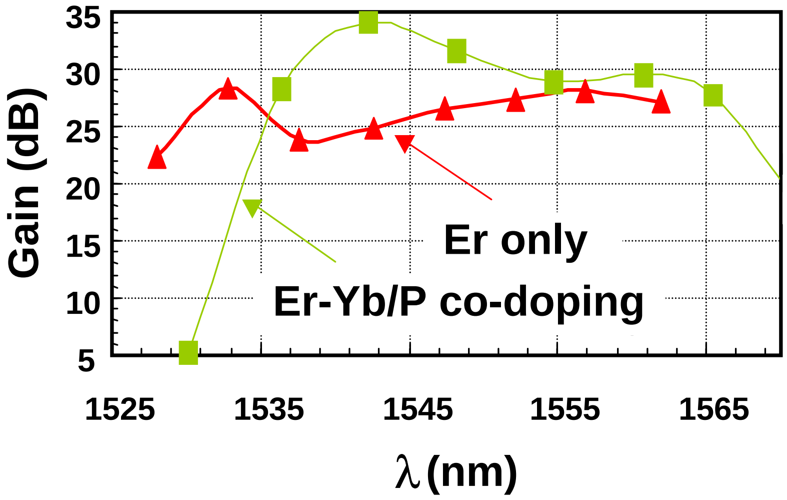


Figure 5: Gain spectra for Erbium doping (red) and Erbium-Ytterbium co-doping (green).

To take advantage of cladding-pumped technology for WDM systems, it is then necessary to increase the pump-to-signal-core overlap by using a reduced pump beam diameter in the double-clad fibre.

Fibre Design for C-band WDM Applications: Ring Doping Technique

With core-doped fibres, the Power Conversion Efficiency (PCE) at balanced gain-peaks (i.e. the gain at 1531nm equals the gain at 1558nm) is improved from a few % up to 15.7% when reducing the multimode core from 100µm down to 50µm, and further improved to 20% with a 30µm core. To reach high average inversion levels (around 60% of ions being excited at balanced gain-peaks), it is efficient to reduce the signal-induced gain saturation and thus the overlap of the signal with the erbium ions. This can be achieved by locating erbium in a ring [1] located outside (but close to) the single-mode core. With a 44µm multimode core, a PCE exceeding 29% can be reached. A way to understand the reasons for the effectiveness of ring doping can be illustrated using the analytical model of Saleh [2].

From this model, the output saturation power P_s^{sat} of an EDFA can be well approximated as:

$$P_s^{sat} \approx P_{p,0}^{out}\left[1 - e^{-\frac{\Gamma_p(\sigma_p^e + \sigma_p^a)}{\Gamma_s(\sigma_s^e + \sigma_s^a)}}\right]$$

where $P_{p,0}^{out}$ is the pump output power with no signal input, σ_s^e σ_s^a σ_p^e and σ_p^a are the cross sections for the absorption and stimulated emissions at the signal and the pump wavelengths, respectively, and Γ_p and Γ_s are the confinement factors for the pump and the signal, respectively. From this simple model, we can see that to increase the saturation power, we can either decrease the confinement factor of the signal or increase the confinement factor of the pump (or a combination of the two). By using ring doping instead of core doping, the greatest effect is to greatly decrease the confinement factor of the signal. At the same time, the confinement factor of the pump could remain unchanged or be increased depending upon the modal distribution in the multimode pump core.

Multiplexer Technologies

Several technologies are used to couple the multimode pump and the single mode signal into the double-clad fibre. One technique is the V-Groove technique depicted in Fig. 6a. This technique is very well adapted to double-clad fibre with 100µm diameter. Operating with such high beam diameters also allows the use of the V-groove side-pumping technique, which has a high manufacturing yield. We have seen above that for such a large multimode pump core diameter, Yb co-doping is mandatory to absorb the pump so this technique is not well suited for telecom applications.

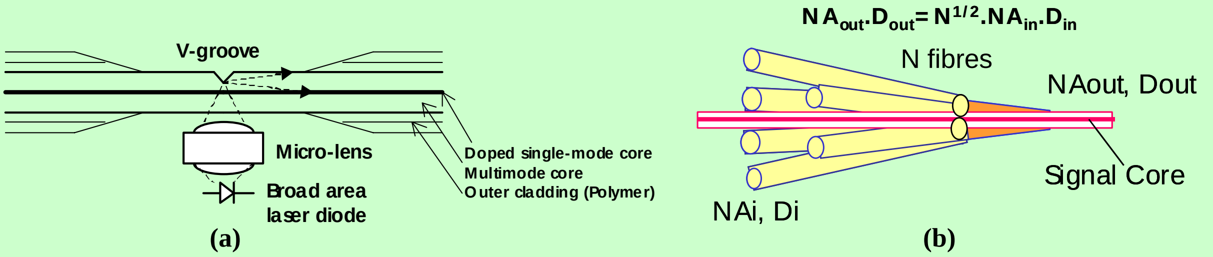


Figure 6: Examples of two pump coupling technologies: (a) V-Groove and (b) Fibre bundle.

A second technique uses a fibre bundle as depicted in Fig. 6b. This technique has the advantage of being an "all-fibre" solution and therefore allows losses to be minimised and facilitates simpler EDFA manufacturing. Moreover, several pumps can be easily coupled to the double-clad fibre enabling pump redundancy and increasing the reliability of the EDFA. However, the use of a fibre bundle with 50µm double-clad fibre is not well adapted. Indeed, to minimise the loss in the bundle, the pump fibres NA and diameters and the multimode core NA and diameter should fulfil the relation given in Fig. 6b. Therefore, the coupling of several pumps in double-clad fibre with 50µm fibres requires:

- Pumps with fibre diameter <<50µm (in this case the advantage of the high pump power brought by a large pump width would then be lost)
- A double-clad fibre with a very high numerical aperture (this is only possible with polymer coating).

A third preferred solution is to use a bulk µ-optics multiplexer made with the same type of technology as the one already used for multiplexers in conventional EDFAs. The advantages of such a multiplexer are that it uses conventional technology and that it is compatible with all-silica double-clad fibres with 50µm diameter. The disadvantage is that with such a multiplexer, only one pump can be coupled. Therefore, this pump should deliver a very high output power. It is also not possible to have pump redundancy with this scheme.

System Validation

CP-EDFAs including the use of the ring doping technique for the doped fibre have been assessed through 10Gbit/s BER measurements [3] and compared with conventional EDFAs. Similar noise and system performance were found. No system penalty is therefore expected for the use of this technology.

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High Brightness Laser Modules

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Introduction

High brightness diode laser modules are used as pump sources for different devices, such as fibre lasers and for signal amplification in telecommunication systems. However, they can also be used in direct material processing applications, such as polymer welding. The main advantages of diode laser modules are their high wall-plug efficiency, their small size and their cost efficiency. For most applications, diode lasers are coupled into single mode fibres (SMF, ~5-10 µm core diameter, depending on the wavelength) or multimode fibres (MMF, 50-800 µm fibre core).

To couple high optical power into a single mode fibre, a diode laser with good beam quality and high output power is necessary. Tapered lasers are a compromise between ridge lasers which offer a very good beam quality and broad area lasers which achieve high output powers. Therefore, tapered lasers have the potential to achieve higher coupled powers than SMF coupled ridge lasers or MMF coupled broad area lasers. Tapered lasers have been shown to achieve nearly diffraction limited output powers of 12 W [1,2].

Single Mode Fibre Coupled Modules

SMF coupled modules are frequently used in telecommunication applications, such as the pumping of Raman amplifiers. The main challenges for the design of a SMF coupled module are the optical system for the SMF coupling and the mechanical fastening of the optical components to ensure a temperature and time stable fibre coupling with a high coupling efficiency.

For the SMF coupling of a tapered laser, an optical system with at least three lenses has to be used – two lenses to collimate the beam and one to focus it onto the fibre core. The two collimation lenses are necessary because of the astigmatism of the tapered laser, which describes the offset between the beam waists in the fast and slow axes of the laser.

Figure 1 shows an optical system for SMF coupling with a rotation-symmetric fast axis collimating (FAC) lens and a cylindrical slow axis collimating (SAC) lens. Crossed cylindrical lenses as FAC and SAC lenses are also possible. As the astigmatism depends on the bias current of the tapered laser, the SAC lens must be adjusted for changing bias currents or must be fixed for one specific operating point.

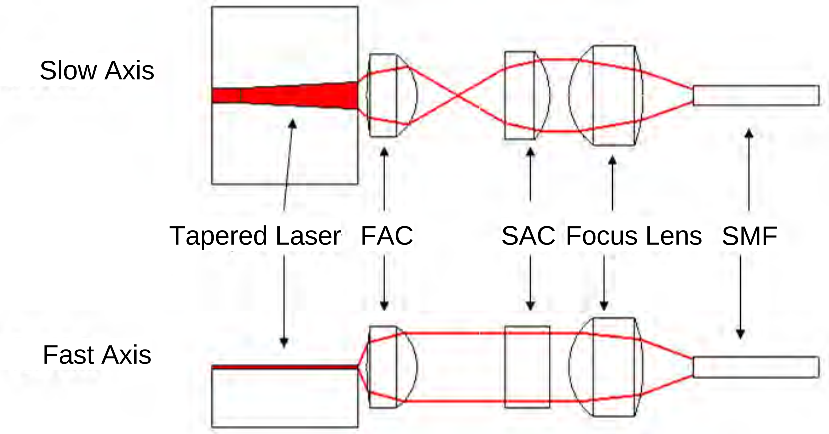

Figure 1: Optical system for SMF coupling.

As is illustrated in Figure 2, an ideal coupling of laser radiation into a SMF occurs if the beam waist of the laser beam lies in the facet of the fibre and the beam waist radius w_0 and the beam divergence Θ_D match the mode field radius w_G and the NA of the fibre.

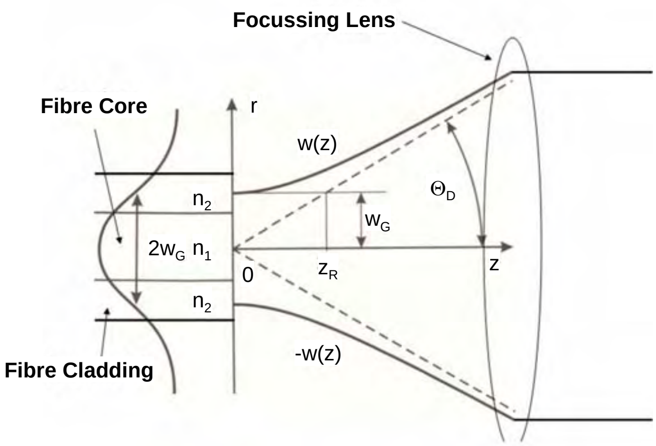

Figure 2: SMF coupling of a Gaussian beam.

The maximum coupling efficiency η_{max} can be calculated according to equation (1) [3].

$$\eta_{\max} = \left(\frac{2 w_0 w_G}{w_0^2 + w_G^2} \right)^2 \tag{1}$$

The maximum coupling efficiency can only be reached if the axis of the beam and the fibre are collinear, the beam waist lies exactly in the fibre facet for both the fast and slow axes, and the beam quality M^2 is nearly 1. If the beam axis is out of alignment, but still parallel to the fibre axis, the maximum coupling efficiency is reduced by η_S. This is described by equation (2), where s is the distance between the beam axis and the fibre axis [3].

$$\eta_s = e^{-\left(\frac{s}{w_G} \right)^2} \tag{2}$$

If the beam axis is tilted with respect to the fibre axis by an angle Θ, the coupling efficiency is reduced by the factor η_Θ. This is described by equation (3) [3].

$$\eta_\Theta = e^{-\left(\frac{\Theta}{\Theta_D} \right)^2} \tag{3}$$

The factor η_Z, which describes the reduction in the maximum coupling efficiency as a function of the distance z_W between the beam waist and the fibre facet [3], can be calculated by equation (4).

$$\eta_z = \frac{1}{1 + \left(\frac{1}{2} z_w / z_R \right)^2} \tag{4}$$

The transmittance T of the optical system also reduces the power which can be coupled into the SMF and considers the losses from reflection and absorption at the lenses and at the fibre facets. Assuming M^2 equals approximately one, the coupling efficiency can be calculated by reducing the maximum coupling efficiency by the factors described above. This is shown in equation (5).

$$\eta = T \eta_s \eta_\Theta \eta_z \eta_{\max} \tag{5}$$

Based on this equation, the dimensions of the module can be calculated and the materials can be selected to ensure a coupling efficiency which is not affected by temperature changes. It can also be used to calculate the influence of misalignment of the lenses due to the positioning and fastening methods employed.

For SMF coupling, fused silica is a well proven material used for lens mounts. It offers a very low thermal expansion coefficient and high transmission in the UV. Thus, lens holders made of fused silica can be easily fastened with UV curing adhesives. The shrinkage of these adhesives should be minimal and in a non critical direction, if possible, to minimise losses in coupling efficiency.

Figure 3 shows a module used for SMF coupling of tapered lasers and amplifiers, which also allow the frequency of a tapered amplifier to be stabilised with a fibre Bragg grating (FBG).

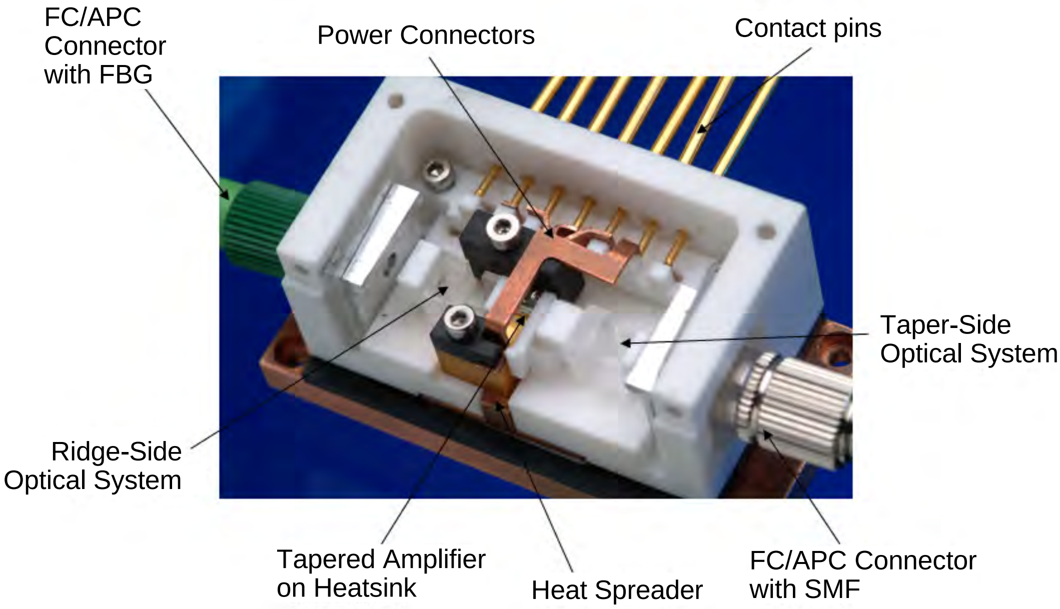

Figure 3: Tapered amplifier module (shown without lid) [4].

Multi Mode Fibre Coupled Modules

Modules Based on Laser Bars

Laser bars generally consist of an equally spaced lateral array of single emitters. This fixed emitter arrangement contains fewer degrees of freedom and results, in general, in less alignment complexity compared to an array of discrete emitters. On the one hand, the module cost decreases due to a reduced complexity, but on the other hand, the flexibility of the beam shaping and coupling concept is limited.

The lateral beam parameter product (BPP) of a broad area or tapered emitter is larger than the transversal BPP. The lateral BPP of the single emitters adds up to a large lateral BPP of the laser bar. The tapered or broad area single emitters are diffraction limited in the transversal direction. This is also valid for a lateral arrangement of emitters in a laser bar. Without any transformation, the BPP of laser bar radiation is very asymmetric. In order to couple laser bar radiation into a fibre, the BPP of the laser bar has to be matched to the BPP of the fibre. This matching can be done by shifting beam quality from the transversal to the lateral direction. The theoretical approach for beam quality shifting is given by equation (6) [5].

$$\tilde{M}_F^{\,2} = n \cdot M_F^{\,2}$$
$$\tilde{M}_S^{\,2} = \frac{1}{n} \cdot M_S^{\,2} \qquad (6)$$

In order to shift the beam quality, the beam from the laser bar is transversally segmented and each segment is rotated around the axis of propagation by 90°. Both reflective and transmissive beam transformation optics have been developed. The transmissive elements will be discussed below.

The transmissive beam transformation optics contain a FAC lens for beam collimation in the transversal axis (fast axis). After the FAC lens, the collimated beam has a fast axis beam waist of few hundred microns. In order to segment and rotate the beam, an array of micro prisms directly follows the FAC lens. The number of prisms is equal to the number of emitters. The prisms are tilted by 45°. After the beam transformation optics, the beams of the single emitters are rotated by 90° and collimated in the lateral axis. The beam quality of the lateral and transversal axes is equalised. Figure 4 illustrates the bea

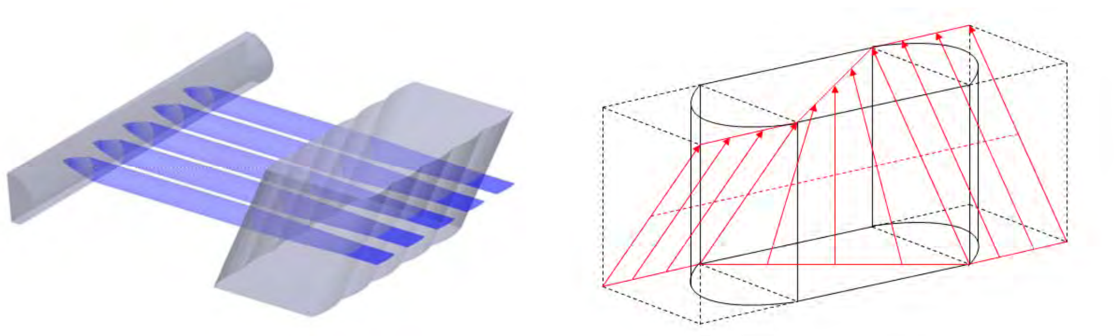

Figure 4: FAC lens and prism array for beam rotation (left) and beam rotation principle (right).

After equalising the beam quality of the fast and slow axes, the beam is then coupled into the fibre by a system of cylindrical lenses. Figure 5 illustrates a module concept based on a transmissive beam transformer.

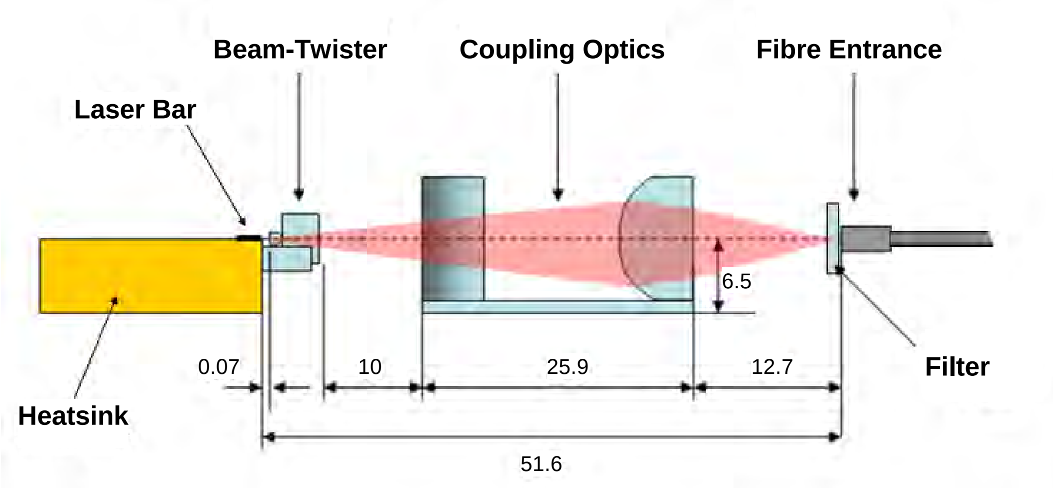

Figure 5: Module concept based on a tapered laser bar and transmissive beam transformation optics. (All dimensions are in mm.)

Modules Based on Single Emitters

Single emitters are used for MMF coupling if a high coupling efficiency or a high coupled power is demanded. As the single emitters can be optically stacked in the fast axis direction (spatial multiplexing), no beam transformation optics are needed to achieve a symmetrical BPP for the fast and slow axes. Thus, the radiation can be adapted to the NA and core diameter of the fibre. Furthermore, compared to a diode laser bar, the heat dissipated by the single emitters is spread over a significantly larger area. Thus, the single emitters can be driven more efficiently at higher currents [6,7].

To achieve efficient fibre coupling, multiple single emitters are combined by spatial multiplexing, polarisation coupling, wavelength coupling or a combination of these methods. For spatial multiplexing the radiation of single emitters can be stacked with a mirror array or a step mirror as shown in Figure 6.

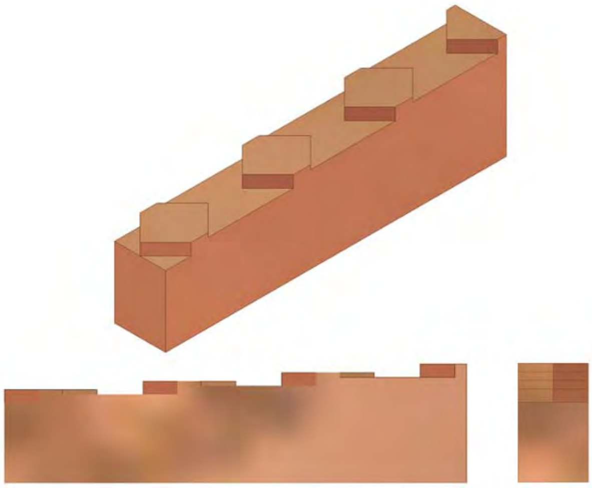

Figure 6: Step mirror for 8 emitters.

Figure 7 shows a setup used for spatial multiplexing and polarisation coupling. A step mirror is used to multiplex five emitters which are combined with a second group of five emitters by a polarising beamsplitter (PBS).

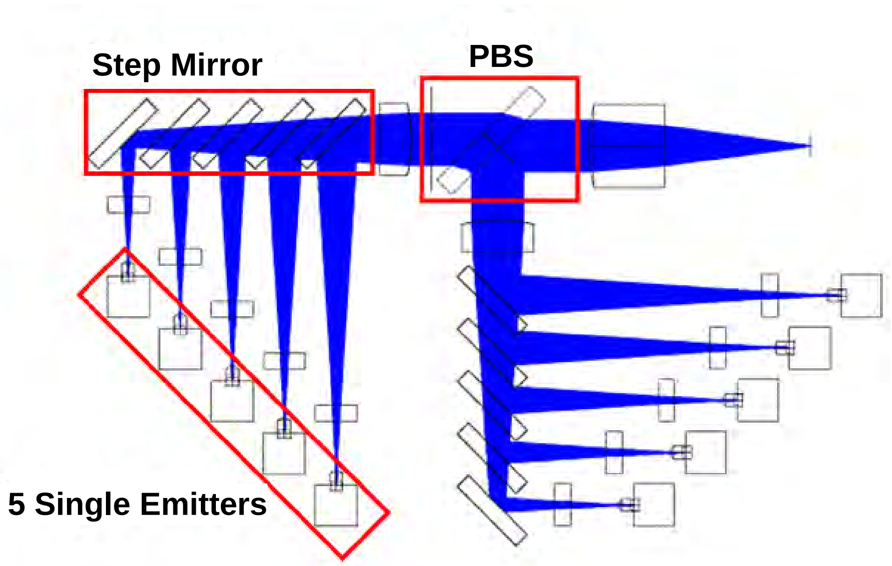

Figure 7: Multiplexing of single emitters [8].

A module which uses step mirrors and polarisation coupling to couple sixteen single emitters into a 50 µm fibre is shown in Figure 8. In this case, single tapered lasers are used. Two groups of eight emitters are collimated individually, multiplexed with the step mirror shown in Figure 6, and then combined by a polarising beamsplitter. The module is designed to achieve a power of up to 50 W out of a 50 µm fibre [4].

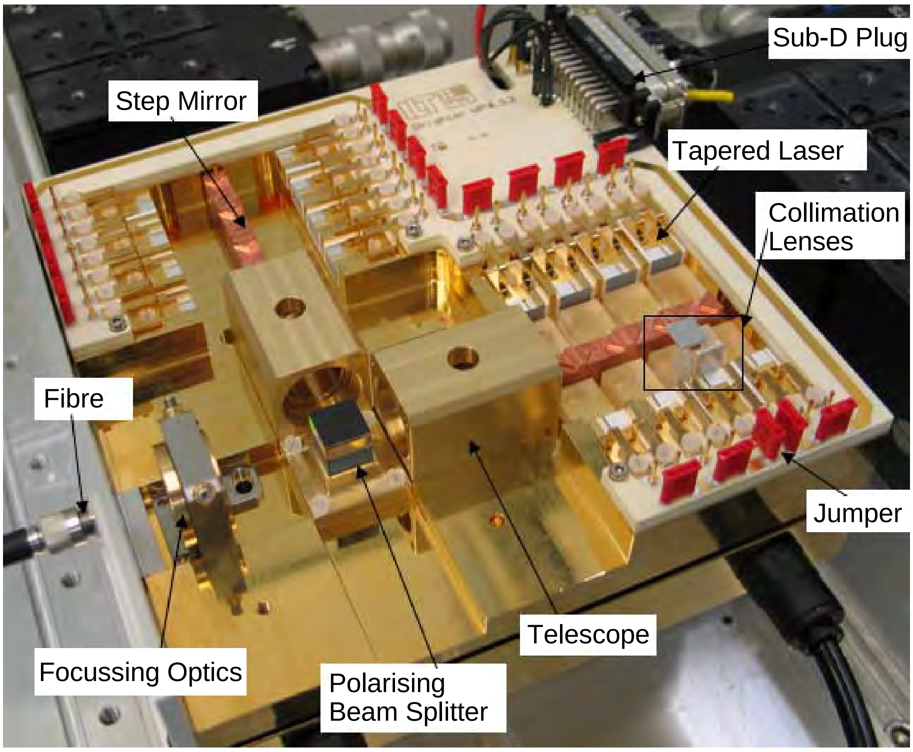

Figure 8: Module for coupling 16 emitters into a 50 µm fibre.

Summary

Laser modules with high brightness can be based upon single emitters or laser bars, depending on the intended application. Single emitters are used for coupling into single mode fibres. Multiple single emitters are used for multimode fibre coupling in applications requiring high coupling efficiencies and output powers. Laser bars are also used for multimode fibre coupling. Although, they achieve lower output powers and coupling efficiencies, they lead to a less complex optical design, which is therefore more cost efficient. In all cases, different techniques for beam shaping, multiplexing and power scaling, some of which are described above, are used to achieve a module which is tailored to its particular application.

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Wavelength Tuning of Laser Diodes by Hydrostatic Pressure and Temperature

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Pressure and temperature change the bandgap of III-V semiconductors and therefore can shift the gain spectrum of laser diodes. With 20 kbar pressure (achievable in a liquid pressure cell), we can increase the energy of the laser emission by about 200 meV for lasers grown on GaAs, InP or GaSb. The main physical limitation of pressure tuning for shorter wavelengths (i.e. between 600 nm and 800 nm) is the reduction of the indirect gap (Γ-X) in the barriers and cladding layers of the laser structure, leading to a strong increase of the leakage and threshold currents. In this wavelength range, temperature tuning can be applied. Cooling the laser down from room temperature (300 K) to about 100 K, we can increase the emission energy by about 80 meV. By applying both high pressure and low temperature, the total tuning range increases to 280 meV. This allows us to reach yellow emission (down to 570 nm), previously unattainable by laser diodes. The combination of pressure/temperature tuning with tuning by an external grating combines the merits of both methods – wide spectral range, narrow linewidth, stable emission wavelength – making this seem a promising technology. However, several issues still have to be addressed, including the reliability of lasers and pressure cells after multiple pressure cycles and the stability of the coupling between the laser diode and fibre under high pressure.

Introduction

Laser diodes have developed very rapidly over the last two decades. Commercial CW devices grown on GaAs, InP and GaSb are available in the 630 nm – 2400 nm spectral range and nitride devices are available in the 410 nm – 480 nm violet range. Single emitters achieve high powers of a few Watts, whilst tapered lasers combine high power and high beam quality. Numerous applications require wavelength tuning. Some examples include spectroscopy (e.g. tunable diode laser absorption spectroscopy), telecommunications (dense wavelength division multiplexing) and medicine (photodynamic therapy involving different photosensitisers). Diode lasers can be tuned by external or internal gratings, forcing the laser to oscillate at a frequency determined by the grating [1]. This method allows for tuning within the gain curve. Another possibility is to shift the whole gain curve of the laser. This can be achieved by high pressure or by low temperature (increased temperature is not practical for diode lasers because the threshold currents increase rapidly and the device lifetime decreases).

In this paper, we review pressure and temperature tuning and the combination of these methods with external cavity tuning. These activities have been developed by the UNIPRESS team within the WWW.BRIGHT.EU and WWW.BRIGHTER.EU projects (using the laser diodes grown by various other partners within the projects).

Special Requirements for Pressure and Temperature Tuning

Pressure and temperature have been widely used for characterising laser diodes [2]. The most practical tool in such investigations has been the piston-cylinder liquid cell. A few experiments have been performed in a diamond anvil cell [3], but the electrical connections to the laser are difficult to realise in this device. For characterisation measurements, it is sufficient to make a few pressure cycles. Pulsed operation of the laser can be applied (so that heatsinking is not a problem) and efficient coupling of light out of the cell is not too important. However, if we want to develop pressure/temperature tuning (by which we mean high power CW lasers operating over hundreds of pressure/temperature cycles without degradation of the laser or pressure/temperature cell), good heatsinking, efficient coupling of the light out of the cell and good quality of the output beam are all much more important.

For edge-emitting lasers, the longitudinal modes are closely spaced and when we shift the gain by pressure or temperature, we observe mode-hops, i.e. the tuning is not continuous but step-like. Moreover, there is some hysteresis when going up and down in energy. In order to avoid these mode hops, it is possible to deposit an anti-reflection coating on one laser facet and use an external cavity configuration, so that the light is reflected back to the laser by an external grating, Bragg fibre or by a photorefractive crystal. This reduces the linewidth of the laser (which is very important for spectroscopy applications [4]) and stabilises the emission wavelength, which can be fine-tuned by the grating.

The physical limitations of pressure tuning are related to the direct-indirect transition (Γ-X crossover) under pressure in materials like AlGaAs, GaAsP and AlGaInP. This is because the Γ-X separation decreases rapidly with pressure (10-14 meV/kbar). The indirect barriers to the waveguide and cladding layers also decrease. In other words, for indirect (X symmetry) waveguides and claddings, the quantum well becomes shallower at increased pressures. This leads to increased leakage of electrons from the well and to an exponential increase in the threshold current with pressure. For longer wavelength lasers (above 900 nm), leakage is usually negligible and the pressure tuning range is only limited by the available pressure range multiplied by the pressure coefficient of the direct bandgap (between 8 and 12 meV/kbar). For InGaN/GaN lasers, leakage to X minima does not occur but the pressure coefficients are below 4 meV/kbar. Therefore, for wavelengths below 800 nm (including nitride lasers), temperature tuning may be a better alternative to pressure tuning. The combination of pressure and temperature tuning yields the widest tuning range and allows emission wavelengths previously unattainable with diode lasers to be reached.

Experimental Details

Our piston-cylinder pressure cell is shown in Fig.1. The inset shows the details of the laser diode mounting, which has to be specifically optimised for reliable operation under pressure. The thermal contact with the body of the cell is important for high-power CW operation. The positioning of the laser with respect to the lens (or fibre) must remain stable under pressure. The pressure-transmitting liquid must be transparent in the spectral range of the laser and hydrostatic up to 20 kbar. In most experiments, we have used gasoline, a pentane-hexane mixture or a glycerin-glycol mixture.

The body of the cell is made of an inner cylinder and one or two outer cylinders clamping the inner one (to reduce the tensile strain under high pressure). The major problem that remains to be solved is that of multiple use gaskets (on the piston). Another requirement concerning the gaskets is the long-term stability under pressure – in some cases we have kept a laser under pressure for months and the emission wavelength remained unchanged.

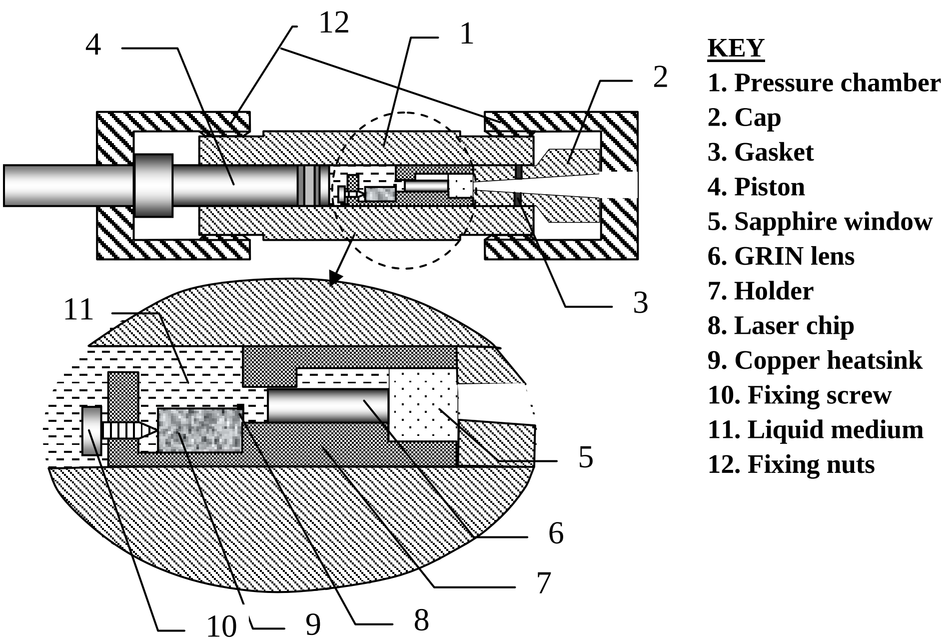


Fig. 1: Outline of the optical high pressure cell.

In order to extract most of the laser light out of the cell, we used the two solutions shown schematically in Fig. 2. These are direct butt coupling of the laser to optical fibre and collimation of the light with a microlens that then passes through the sapphire window. Direct butt coupling is convenient because many applications require light in an optical fibre. However, we could only use multimode fibres with 50 – 200 micron core diameters. Laser polarisation is scrambled in such fibres and speckles appear at the output. We were not able to achieve good quality (and stable with pressure) coupling to a single-mode fibre with a core diameter of a few microns.

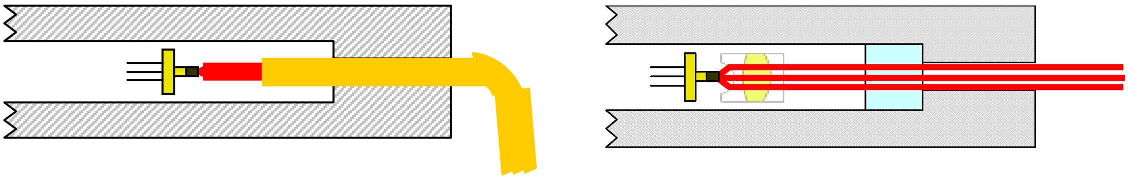


Fig. 2: Two methods of extracting the laser light from the cell: butt coupling to an optical fibre (left) and collimating with a microlens and passing through a sapphire window (right).

The solution with the sapphire window required a collimating lens which is not sensitive to the changes of the refractive index of the pressure medium. The refractive index of gasoline increases from 1.35 up to 1.55 at 20 kbar of pressure [5]. We designed a triplet consisting of two lenses from BK7 glass and one lens from ZnSe (see Fig. 2). This triplet was indeed insensitive to the index of the medium but cracks appeared after a few pressure cycles and the lens was no longer transparent. We achieved better results with graded-index lenses. These lenses form the beam inside the lens due to the radial gradient of the index. We still observe some deterioration of the beam at the highest pressures, but further improvements of the microlens are still possible.

One more optical problem arises at wavelengths above 1 micron where gasoline (and pentane-hexane) start to absorb strongly, especially in the band around 1700 nm and above 2250 nm (see Fig. 3). It is therefore important to keep the thickness of gasoline layer as small as possible. This is easy for fibre butt coupling where a distance of only 50-100 microns from the laser to the fibre is needed. However, with the microlens and the optical window, the layer of gasoline needs to be about 0.5 mm thick, which can reduce the laser emission power in the absorption bands discussed above.

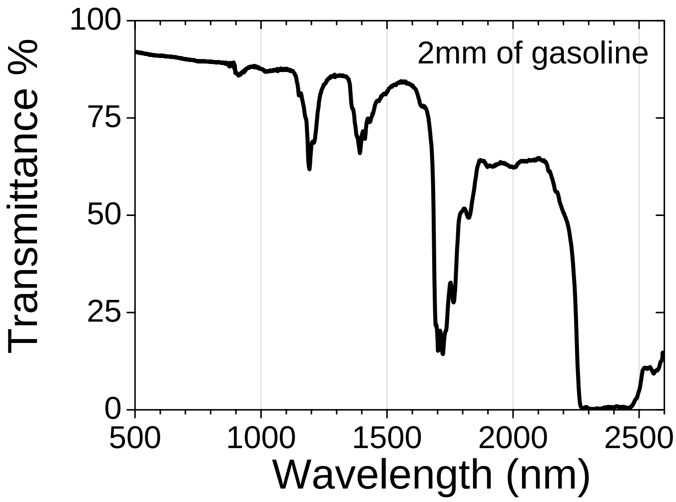


Fig. 3: Transmittance of a 2 mm layer of gasoline measured by a spectrophotometer. Strong absorption bands occur at around 1700 nm and 2300 nm.

The pressure cell is placed under a small hydraulic press (see Fig. 4). With the light coming through the fibre we can place the fibre anywhere in the optical system. When using the window, the collimated beam is reflected at 45° from a mirror placed below the cell so that the output beam is parallel to the optical table. This solution is necessary for coupling the light to an external grating. We used the Littrow configuration, where the first order of diffracted beam is sent back to the laser and the zeroth order is used as an output beam. The grating was connected to another mirror and these were rotated around the axis being the intersection of the plane of the grating and the plane of the mirror (following the method described in [5]). With this geometry the output beam has a fixed direction while rotating the grating.

Another setup used for pressure/temperature tuning is shown in Fig.5. Here the pressure is fixed, but the temperature can be varied.

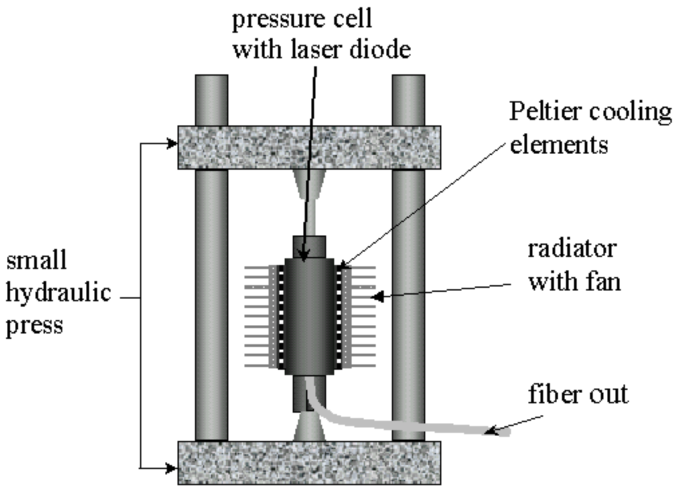


Fig. 4: Pressure cell with Peltier cooling system (down to -50°C) placed under a hydraulic press. The laser light comes out through the optical fibre. In case of the window in the cell, the collimated output beam is reflected from a mirror at the bottom of the press.

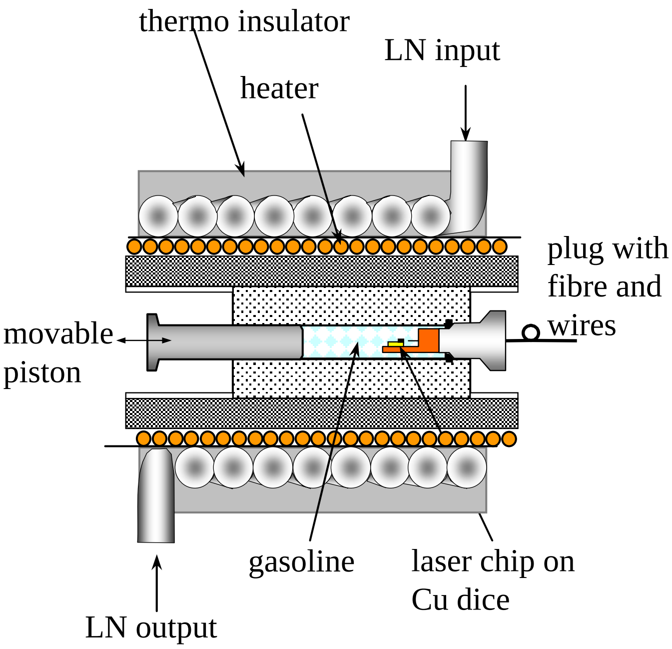


Fig. 5: Pressure cell with liquid-nitrogen cooling system. The position of the piston is fixed but temperature tuning can be performed (down to -190°C). The laser output is through an optical fibre, but an optical window is also possible.

We now discuss laser diode mounting appropriate for pressure or temperature tuning. A semiconductor diode laser is usually soldered p-side down (with In or AuSn solder) to a submount. The submount is then mounted onto a heatsink. In order to avoid soldering-induced strain, the submount is chosen so that the thermal expansion is close to that of semiconductor. The thermal conductivity of the submount must also be high, especially for high-power lasers. Typical submounts used commercially include AlN, SiC and diamond. As shown in Table 1, these submounts are much harder than GaAs (or InP). Thus, large tensile strain is generated in GaAs lasers that are soldered to AlN or SiC and then operated under high pressures. It is hard to find submounts with both thermal expansion and compressibility matched to GaAs. The closest is silicon, but its thermal conduction is not the best. For Cu and Ag heatsinks, the strains generated by pressure compensate the strains generated by temperature (i.e. strains generated while cooling down after soldering). The strains depend on the solder (soft indium solder can relax some of the strain) and on the size of the chip (for small chips, the strains are relaxed). For indium solder after multiple pressure cycles, we found that it was often the solder which degraded, not the laser.

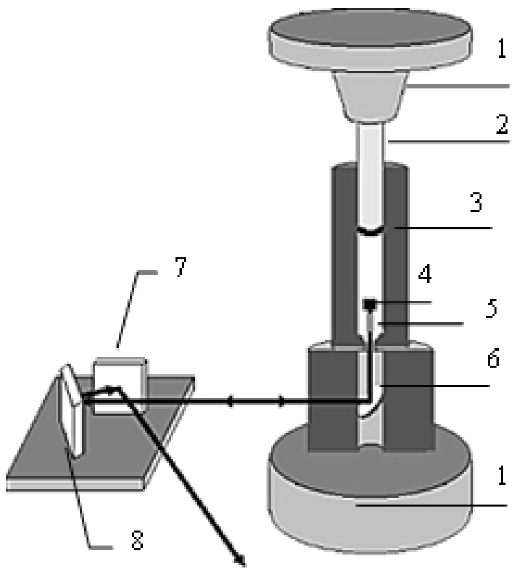
After re-soldering (heating up to 180 °C) the laser recovered its initial characteristics. We also found that red InGaP/AlGaInP lasers were most fragile, i.e. they degraded after pressure cycles much more than other lasers. For this reason, this type of laser was used in our mounting tests. We obtained the best results for lasers mounted with AuSn on Si and with In on Cu or Ag. Obviously, it is also important to have the solder without any voids because under pressure these may cause cracking of the laser chip.

Material	GaAs	Cu	SiC	Ag	AlN	Si
Linear compressibility $\Delta L/L/\Delta p$ (%/GPa)	0.44	0.24	0.13	0.33	0.16	0.33
Thermal expansion coefficient (10^{-6}/K)	5.7	16.5	4	18.9	4.5	2.6
Thermal conductivity at 300K (W/m/K)	55	400	300	430	170	140

Table 1: Thermal and pressure-related parameters of some common submount and heatsink materials.

For the temperature tuning, we constructed a small cryostat with the laser diode and the micro-optics in a vacuum chamber. Temperature tuning is much simpler experimentally than pressure tuning. Standard collimating optics can be used, as well as standard mounting of the laser chip (since the submounts are thermally expansion matched to the semiconductor chip). Moreover, the threshold currents usually go down and the lifetime of a laser diode is usually increased at low temperature. There can be problems with p-type claddings at low temperatures because in some materials (e.g. in nitrides) a high concentration of holes cannot be achieved and the carriers can be frozen onto the acceptors at low temperatures. Also, the expansion matching of the submounts only occurs around room temperature. At low temperatures, the thermal expansions can differ and cause strain. Coupling to an external grating is straightforward and can be achieved from both facets of the laser, since the cryostat has two (or more) optical windows. However, the tuning range with the grating decreases rapidly at low temperature because the width of the gain curve decreases with temperature.

The combination of pressure and temperature tuning (as in the setups shown in Fig. 4 and Fig. 5) yields the widest tuning range and is particularly useful for red lasers, since it allows yellow-green emission to be obtained – something that is otherwise not directly available from a laser diode. It is also possible to simplify this task by cooling the pressure cell (with a laser diode inside) down to a fixed temperature (e.g. liquid nitrogen at -190°C or dry ice at -80°C). We can then use a simple thermos with the pressure cell inside and obtain different emission wavelengths by adjusting the pressure. Finally, Fig. 6 shows the setup for combining external resonator methods with pressure tuning. This allows single-mode emission over a wide tuning range to be obtained. Instead of the grating, we have also carried out experiments using a photorefractive crystal cavity (see next section).



KEY
1. Hydraulic press
2. Piston
3. Pressure cell
4. Laser diode
5. GRIN lens & window
6. Mirror
7. Additional mirror
8. Diffraction grating

Fig. 6: Pressure tuning combined with an external grating (an additional mirror is used to fix the direction of the output).

Results

For longer wavelength lasers, pressure tuning is only limited by the available pressure range. Using a 20 kbar pressure cell, a tuning range of about 200 meV can be achieved. For InGaAs/GaAs lasers this means tuning from 960 nm to 830 nm with almost constant output power over the whole tuning range [7,8]. This is shown in Fig. 7, where we plot the emission spectra from a pressure tuned 960 nm tapered InGaAs/GaAs laser (fabricated by IAF) and the threshold currents vs pressure at different temperatures. For tapered lasers, the beam-quality parameter (M^2) is one of the most important characteristics. The M^2 value was around 1.3 for the IAF laser, which is a very low value. This value was found to be independent of pressure (see Fig. 8), which is very encouraging for pressure tuning.

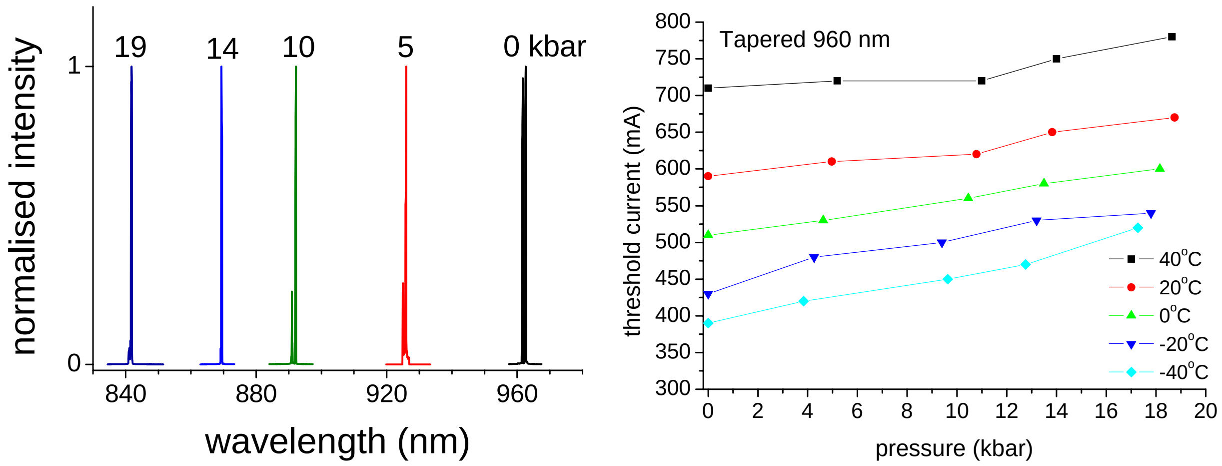


Fig. 7: Emission spectra at different pressures (left) and threshold currents vs pressure and temperature (right) for a 960 nm tapered laser from IAF.

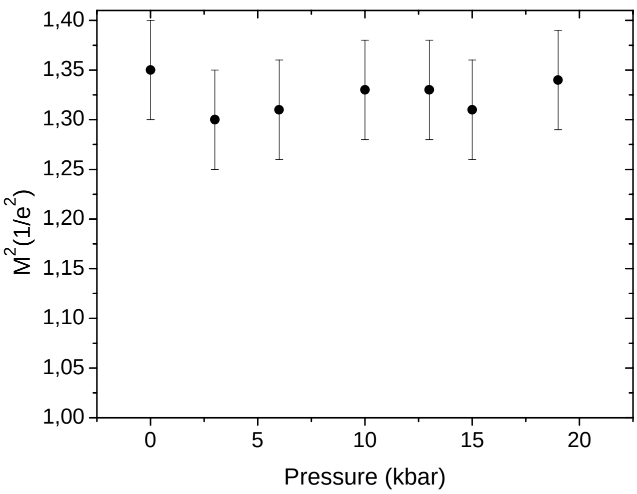


Fig. 8: Beam quality parameter M^2 as a function of pressure for the 960 nm tapered laser from IAF.

The most spectacular tuning range (a range of 700 nm) was achieved for a 2400 nm InGaAsSb/AlGaAsSb laser diode [9] obtained by our collaborators at Montpellier University (see Fig. 9). In this case, the thresholds went down and then above 8 kbar started to increase. We suspect that this increase may be caused by electron leakage.

For wavelengths between 600 nm and 800 nm, the tuning range is limited by the increased leakage under pressure. Figure 10 shows the threshold currents vs pressure at a few different temperatures for 800 nm InGaAsP/AlGaAs lasers and for 650 nm InGaP/AlGaInP lasers (grown by FBH). For these lasers, we can combine pressure and temperature tuning. This is discussed in the next section.

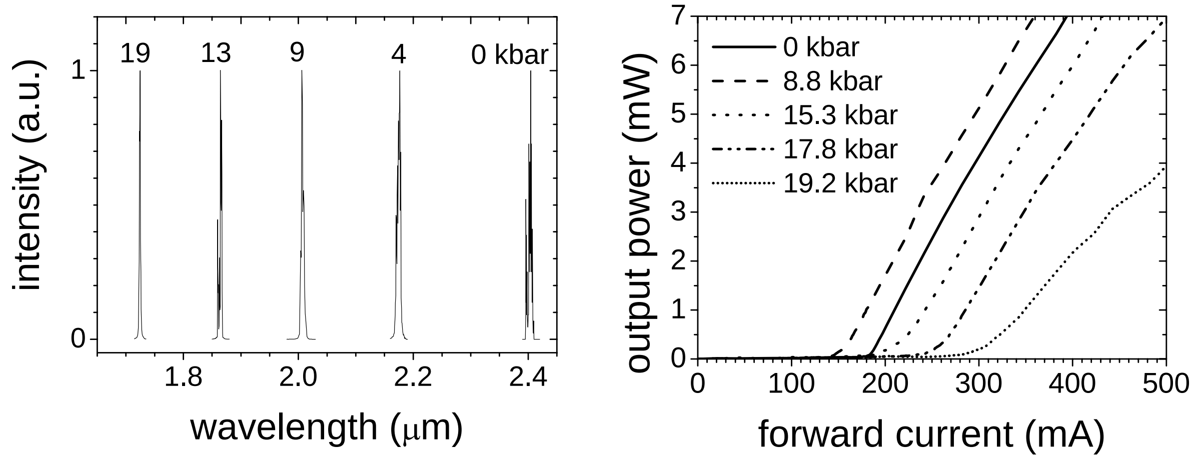


Fig. 9: Emission spectra (left) and light-current characteristics (right) for a 2400 nm laser at different pressures.

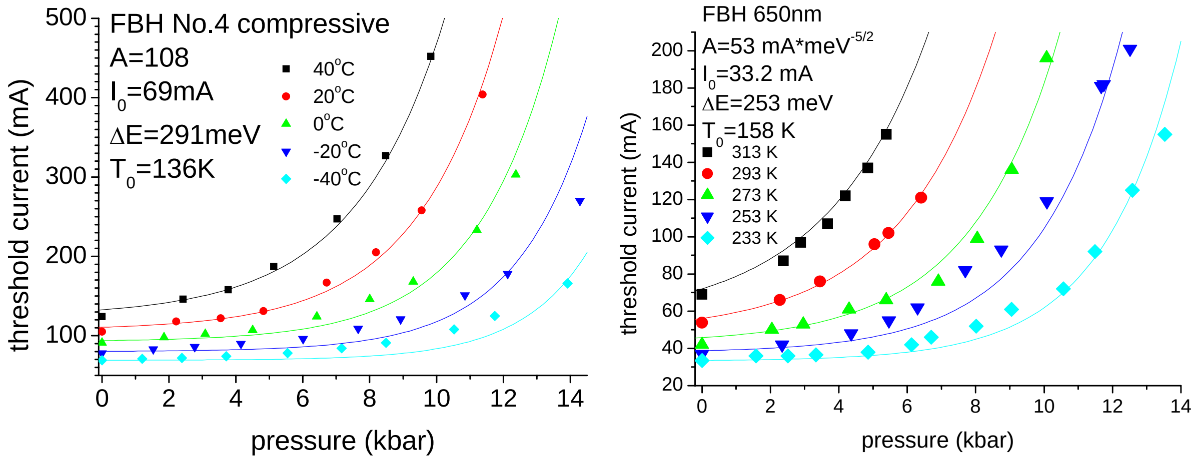


Fig. 10: Threshold currents vs pressure at various temperatures of 800 nm (left) and 650 nm lasers (right) grown by FBH.

Using the setup shown in Fig. 6, we combine pressure tuning with external resonator methods [11,12]. We employed a grating with 20% light diffracted in the first order and 70% in the zeroth order (in Littrow configuration). The tapered laser fabricated by IAF was placed in the pressure cell with a GRIN collimating lens and a sapphire window. A cylindrical lens for collimating the slow axis was placed outside the pressure cell. At each pressure, tuning by the grating has been performed (see Fig. 11). Single-mode emission with powers above 500 mW was achieved over a 140 nm tuning range.

Instead of the diffraction grating, we have also used an external cavity formed by the use of a photorefractive crystal ($KNbO_3$ doped with Rh and Mn). In this case, it was not possible to perform fine tuning at each pressure (like it was with the grating), but single-mode emission combined with a wide pressure tuning range (120 nm) was obtained (see Fig. 12).

Visible laser diodes are available in the red (690-635 nm) and in the blue (410-480 nm) spectral ranges. Large strains and indium segregation in the InGaN/GaN system prevent the shift from blue to green, while insufficient confinement and large leakage currents prevent the shift from red to yellow and green in the AlGaInP/InGaP system. The only access to the yellow and green range has been achieved by frequency doubling of infrared laser diodes or by frequency doubling of diode-pumped solid state lasers. This spectral range has some important applications in dermatology and ophthalmology. Plastic fibres also achieve their maximum transmission around 580 nm.

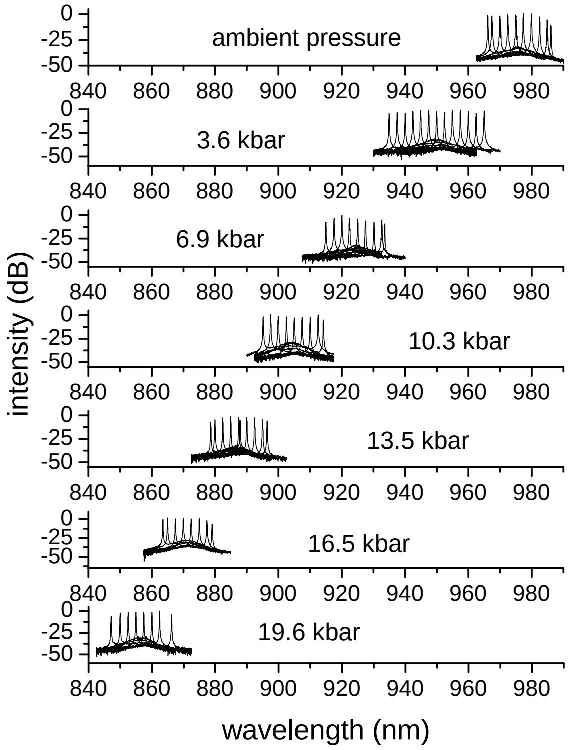


Fig. 11: Emission spectra for a tapered laser coupled to an external diffraction grating. At each pressure, tuning with the grating was performed (each emission line corresponds to a given position of the grating).

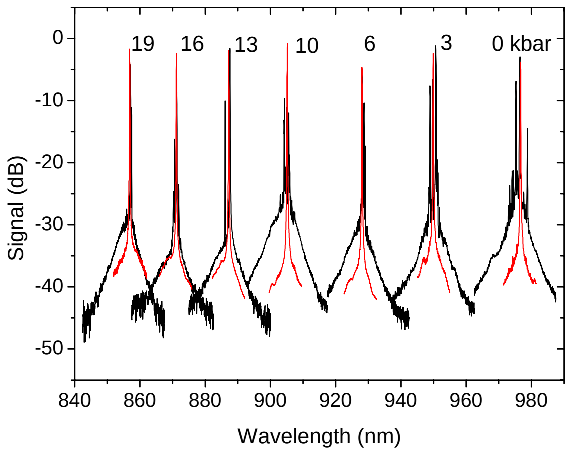


Fig. 12: Emission spectra of the tapered laser with (red line) and without (black line) the photorefractive $KNbO_3$ crystal doped with Rh and Mn (note that the intensity scale is logarithmic).

As shown in Fig. 10, pressure tuning is not effective for red lasers because of the increased leakage currents. However, the combination of high pressure and low temperature has been shown to yield a 70 nm tuning range with a low threshold current and a good external efficiency [13]. In Fig. 13, we show the emission spectra for a 645 nm laser diode (fabricated by OSRAM) at different pressures and temperatures. In this case, the laser was coupled to a fibre (in a cooling system as shown in Fig. 5). An output power of 300 mW was obtained from a 200 micron fibre over the range from 645 nm down to 575 nm. It is also possible to use a pressure cell with a window, which would allow the laser to be coupled to an external resonator. There are many reliability issues (related to multiple pressure and temperature cycles), which remain to be solved. However, the possibility of reaching yellow-green emission seems valuable. Fig. 14 shows a photograph of the emission from a red laser diode, a similar diode tuned by temperature and the diode tuned by both pressure and temperature.

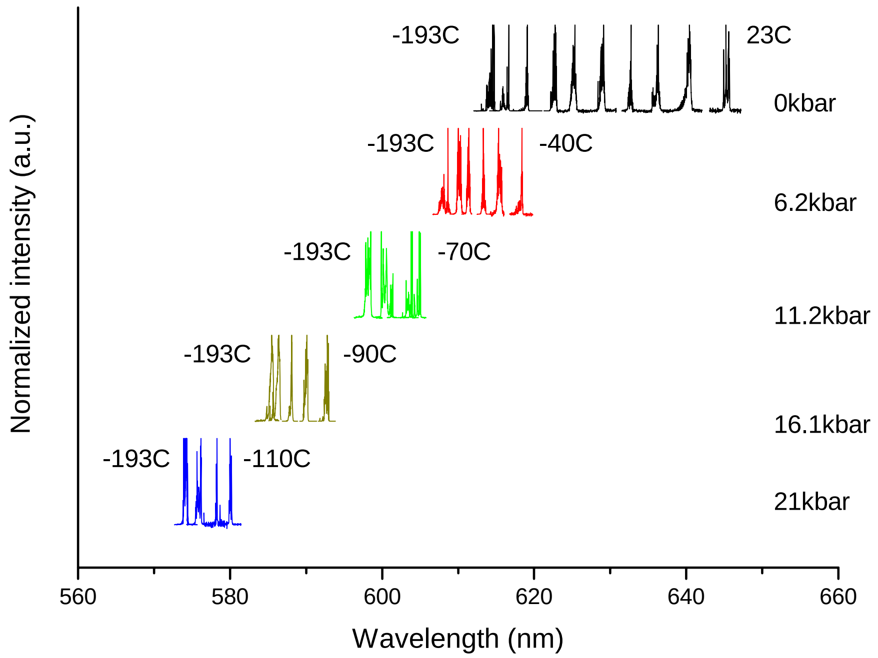


Fig. 13: Emission spectra of a red 645 nm laser tuned by temperature at different pressures. The lowest temperature was -193°C and the highest depends on the pressure and is shown at the right-hand side of the spectra at each pressure.

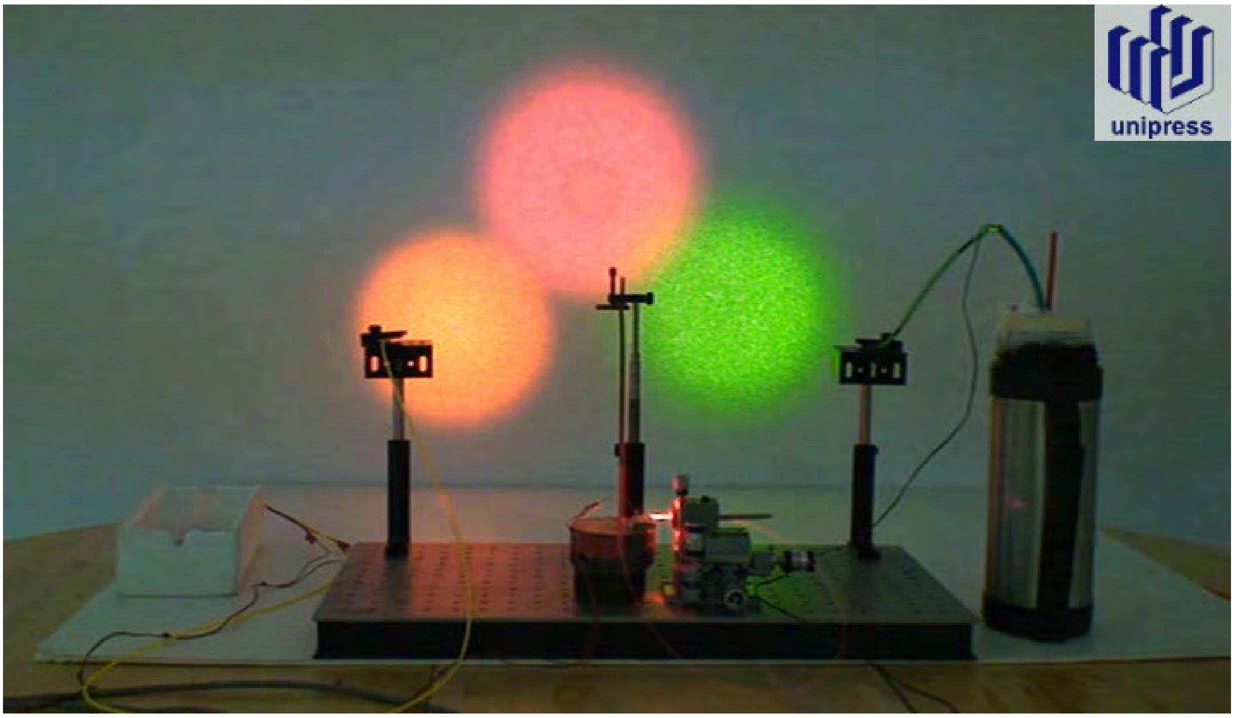


Fig. 14: Emission from fibre-coupled laser diodes. The red emission in the centre comes from an OSRAM laser diode at ambient conditions. The orange emission to the left is from a red laser cooled to liquid nitrogen temperature. The green emission to the right comes from a red laser under 18 kbar of pressure and at liquid nitrogen temperature (the pressure cell is dipped in the thermos filled with liquid nitrogen).

Conclusions

Pressure tuning in 200 meV range has been demonstrated for infrared laser diodes in the 800 nm - 2400 nm spectral region. For the shorter wavelengths, temperature tuning or a combination of pressure and temperature tuning seems more practical. In particular, the yellow-green region can be reached by tuning red lasers. The combination of pressure tuning with tuning by an external grating combines the merits of both methods, i.e. a wide spectral range, narrow linewidth, single-mode emission and good beam quality.

Special care must be taken to ensure good reliability of the lasers and of the tuning module (reduced mounting strains, good heatsinking in the cell, special micro-optics, tungsten carbide inserts in the cell and multiple-use gaskets). Several improvements are still required to create a user-friendly pressure-tuned module, which can be used by non-specialists.

Acknowledgments

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Red Lasers for Medical Applications

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Introduction

Recent technological developments have boosted the use of semiconductor lasers for various medical applications. In this context, these devices provide key advantages such as compactness, power and reliability. Currently, near infrared lasers are established sources in applications like dermatology and surgery. Beyond this, red emitting laser bars with improved performance are being developed within the WWW.BRIGHTER.EU project to replace bulky argon-ion pumped dye lasers for cancer treatment with photodynamic therapy. These activities, and the associated challenges, will be the topic of this article.

Application requirements

Photodynamic therapy (PDT) is a treatment that uses a photosensitizer and a light source emitting at a particular wavelength. The photosensitizer agent is injected into the blood stream and accumulates within several hours in cancer cells. When the photosensitizer is exposed to a specific wavelength of light, they produce singlet oxygen that kills the cells. Since the accumulation probability of the photosensitizer is significantly enhanced in cancer cells, selective treatment can be achieved. Due to its nature, the PDT procedure usually has fewer undesirable side-effects than chemotherapy, potentially offering the cancer patient a greater chance for recovery and better quality of life during treatment.

A limitation of photodynamic therapy is the penetration depth of light into tissue, which restricts this treatment to tumours on or just under the skin. However, coupling the light through optical fibres opens the path for interstitial photodynamic therapy of larger tumours or organs. Two aspects for improving the next generation PDT systems are directly linked to the excitation source:

- Innovative photosensitizers like ALA are designed to show a significant absorption band in the wavelength range around 635 nm, a spectral band, where a reasonable penetration depth of light into tissue is achieved
- Scalability of optical power by using the light of different laser emitters coupled into a fibre bundle

These requirements define the key parameters for semiconductor light sources as they are developed within the BRIGHTER Consortium. Diode laser systems are lightweight and easy to handle. Latest progress in performance leads to cost efficient high power devices, which can be used as reliable light sources, allowing PDT to be extended to a much broader variety of situations.

Figure 1: Modern medical treatments like photodynamic therapy require reliable laser sources at a specific wavelength (e.g. 635 nm) in order to provide efficient interaction between the light source and the photo-activated drug.

Red high power lasers

The material system of choice for semiconductor lasers emitting in the 630-680 nm range is the $(Al_xGa_{1-x})_yIn_{1-y}P$ alloy. High optical outputs can then be achieved by fabricating broad area lasers, where the gain and guiding in the lateral dimension are defined by the wide contact stripe.

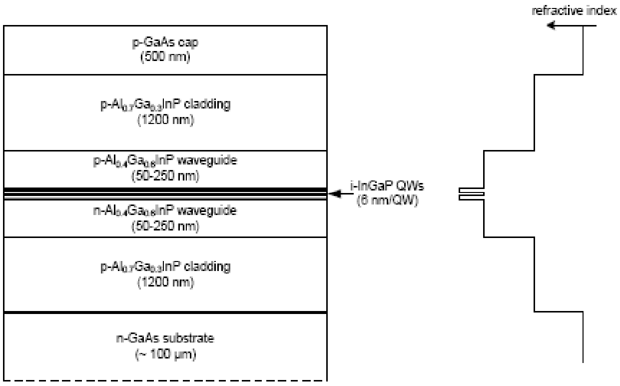

Figure 2: Standard AlGaInP epitaxial structure [1].

In a typical device, as depicted in Fig. 2, one or more quantum wells are sandwiched between waveguide and cladding layers with different aluminium concentrations. All regions but the quantum well are grown with an indium content of 51% and are thus lattice matched to the GaAs substrate. The indium content and thickness of the quantum well, on the other hand, are carefully selected to obtain the desired wavelength. Depending on this choice, the active region will experience either compressive or tensile strain, therefore affecting the gain spectra and favouring TE or TM polarisations, respectively (see the work presented by UNIPRESS in this newsletter).

The intensity profile and divergence of the laser mode in the fast axis direction, as well as its confinement factor, are tailored through the thickness and material composition of the waveguide layers (see Fig. 3). On the one hand, narrow "Gaussian"-shaped vertical far-field patterns are preferred for efficient fibre coupling (to bring light to the tissue). However, regarding the confinement factor, a trade-off must be reached between low thresholds and catastrophic optical damage power levels (related to the peak power of the mode at the position of the quantum wells).

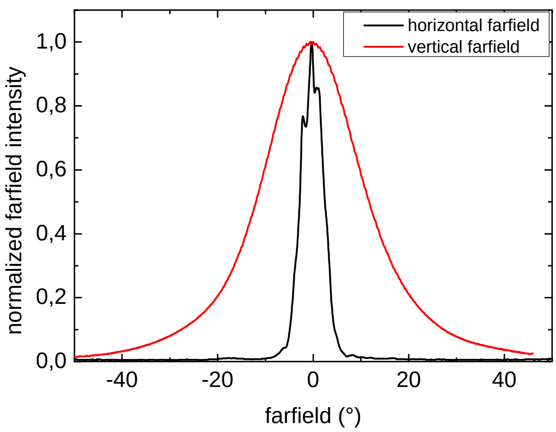

Figure 3: Measured transversal and lateral far-field patterns [1].

One challenge specific to the design of red semiconductor lasers is achieving good injection efficiencies (i.e. the percentage of injected current that is converted into laser light). In AlGaInP devices, the band-offset between the quantum well and the waveguide and cladding layers is typically small. As a result of the low potential barrier, carriers (particularly electrons) can escape from the quantum well via thermionic emission and recombine elsewhere. Furthermore, leakage currents increase exponentially with temperature leading to reduced T_0 values.

A great variety of less well known material parameters influence the leakage phenomena, complicating the design and modelling of red lasers. Amongst these, band alignment is critical: since the potential barrier is reduced for shorter operation wavelengths, the injection problem worsens, explaining the performance gap between 650 and 635 nm lasers (see Fig. 4). On the other hand, the carrier mobilities on the p-side of the structure (connected to drift and diffusion transport) are also of great importance. These issues are being analysed within the scope of BRIGHTER in collaboration with Universidad Politécnica de Madrid [2].

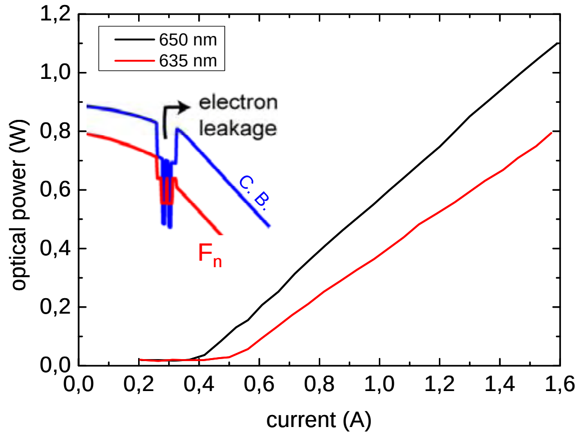

Figure 4: Comparison of two similar laser structures emitting at 635 and 650 nm. Both the threshold current and slope efficiency are affected by the decrease in injection efficiency at shorter wavelengths. The inset illustrates the main mechanism responsible for this, namely, the leakage of electrons into the p-waveguide and p-cladding.

The fraction of the applied power not converted into light dissipates as heat inside the device and causes a rise in the temperature of the active region. This, in turn, reduces the injection efficiency. This coupled problem makes thermal management a critical issue for red lasers (and more so in the 635 nm case).

Red single emitter lasers

Many laser applications are based on a single laser emitter as the excitation source. A very common mount for a single emitter semiconductor laser is the C-mount as presented in Fig. 5. In this case, the laser chip is soldered with the epi-side down on a heatspreading submount material like AlN. The AlN heatspreader is then soldered on the copper heatsink. This enables very efficient heat transport away from the semiconductor chip. The second advantage of this concept is the small footprint of the device, enabling flexible integration into various laser module concepts. The laser diode is mounted in a way such that its front facet is positioned close to the edge of the heatsink, providing free access for light coupling optics or direct fibre coupling.

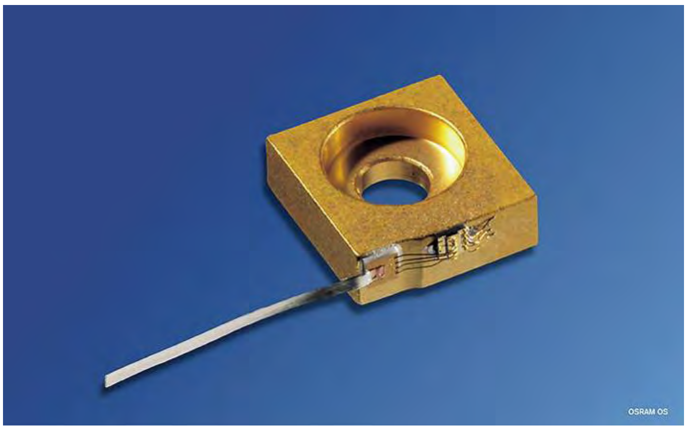

Figure 5: Single semiconductor laser chip mounted on C-mount. Due to the open mounting the output facet is accessible for direct light coupling into a single fibre.

The state-of-the-art for red single emitter semiconductor laser chips using this mounting scheme is an optical output power of ~500 mW. However, the required optical power levels for future PDT systems are in the range of 3-5 W. This can, in principle, be achieved by using several single emitters in parallel. Nevertheless, the effort for increasing the power scales linearly with the number of single emitters in use, since control of the laser and coupling of the light has to be done and to be optimised separately for every single emitter. The increasing complexity is a clear disadvantage with respect to cost and reliability.

Red laser bars

The alternative concept for increasing the optical output power is the use of laser bars. In this case, the single emitters are monolithically integrated and positioned in parallel. Under operation, the lasers radiate in parallel and enable, in principle, the up-scaling of the output power.

The Sirilas® laser package

An advanced laser package concept developed by OSRAM Opto-Semiconductors is established under the trademark Sirilas. The package concept is based on a TO 263 copper leadframe with high thermal conductivity, typically used in high power electronics. The housing is suitable for laser bars up to 6.5 mm in width and 4 mm in emitter length. The laser bar is mounted close to the front edge of the copper heatsink, as shown in Fig. 6. Coupling the light into optical elements like fibres can easily be done, since the light-emitting facet of the laser is freely accessible in this housing concept.

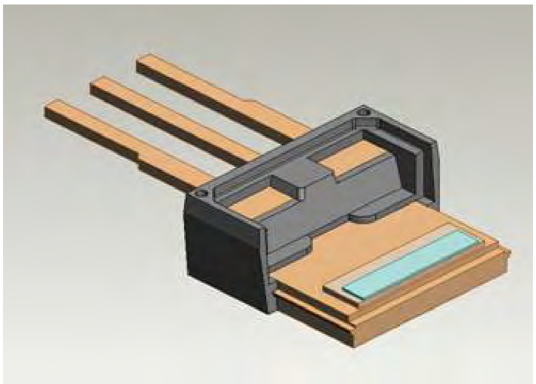

Figure 6: Sirilas laser housing, suitable for laser bars up to 6.5 mm in width and 4 mm in emitter length.

As in the mounting of single emitters, the laser bars are soldered onto a heatspreader such as CuW that acts as an intermediate layer to the copper baseplate. Red laser bars are always mounted p-side down, due to the huge amount of dissipated heat that needs to be dealt with. On top of that, due to the relatively large length of laser bars, great care should be taken during mounting in order to prevent problems such as soldering inhomogeneities, which may affect the performance and lifetime of the bars.

For improved heat management, the Sirilas is also available with an active liquid cooling system. However, the liquid cooling makes the equipment more complex. This results in a more expensive and larger module, potentially more vulnerable to system failure. Since for medical treatment systems reliability and simplicity of operation is of key importance, the focus for this application is only on passively cooled laser bar concepts, demanding strongly improved heat management within the Sirilas housing.

The thermal management of a laser bar is essentially different to that of a single emitter, since the dissipated heat of the adjacent emitters will influence the performance of the whole device. Figure 7 shows the temperature distribution, under typical operating conditions, in a laser bar containing 5 emitters (500 μm pitch between the adjacent emitters, each 100 μm wide). This simulation accounts for the thermal properties of CuW as the heatspreader between the laser bar and the Cu heatsink. The thermal crosstalk between the emitters can clearly be observed, which generates a significant gradient in temperature between the central emitter and those at the edge of the bar. This makes the heat management more critical and causes the overall output power of a bar to scale nonlinearly with the number of emitters.

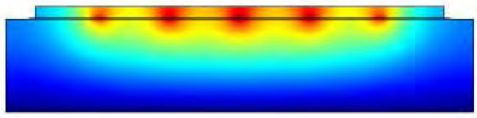

Figure 7: Thermal model of a red laser bar in a Sirilas package (increasing temperature from blue to red). The thermal crosstalk between emitters increases the junction temperature of the central emitter, making bar thermal management more difficult.

A dominant factor in the heat dissipation from the semiconductor laser bar into the package is the thermal conductivity of the laser submount. Therefore, one aspect for development is the evaluation of novel submount materials. Copper-diamond (CuDia), for example, is an innovative and promising candidate, since its thermal conductivity exceeds the value of the established CuW. More efficient heat dissipation will reduce the junction temperature of the laser at a given operation current and will result in a higher optical output power.

Figure 8 shows the quantitative impact of different heatsink materials on the output power of red laser bars in a Sirilas package. The semiconductor chips are emitting around 640 nm. In this case, the laser bars consist of 10 emitters with a width of 50 µm and a pitch of 250 µm. The resonator length is 1200 µm. By direct comparison of the two P-I characteristics, the clear advantage of the sample with CuDia submount becomes evident. The latter shows a steeper slope, resulting in more than 20% higher output power (3.7 W vs. 3.0 W) at a current of 6 A.

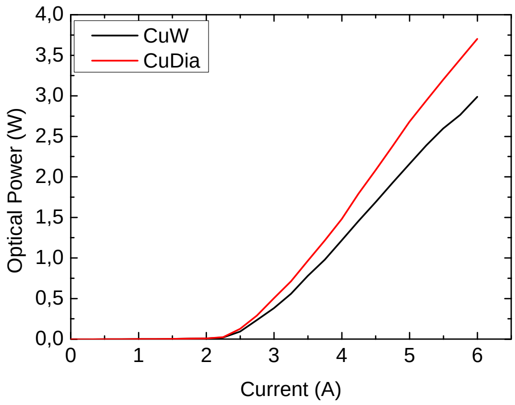

Figure 8: Impact of heatsink material on optical performance. Innovative heatsink materials open the way for strongly increased output powers.

Summary

The development of red laser bars for medical therapy in the wavelength range around 635 nm is challenging. Several laser parameters like carrier injection efficiency, confinement factor of the laser mode and the level of catastrophic optical damage at the facet are closely linked and often require a trade-off to be made.

Within BRIGHTER, significant progress in performance has been made with the use of innovative materials (CuDia) as heat spreaders between the semiconductor chip and heatsink. Based on this particular heatsink material and by using short (3.5 mm) laser bars with an improved epitaxial design, we have demonstrated optical output powers in excess of 3 W, making these devices suitable as excitation sources for photodynamic therapy.

The next key aspect for further development of red laser bars will focus on improving the mirror stability by reducing the facet absorption. This will reduce the impact of self heating processes at the facet, increasing the power level at which catastrophic optical mirror damage (COMD) occurs. The optimised laser facets will enable the same optical output power to be reached with a reduced active emitter width, thereby simplifying the thermal management of the laser bar.

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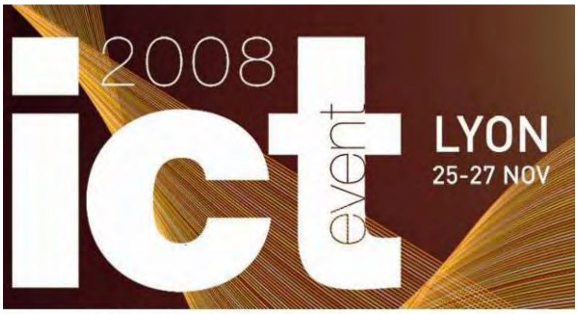
BRIGHTER @ ICT 2008



Europe's biggest ICT research event!

Towards the end of 2008, the BRIGHTER Consortium took part in Europe's biggest ICT research event, with a booth at ICT 2008.

The 2008 ICT Event, organised by the European Commission's Directorate General for the Information Society and Media, took place in Lyon, France from the 25th to the 27th of November 2008.

The biennial ICT Event is the most important forum for discussing research and policy in information and communication technologies at European level.

The event brings together researchers and innovators, policy and business decision makers working in the field of ICT. In 2008, more than 4,500 delegates attended the three day event. The 2008 ICT Event included more than 180 exhibits showcasing the latest breakthroughs in European research projects, including the BRIGHTER Project booth in the ICT for Wellbeing Village and a booth from project partner Biolitec in the SME Village.

The BRIGHTER exhibit (see photo below) was packed with demonstrations for visitors to see and interact with, including a state-of-the-art green laser source based on a frequency-doubled infrared laser, a range of laser diode samples and a dynamic simulation visualiser through which the internal workings of a laser diode could be investigated. Posters summarised the main application areas of the project – biomedical, communications and displays – whilst a rolling presentation gave more information about all topics related to the project. Our project film clip (see next page) was also premiered on the BRIGHTER booth. Visitors to the booth were also able to talk with experts from the Consortium, read our project e-Newsletters and take away a USB key containing more information about the project.

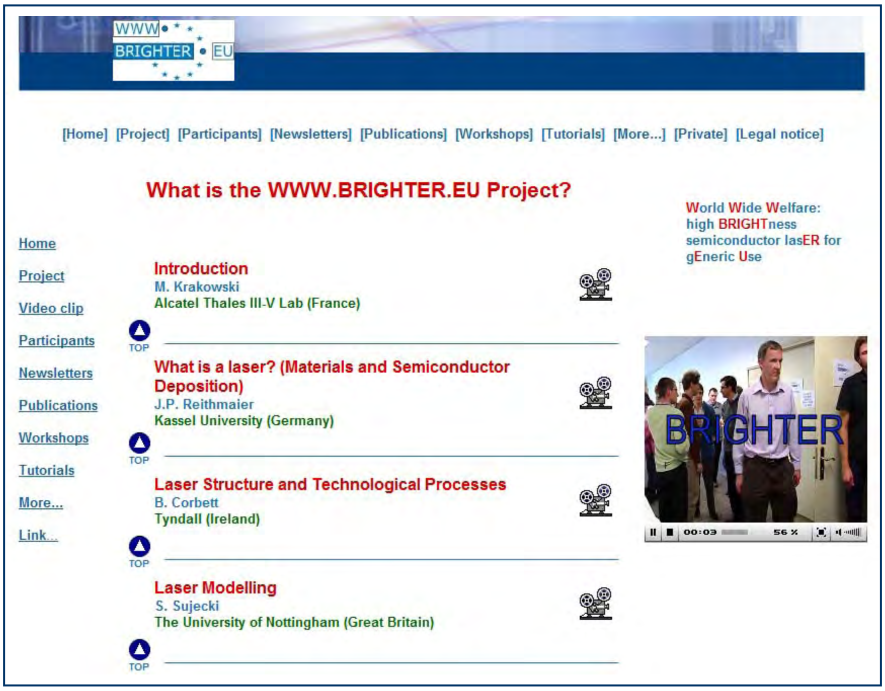
We would like to thank all who visited us at ICT 2008 and hope that you enjoyed learning about our project!

PROJECT FILM CLIP

Over the course of the project, the Consortium has produced a short, 15 minute, film clip about the different aspects of BRIGHTER. The aim of the film is to raise awareness of the BRIGHTER project and its activities. The completed film was on display at the BRIGHTER booth at the recent ICT Event in Lyon and was also distributed to visitors to the booth. The total film is divided into 11 short segments (see list below), which are now available to view on our project website at http://www.ist-brighter.eu/clip.htm. Just click on the video camera to watch a clip (see screenshot below). The videos can also be viewed in full screen mode if you wish.

BRIGHTER Film Segments

1. **Brighter: Project Introduction**
2. **What is a laser? (Materials and Semiconductor Deposition)**
3. **Laser Structures and Technological Processes**
4. **Laser Modelling**
5. **Frequency Doubling**
6. **Reliability and Degradation**
7. **Laser Packaging**
8. **Display Applications**
9. **Medical Applications**
10. **Telecom Applications**
11. **Dissemination**



Above: Example of the film clip page that can be found on the BRIGHTER website at http://www.ist-brighter.eu/clip.htm. Right hand column: Some of the participants in the BRIGHTER project in screenshots taken from the film clip.

SELECTED RECENT PUBLICATIONS

Laser Materials, Amplifiers and Modules

- B. Sumpf, K.-H. Hasler, P. Adamiec, F. Bugge, J. Fricke, P. Ressel, H. Wenzel, G. Erbert, G. Tränkle, "1060 nm DBR tapered lasers with 12 W output power and a nearly diffraction limited beam quality," Proc. SPIE Vol. 7230, 72301E, 2009.
- N. Michel, H. Odriozola, C.H. Kwok, M. Ruiz, M. Calligaro, M. Lecomte, O. Parillaud, M. Krakowski, M. Xia, R.V. Penty, I.H. White, J.M.G. Tijero, I. Esquivias, "High modulation efficiency and high power 1060 nm tapered lasers with separate contacts," Electron. Lett. Vol. 45, pp. 103-104, 2009.
- P. Adamiec, B. Sumpf, D. Feise, K.-H. Hasler, P. Ressel, H. Wenzel, M. Zorn, M. Weyers, G. Erbert, G. Tränkle, "Twin-contact 645-nm tapered laser with 500-mW output power," IEEE Photon. Technol. Lett. Vol. 21, pp. 236-238, 2009.
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- R. Ostendorf, C. Schilling, G. Kaufel, R. Moritz, J. Wagner, G. Kochem, P. Friedmann, J. Gilly, M.T. Kelemen, "High-power frequency stabilized tapered diode amplifiers at 1064 nm," Proc. SPIE Vol. 7198, 719811, 2009.
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- J.W. Tomm, M. Ziegler, V. Talalaev, C. Matthiesen, T. Elsässer, M.B. Sanayeh, P. Brick, H. König, M. Reufer, "New approaches towards the understanding of the COD process in in-plane diode lasers," Proc. SPIE Vol. 7230, 723030, 2009 (invited).
- J. LeClech, M. Ziegler, J. Mukherjee, J.W. Tomm, T. Elsässer, J.-P. Landesman, B. Corbett, J.G. Mclnerney, J.-P. Reithmaier, S. Deubert, A. Forchel, W. Nakwaski, R.P. Sarzala, "Micro-thermography of diode lasers: the impact of light propagation on image formation," J. Appl. Phys. Vol. 105, 014502, 2009.
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Medical Imaging and Lasers in Medicine

- J. Axelsson, J. Swartling, S. Andersson-Engels, "In vivo photosensitizer tomography inside the human prostate," Opt. Lett. Vol. 34, pp. 232-234, 2009.
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PROJECT e-NEWSLETTERS

Don't miss the next WWW.BRIGHTER.EU e-Newsletter!

Look out for the following in Edition 6 in September 2009:

- Partner profiles – *Alcatel-Thales III-V Lab; Alcatel-Lucent Bell-Labs (France); Institute of Communication and Computer Systems (ICCS), National Technical University of Athens; Lund Laser Centre*
- "Laser beam quality – Measurement & optimisation" – *III-V Lab*
- "3D binocular and fluorescence imaging of tumours" – *ICCS*
- "Large spot size lasers" – *Tyndall National Institute*
- "High-speed modulated lasers" – *University of Cambridge*


e-Newsletter n°6

September 2009

Available at http://www.ist-brighter.eu

WWW.BRIGHTER.EU

World Wide Welfare: High-Brightness Semiconductor Lasers for Generic Use

WWW.BRIGHTER.EU is an integrated project supported by the European Commission's Information Society Technologies programme

CONTENT

Greetings from the Project Coordinator 2

PROJECT NEWS

Latest Achievements 3

e-Newsletter Back Issues

If you missed any of the previous 4 e-Newsletters, or would like to see our 3 e-Newsletters from the earlier WWW.BRIGHT.EU project, please visit our website at http://www.ist-brighter.eu, where copies of all published e-Newsletters can be downloaded.

Some highlights of previous e-Newsletters!

Applications Articles

- Interstitial photodynamic therapy
- External cavity laser systems
- Diode lasers for display applications
- Optical wireless communication systems

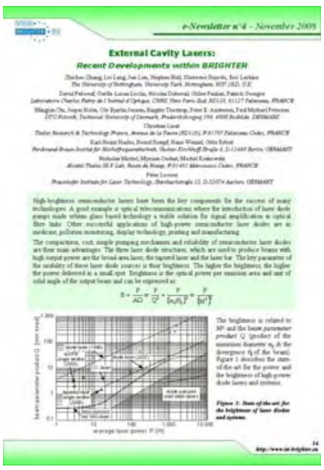
……and many more

Technical Papers

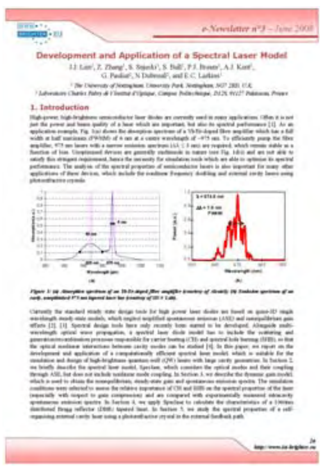
- Mirror heating in high-power lasers
- Spectral modelling of high-brightness laser diodes
- High-brightness tapered lasers with multiple contacts
- By-emitter degradation analysis of high-power laser bars

……and many more


Recent Progress in Interstitial Photodynamic Therapy for Solid Tumors


External Cavity Lasers: Recent Developments within BRIGHTER


Mirror Heating in High Power Lasers


Development and Application of a Spectral Laser Model

CALENDAR OF EVENTS

31st May – 5th June
Conference on Lasers and Electro-Optics (CLEO), *Baltimore, MD, USA*

5th June
LEOS Semiconductor Laser Workshop, *Baltimore, MD, USA*

8th – 12th June
European Materials Research Society (EMRS) – Spring Meeting, *Strasbourg, France*

6th – 13th June *[See page 41]*
International Graduate Summer School on Biophotonics, *Ven, Sweden*

14th – 19th June
European Conference on Lasers and Electro-Optics (CLEO-Europe), *Munich, Germany*

14th – 18th June
European Conferences on Biomedical Optics (ECBO), *Munich, Germany*

15th – 18th June
LASER 2009 – World of Photonics Exhibition, *Munich, Germany*

28th June – 2nd July
International Conference on Transparent Optical Networks (ICTON) , *São Miguel, Azores, Portugal*

13th – 17th July
Optoelectronics and Communications Conference (OECC) , *Hong Kong*

2nd – 6th August
SPIE Optics + Photonics 2009 – Conference and Exhibition, *San Diego, CA, USA*

10th – 14th August
New Frontiers in Optical Technologies Summer School, *Tampere, Finland*

30th August – 3rd September
Pacific Rim Conference on Lasers and Electro-Optics (CLEO-Pacific Rim), *Shanghai, China*

13th – 17th September *[See page 42]*
Defects – Recognition, Imaging and Physics in Semiconductors (DRIP), *Wheeling, WV, USA*

14th – 17th September
European Materials Research Society (EMRS) – Fall Meeting, *Warsaw, Poland*

14th – 18th September *[See page 42]*
Numerical Simulation of Optoelectronic Devices (NUSOD), *Gwangju, Republic of Korea*

20th – 24th September
European Conference and Exhibition on Optical Communication (ECOC), *Vienna, Austria*

4th – 8th October
IEEE LEOS Annual Meeting, *Belek-Antalya, Turkey*

14th October *[See page 43]*
High Power Diode Lasers & Systems Meeting, *Coventry, UK*

14th – 15th October
Photonex 2009 Event, *Coventry, UK*

2nd – 6th November
Asia Communications and Photonics Conference and Exhibition (ACP), *Shanghai, China*

BIOPHOTONICS '09

Biophotonics '09

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Biophotonics '09

6-13 June, 2009
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- Peter E. Andersen
  Technical University of Denmark
  Dept. of Photonics Engineering, Denmark
- Stefan Andersson-Engels
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  Physics Department, Sweden

Biophotonics '09

The purpose of Biophotonics '09 is to provide education for graduate students and young scientists at the highest international level within biophotonics. Hosting renowned lecturers from all over the world, the educational program is held in an international atmosphere enhancing exchange of scientific ideas and technological advances within the fields of biomedical optics and closely related areas.

At Biophotonics '09 the invited lecturers will give extended presentations providing basic understanding as well as state-of-the-art within:

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- Optical trapping and its applications in biophotonics
- Optical biosensors
- Molecular imaging based on optical methods
- Optical coherence tomography and coherence domain optical methods in biomedicine

Lecturers at the 4th International Graduate Summer School Biophotonics '09:

- Darryl J. Bornhop, Vanderbilt University, USA
- Kishan Dholakia, University of St. Andrews, United Kingdom
- Stefan W. Hell, Max-Planck-Institute for Biophysical Chemistry, Germany
- Joseph Izatt, Duke University, USA
- Steven Jacques, Oregon Health & Science University, USA
- Eva Sevick-Muraca, University of Texas, USA
- Katarina Svanberg, Lund University Hospital, Sweden
- Sune Svanberg, Lund University, Sweden
- Roy Taylor, Imperial College London, United Kingdom
- Bruce Tromberg, Beckman Laser Institute, USA
- Hubert van den Bergh, Ecole Polytechnique Fédérale de Lausanne, Switzerland

Publish your contribution in Journal of Biomedical Optics

Following the school, a special section appearing in Journal of Biomedical Optics (JBO) entitled "Selected Topics in Biophotonics" comprising review papers and contributed papers from the school are published.
All manuscripts under-go peer-review in accordance with the editorial standard of JBO.
The special section is scheduled for 2010.

NUSOD '09 CONFERENCE – SEPTEMBER 2009

9th International Conference on

Numerical Simulation of Optoelectronic Devices

14th – 18th September 2009

Gwangju Institute of Science and Technology (GIST)
Gwangju, Republic of Korea

Conference Chairs: Yong-Tak Lee, GIST, Korea and Joachim Piprek, NUSOD Institute, USA

The NUSOD conference connects theoretical research and practical device development in optoelectronics. Papers are solicited on the theory, modelling, simulation and analysis of optoelectronic devices including materials, fabrication and applications. Researchers, device engineers and software developers are invited to discuss the advancement and use of numerical tools in photonics and electronics. A special issue of Optical and Quantum Electronics will give authors the opportunity to publish expanded versions of their paper.

Find out more online at:
www.nusod.org/2009

Paper Submission Deadline:
11th May 2009

DRIP-XIII CONFERENCE – SEPTEMBER 2009

13th International Conference on

Defects – Recognition, Imaging & Physics in Semiconductors

13th – 17th September 2009

Oglebay Resort & Conference Center, Wheeling, West Virginia, USA

Conference Chair: Marek Skowronski, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA

As semiconductor technology has matured, so have the techniques for detection, identification and imaging of defects. Decreasing feature size, increasing wafer size and purity level, reduction of layer thickness and introduction of new materials have presented new challenges at every stage of semiconductor technology development. This evolution of the field continues today, and the new challenges will be the focus of DRIP-XIII. The DRIP conference is an established international conference series with a tradition of more than 20 years, which brings together the leading scientists in the fields of semiconductor physics and technology.

Find out more online at:
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Early Registration Deadline: 21st August

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ANNOUNCEMENT OF MEETING

High Power Diode Lasers & Systems

Date: Wednesday 14th October 2009

Venue: Royal Conference Suite, Stoneleigh Park, Coventry CV8 2LZ

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