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

EDITORIAL

Welcome to the 6th 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 one or more of the previous five editions of our e-Newsletter, then please visit our website to download your copy.

Our project is coming to an end and this is our final e-Newsletter. We hope that you enjoy this final edition and have also found the previous editions interesting and informative.

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GREETINGS FROM THE PROJECT COORDINATOR

Michel Krakowski
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Dear Reader,

Welcome to the sixth and final 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 progress with several new developments. Our recent highlights include: 1.5 W of green emission from a frequency-doubled infrared laser diode that can be modulated at 100 MHz for display applications; a new 4-port laser system for interstitial photodynamic therapy (PDT) with more than 2 W of output power (635 nm or 652 nm) per port; pre-clinical studies of medical diagnostic tools based on fluorescence imaging that can be used for the monitoring the PDT treatment of skin tumours; improved quasi-3D models for quantum dot tapered lasers and the identification of a preferential submount for red laser diodes in pressure tuning applications.

Inside this e-Newsletter, you will find an update on some of our latest achievements followed by profiles of the final four project partners. The profiles are followed by a feature article on female researchers within the project and on the need to actively engage more women in the ICT sector. There are four extended articles in this e-Newsletter. Two applications articles cover the topics of fluorescence imaging for tumour diagnosis and laser beam quality. Technical papers are presented on gigabit/s direct modulation of tapered lasers and on large spot size lasers. There is a short report on the successful 4th International Summer School, Biophotonics '09, which was organised by our partners from the Technical University of Denmark and Lund University, Sweden. The upcoming High Power Diode Lasers and Systems meeting, where several project partners will be presenting, is previewed. This meeting will be held during the Photonex '09 exhibition on 14th October in Coventry, U.K. and we look forward to meeting you if you are able to attend this event. At the end of this edition, you can find details of the project resources that are now available online (including tutorials, e-Newsletters, workshop presentations and the project film clip), a list some of our recent publications and a calendar of coming events.

Michel Krakowski

TECHNICAL ACHIEVEMENTS
Towards the Project Objectives

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

New Laser System for Interstitial Photodynamic Therapy (PDT)

Biolitec has developed, within the EC-project WWW.BRIGHTER.EU, a new laser system for interstitial PDT. It is based on the newest diode technology stemming from BRIGHTER project partners. These highly reliable diodes emitting at 635 nm or 652 nm now allow PDT laser systems with more than 2 W of output power per laser port.

The device (pictured below) features 4 laser ports and 4 ports for fluence detection fibres. The laser ports can be controlled individually in terms of laser power and emission duration. These parameters can be easily set via the integrated colour touch screen. The fluence detection ports record the amount of light scattered into isotopic probes. This allows the doctor to monitor whether specific regions have been sufficiently treated or whether other regions have obtained a too high an irradiation dose. The principal architecture of the system allows the number of laser or detection ports to be increased as required for the targeted treatment volume and indication.

For further information, please contact:
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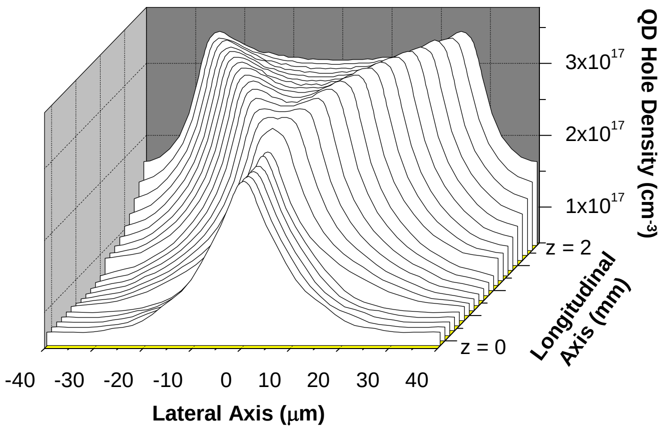
Quasi-3D Model for Quantum Dot Tapered Lasers

A quasi-3D model for Quantum Dot (QD) tapered lasers has been developed within the BRIGHTER project by the Technical University of Madrid (UPM). The model is an extension of a previous model developed by UPM and the University of Nottingham for quantum well tapered lasers. It includes the solution of the complete bipolar electrical, thermal and optical equations in steady state. For the QD region, a multi-population non-equilibrium model is considered. In this laser model, the interactions between the Wetting Layer (WL) and each QD level and size are considered in terms of processes of carrier capture / escape. The model includes the inhomogeneous broadening due to the different QD sizes, the homogeneous broadening in the gain, and different mechanisms for carrier recombination as well as the contributions of the carriers in the WL.



Profile of QD hole density in a tapered laser, showing the spatial hole burning in the centre of the cavity due to the high stimulated emission in this region

High Power Diode Lasers & Systems Meeting
14th October 2009, Coventry, UK

This event, the second to be held as part of the annual Photonex exhibition and this year co-sponsored by the BRIGHTER project, will highlight the latest advances in diode lasers & systems covering topics from advanced and novel pump laser diodes through to research and industrial systems.

Several BRIGHTER participants will be speaking at this event, so don't miss your chance to meet us and hear first hand about some of the recent project activities. More details can be found on pages 35-36 and online at http://www.photonex.org/hpdls.php.

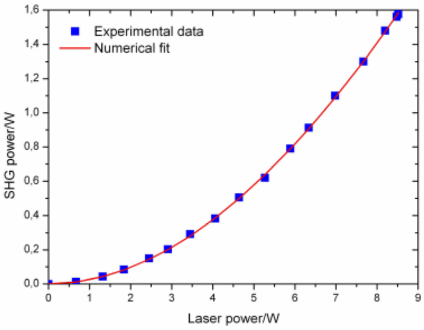
TECHNICAL ACHIEVEMENTS
Towards the Project Objectives

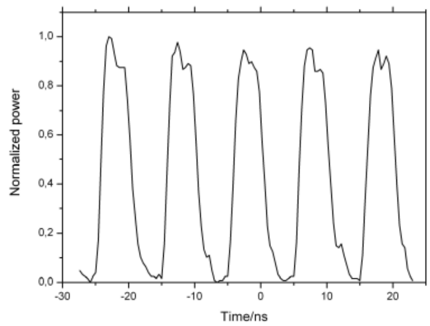
Compact green source for laser displays – 1.5 W output at 531 nm modulated at 100 MHz

DTU Fotonik has demonstrated a compact and robust high-power green laser system emitting more than 1.5 W of output power at a wavelength of 531 nm. The system is based on single-pass SHG of a 1062 nm high power multi-section DBR tapered laser from project partner, the Ferdinand-Braun-Institut für Höchstfrequenztechnik (FBH).

By modulating the current to the ridge section of the laser with a modulation frequency of 100 MHz, the green light has been equally modulated, making it ideal as a compact, robust and efficient green light source for laser display applications.

O.B. Jensen et al., Optics Express Vol. 17, pp. 6532-6539, 2009



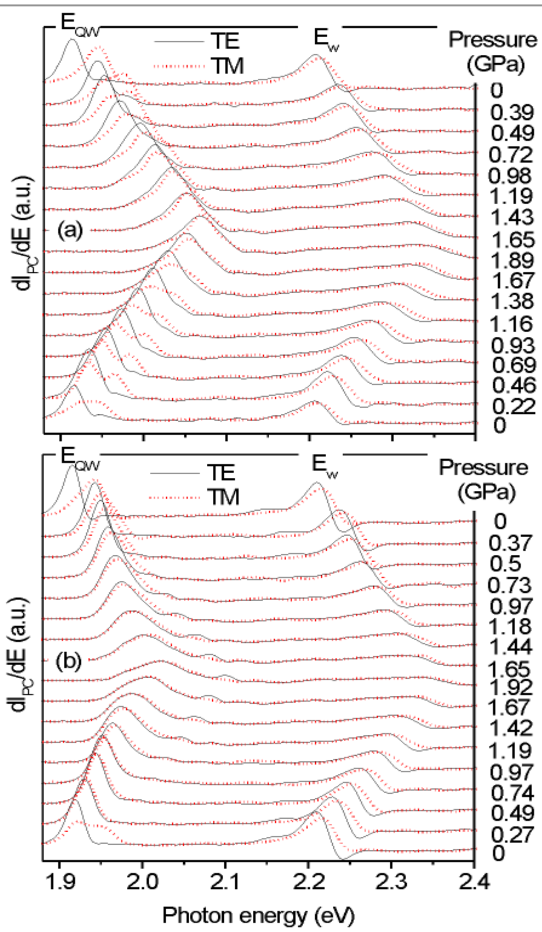


Pressure tuning of mounting-induced strains affecting red-emitting (Al)InGaP laser diodes

We have studied the pressure tuning of red-emitting diode lasers packaged on Si, AlN and diamond submounts. The bandstructure is probed by measuring photocurrent (PC) spectra in conjunction with electroluminescence (EL) measurements. By using the PC technique, we benefit from the unique option to simultaneously monitor both the quantum well (QW), that is responsible for the device functionality, and the waveguide, which serves as an indicative 'bulk' strain sensor.

For all samples, we directly observe the broadening of the absorption edge of the waveguide at elevated pressure, which is attributed to the increasing influence of the X minima of the Brillouin zone. For the devices packaged on diamond and AlN, we are able to distinguish between degradation and an unusual electronic behavior of the QW, resulting in unexpectedly low pressure tuning rates. Consistently, we find the devices packaged on Si to be least affected by the strain caused by the bulk modulus mismatch. The QW EL and QW PC resonances both show the expected pressure tuning rate and, of the investigated submount materials, this appears as the preferential option for applications. The main drawback, however, is the relatively poor thermal conductivity of Si submounts.

The figures show first derivatives of the PC spectra of a device mounted p-down on Si (a) and on diamond (b) for TE (full black lines) and TM (dotted red lines) polarised excitation light. The data starting at the top are the initial ones, whereas those towards the bottom were taken as the pressure was reduced. Notice the similar behavior of the waveguide resonance at ~2.2eV, but the clearly different pressure tuning of the QW resonance at ~1.9eV.



This work was a collaborative effort between partners UNIPRESS, MBI & OSRAM and has been published at: B. Piechal et al., Appl. Phys. A Vol. 97, pp. 179-184, 2009.

TECHNICAL ACHIEVEMENTS
Towards the Project Objectives

Fluorescence imaging for biomedical diagnostics

One of the project applications is to develop sources for medical diagnostic imaging tools based on fluorescence and demonstrate their use for such applications. Lasers intended for fluorescence imaging have been used for some time in pre-clinical studies and test measurements and are now ready for use in clinical studies.

In pre-clinical studies, we have mainly been concerned about measuring the pharmacokinetic behaviour of a novel photosensitiser for photodynamic therapy based on meso-tetra hydroxyphenyl chlorin (mTHPC), also known as Temoporfin or Foscan®. It is a second generation photosensitiser that offers many potential advantages including high chemical purity, improved tumour selectivity, a fast clearance, and a major absorption band at wavelengths longer than 650 nm, yielding improved penetration of the treatment light as compared to first generation photosensitisers. In order to optimise the distribution properties of the photo-sensitisers, liposomes have been designed as carriers in improved delivery systems. Fospeg is a liposomal formulation of m-THPC. Liposomes with PEG coating, a synthetic hydrophilic polymer, improve the stability of the liposomes and prolong their half-lives in circulation. An experimental study was conducted with the aim to investigate the pharmacokinetics of mTHPC in such pegylated liposomal formulation. This was conducted using fluorescence imaging and HPLC analysis of excised tissue samples.

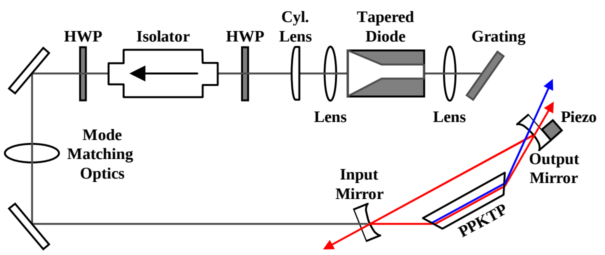


Fig 1. Set-up of the laser system developed by DTU Fotonik within the project. The second harmonic output beam exits through the mirror and is directed to the fibre coupler via a mirror.

For the measurements, we used a fluorescence imaging instrument developed within the project. The system was based on a CCD camera and a Liquid Crystal Tunable Filter (LCTF). The arrangement for the excitation source is illustrated in Fig. 1. It employs a tapered diode amplifier placed in an external cavity with a Littrow feedback grating. The light from this source was frequency doubled in an external 3-piece ring resonator containing a periodically-poled KTP crystal. The entire laser system was built on breadboard and placed on a cart to make it mobile. This provided an output of 100 mW from the fibre at 405 nm.

The data obtained provide a similar bio-distribution for Fospeg as for Foslip, a formulation of Foscan in non-pegylated liposomes, suggesting that the pegylated liposomes are not much better than conventional liposomes as vehicles for mTHPC in connection with PDT. Fluorescence measurements are also shown to provide a very good estimate of the drug concentration, if calibrated using the same organ.

Similar measurements have subsequently been made on malignant skin tumours. The aim of these measurements has been to find methods for objective and minimally-invasively determination of the boundaries of these tumours. In these cases, topically applied 5-amino-levulinic acid (ALA)-induced protoporphyrin IX (PpIX) has been used as a tumour marker. Presently, we are working on evaluating how tissue auto-fluorescence imaging could be used to provide this and other diagnostic information. In this case, we are using a pulsed excitation source at 355 nm, also developed by DTU Fotonik within the project.

For further information, please contact:

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On the laser system: *Prof. Peter Andersen, DTU Fotonik*
email: peta@fotonik.dtu.dk

On Foscan, Foslip or Fospeg: *Dr. Susanna Gräfe, biolitec AG*
email: graefe@biolitec.com

The 4th International Graduate Summer School Biophotonics ’09

The 4th International Summer School Biophotonics ’09 took place in June 2009. The School was organised by BRIGHTER project partners from the Technical University of Denmark and Lund University, Sweden together with Photonics for Life, a European network of excellence for biophotonics. Biophotonics ‘09 had 74 participants from 21 countries worldwide with approximately 25% of the participants from outside the EU – the majority (16%) of these from the US and Canada. More details can be found on page 34 or online at http://www.biop.dk/biophotonics09.

PARTNER PRESENTATIONS

In this section of the e-Newsletter, we introduce the final 4 partners in our Consortium. In this edition, profiles are presented for Alcatel-Lucent Bell Labs (France), Alcatel Thales III-V Lab, the Institute of Communication and Computer Systems (ICCS) of the National Technical University of Athens and the Lund Laser Centre. If you have missed the profile of any other partner, it can be found in one of our previous e-Newsletters, all of which are available online at http://www.ist-brighter.eu.

Alcatel-Lucent Bell Labs (France)

Alcatel-Lucent provides solutions that enable service providers, enterprises and governments worldwide to deliver voice, data and video communication services to end-users. As a leader in fixed, mobile and converged broadband networking, IP technologies, applications, and services, Alcatel-Lucent offers the end-to-end solutions that enable compelling communications services for people at home, at work and on the move. With operations in more than 130 countries, Alcatel-Lucent is a local partner with global reach. The company has one of the largest research, technology and innovation organizations focused on communications – Alcatel-Lucent Bell Labs – and the most experienced global services team in the industry. Alcatel-Lucent achieved revenues of 16.98 billion Euro in 2008 and is incorporated in France, with headquarters in Paris.

Alcatel-Lucent Bell Labs in France

Bell Labs, the innovation arm of Alcatel-Lucent, aims to create new growth opportunities with disruptive innovation and to provide a competitive market advantage for Alcatel-Lucent. As part of the innovation engine behind Alcatel-Lucent, Bell Labs designs products and services that are at the forefront of communications technology, and conducts fundamental research in fields important to communications. Bell Labs is helping Alcatel-Lucent to take the lead in shaping tomorrow's broadband networks powered with service intelligence at every network layer. Separated into 8 domains, each covers the continuum of an entire research lifecycle from generation to transfer and is involved in the mentoring of active research projects and developing and transferring technologies to the business.

Activities within WWW.BRIGHTER.EU

The contribution of Alcatel-Lucent Bell Labs France in the project is to test and assess the sources developed by the project for telecommunication applications related to amplification of the optical signal in optical transmission systems. The goal is to benefit from the high brightness, reliable, low cost, low power consumption and compact sources of the BRIGHTER project for distributed Raman amplification as well as for high power Erbium Doped Fibre Amplifiers (Cladding-Pumped EDFAs and conventional EDFAs).

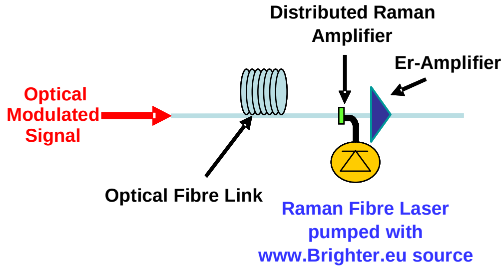

Illustration of application of a WWW.BRIGHTER.EU pump source for distributed Raman amplification

The applications of these amplifiers range from ultra-long optical transport systems to unrepeated submarine optical links and next generation Fibre To The Home (FTTH) systems.

For the Raman amplifiers as well as for the high power EDFAs, a first phase is dedicated to the specifications of the pump sources as well as the specifications of the test beds. In a second phase, modelling for the design of the Raman fibre lasers used for Raman amplification and for the design of the CP-EDFA has been developed, including data measurements on fibres and validation of the models. In a third phase, the amplifier pump sources are assembled and tested. Eventually, system validation is performed with the amplifier prototypes.

Optical communication system test bed

Further Information

Further information can be obtained from:
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www.alcatel-lucent.com

Alcatel Thales III-V Lab

Alcatel Thales III-V Lab is a private R&D organisation between Alcatel-Lucent and Thales established since July 1st 2004, under the French "Economic Interest Group" (GIE) status. Relying on the expertise of "Alcatel-Lucent Bell Labs France" and "Thales Research and Technology," it concentrates in a single entity one of the most advanced industrial research groups in the field of III-V semiconductors in Europe. Its staff amounts to approximately 100 people, and includes highly qualified recognised experts.

The mission of Alcatel Thales III-V Lab is to perform R&D on III-V semiconductor components, from basic research to development, taking advantage of the synergies between the technologies developed for the different markets addressed by Thales and Alcatel-Lucent, such as telecom, space, defence and security.

Alcatel Thales III-V Lab has also the capacity to produce and sell components (epitaxial wafers, processed wafers, modules) in small quantities (typically a few tens of wafers); this is one of its main business development axes. Such capacity is particularly adapted to address the rapid evolution of the market in a flexible way, allowing partner companies (modules or systems manufacturers, including of course the parent companies Alcatel-Lucent and Thales) to have an early access to the components. In a second step, depending on the market evolution and if larger quantities are required, the technology will be transferred to a partner company with larger production capacities.

The facilities of Alcatel Thales III-V Lab, located in Marcoussis and Palaiseau, near Paris, include 4000 m^2 of clean rooms, advanced material synthesis (MOCVD, MBE), advanced device processing (RIE, ICP, CAIBE, IBE, e beam lithography, stepper), measuring, modelling and designing equipment.

Main Research Topics:

- Optical sources & detectors for telecoms at 10-40Gb/s and above
- Micro/nano-electronics circuits for telecoms at 40Gb/s and above (analogue and digital)
- High power and high brightness semiconductor lasers
- Quantum cascade semiconductor lasers
- Semiconductor lasers for atomic clocks & gas detection
- Quantum dot lasers and mode-locked lasers
- High speed analogue optoelectronic components and functions for microwave photonics
- Microwave components (HBT MMICs) based on GaN (high power, efficiency & robustness, wide band)
- High-resolution IR imaging sensors based on QWIP focal plane arrays & GaInAs/InP photodetector arrays

Palaiseau site

Marcoussis site (headquarters)

Activities within WWW.BRIGHTER.EU

III-V Lab is the project coordinator and leader of WP0 (Management) and WP1 (Growth & Processing). III-V Lab also participates in WP2 (Simulation, Design & Characterisation), WP5 (Reliability) and WP9 (Training, Dissemination & Popularisation).

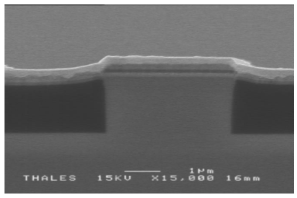
III-V Lab is in charge of developing high wall plug efficiency laser structures at 975nm and 1060nm and to realise tapered laser single emitters and bars (design, epitaxy, process, measurements, reliability studies).

Further Information

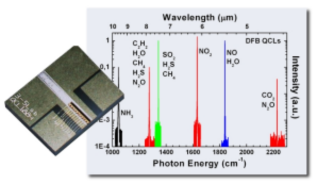
For more information about the BRIGHTER project, please contact project coordinator Michel Krakowski (email: michel.krakowski@3-5lab.fr)

For more information about III-V Lab, please visit our website http://www.3-5lab.fr

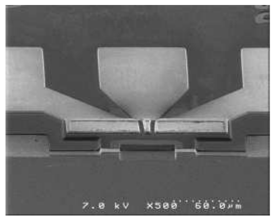
MBE Growth



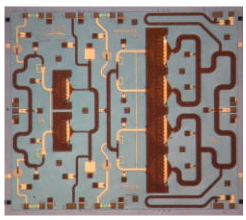
Ridge Laser



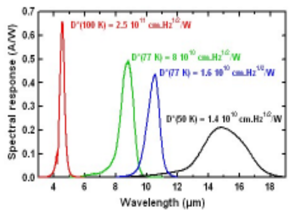
Quantum Cascade DFB Lasers for Spectroscopy



40 Gb/s PIN Photodiode



50W 10GHz GaN High Power Amplifier



QWIP (640x512 @ 9µm, 75K)

Institute of Communications and Computer Systems (ICCS)

The group at National Technical University of Athens is within the Institute of Communications and Computer Systems (ICCS), originally founded in 1989, to carry out research and development activities in the fields of telecoms, computer systems, neural networks, software and hardware engineering, multimedia applications, photonics, biophotonics, bioengineering, bioinformatics, robotics and renewable energy sources.

The Institute is associated with the School of Electrical and Computer Engineering (SECE). The personnel of ICCS consist of Research Scientists and more than 500 Associate Scientists (including PhD students). The research carried out in ICCS is substantially supported by SECE University Professors. ICCS is very active in European funded research activities and has been the project manager of many EU projects in various programmes (e.g. EC, ISIS, RACE II, ESPRIT, IES, ACTS, INFOSEC, BRITE-EURAM, STRIDE, MIP-Informatics, Telematic Applications, IST, GROWTH, QoL, JOULE, ENERGIE, etc.), in all the above mentioned research areas. ICCS was ranked 13th among European Institutes in FP6 project participation.

The members of the group are also members of the Laboratory of Biomedical Optics and Applied Bio-physics, which is associated with ICCS and the School of Electrical and Computer Engineering and is headed by Professor Dido Yova.

The Laboratory covers research areas in the fields of biophotonics, nanobiophotonics, fluorescence molecular imaging using specific external probes, linear and non-linear imaging microscopy, functional cell imaging, free-radicals and anti-oxidants, optical methods in tumour treatment and detection such as photodynamic therapy and photodiagnosis, development of non-contact 3-D computer vision systems and bioinformatics.

School of Electrical and Computer Engineering building

The results of research on the above mentioned fields have been published in more than 150 international journal papers and conferences during the recent years.

Activities within WWW.BRIGHTER.EU

Within the BRIGHTER project, the laboratory is realising a Fluorescence Molecular Imaging System (FMIS) adopted for small animals. In this context, a robust theory for solving the inverse problem in fluorescence imaging has been developed. In addition, the FMIS was developed incorporating a laser from the BRIGHTER project at 680 nm (from the Fraunhofer Institute), a scanning subsystem and the corresponding software. The developed FMIS is used for fluorescence tomography of embedded tumors (e.g. prostate cancer).

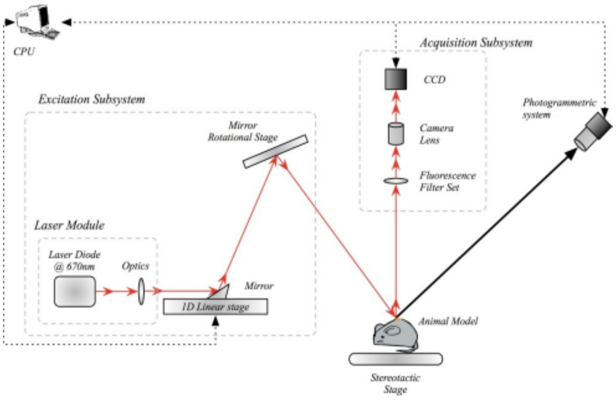


Diagram of the Fluorescence Molecular Imaging System

In addition, ICCS has been involved in the pre-clinical evaluation of laser systems for Interstitial Photodynamic Therapy with project partner Biolitec.

Finally, ICCS is responsible for the co-ordination of the gender monitoring issues within the project and the creation and implementation of a gender action plan. For more information on this, see the article on page 10.

Further Information

Further information can be obtained from:

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Email: didoy@central.ntua.gr

Web: http://www.bio-optics.ece.ntua.gr

Lund Laser Centre

Lund Laser Centre (LLC) is located within Lund University in Sweden and specializes in exploring light-matter interactions both for basic research and for a large number of applications. Being one of the largest laser laboratories in Northern Europe, it is included in the European Commission Large Scale Infrastructure programme, meaning that any researcher within the EU can apply to use this laboratory for projects requiring unique equipment or expertise available at LLC. Information about facilities and application procedure is available through the home-page: www.llc.lth.se.

Lund University also hosts a Medical Laser Centre as an active part of the Lund Laser Centre. This Centre is headed by Prof. Stefan Andersson-Engels and Prof. Katarina Svanberg of the Department of Physics and Department of Oncology, respectively. They are also in charge of the LLC activities within the Brighter project. The research at the Centre is within the field of biomedical optics with clinical applications. At the Centre, we have been and are working with methods for diagnostic and therapeutic purposes. For diagnostics, we have mainly been working on fluorescence spectroscopy and imaging. This is also the main part of our contributions to the BRIGHTER project. Another main part of our research is to understand how light is propagating in strongly scattering media such as biological tissue. Optical properties as well as models for light propagation in media, optically described by these properties, are thus central parts in our research. We have therefore developed techniques to measure optical properties in biological tissue, both for diagnostic purposes and for dosimetry in connection to photodynamic therapy (PDT). These properties can then be used in models to estimate the light propagation of importance for the application.

The expertise gained in modelling and measurements of optical properties has been used to develop a novel interstitial photodynamic therapy system with online feedback. Spectroscopy is used to reveal the presence of important constituents for PDT during the treatment: light, photosensitizer and oxygen. This work yields a possibility to treat larger tumour volumes and may thus allow inclusion of new indications to be treated with PDT. Presently, a pilot clinical study for treatment of malignant lesions in the prostatic gland is just finishing.

Clinical fluorescence spectroscopy / imaging studies have been conducted to evaluate the potential of the technique for characterizing colonic polyps as well as laryngeal and brain tumours with very good results. Fluorescence techniques are also refined to enable improved depth resolution in fluorescence molecular imaging.

Historically, the Centre has contributed significantly to the field of Biomedical Optics. The group has been a pioneer in both fluorescence spectroscopy and time-resolved remittance measurements for tissue diagnostics as well as in PDT therapy using topically applied ALA for photosensitization.

Activities within WWW.BRIGHTER.EU

The contribution to the project is to explore biomedical applications of the novel sources developed within the project. We are especially studying the possibilities of the violet and ultraviolet lasers for fluorescence imaging and spectroscopy of superficial lesions – mainly for diagnostic purposes of early stage malignant tumours. Such systems have in the past been suffering from a bulky source. With the compact and low-cost novel sources developed within the project, there is a clear potential to develop fluorescence imaging systems that will be widely utilized in clinical diagnostic procedures. Such systems have been developed by the group and are now used in first clinical studies. The figure below illustrates the first patient studied with a first functional model of this system, in connection with photodynamic therapy of a basal cell carcinoma of the skin.

A patient undergoing photodynamic therapy and studied with a first functional model of the fluorescence imaging system developed within the BRIGHTER project.

The group has also been involved in fluorescence tomography studies of lesions located deeper within bulk tissue. Again instruments and evaluation algorithms have been developed. These are now utilized in pre-clinical studies.

Another important activity is that we, with support from the project, have arranged the biannual graduate summer schools Biophotonics ’07 and ’09 together with DTU in Denmark.

Further Information

Further information on the groups’ activities can be found at: http://www.atomic.physics.lu.se/biophotonics

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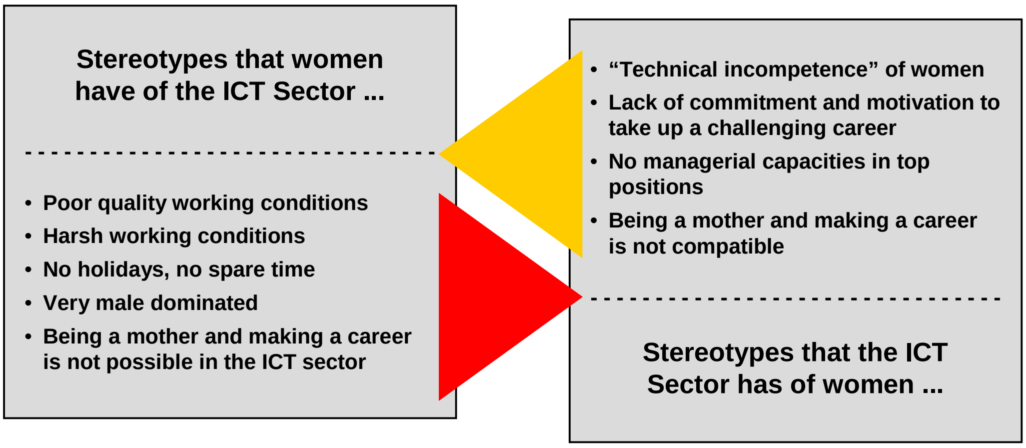
*Climbing scientific Everests against all odds while being a woman**

Eleni Alexandratou and Dido Yova

Institute of Communications & Computer Systems (ICCS), Laboratory of Biomedical Optics & Applied Biophysics School of Electrical & Computer Engineering (E.C.E.), Zografou Campus, GREECE

The Commission, together with leading technology companies, are trying to get more young women interested in ICT careers in a drive to avoid a predicted shortage of some 300,000 qualified engineers by 2010. **"It is unacceptable that Europe lacks qualified ICT staff. If this shortage of computer scientists and engineers is not addressed, it will eventually slow down European economic growth"** said *Information Society Commissioner, Viviane Reding*, addressing a conference exploring the potential for women in the ICT sector.

The main stereotypes that women have of the ICT sector and vice versa are summarised in the picture below. *[Taken from "Best Practices for Even Gender Distribution in the 25 Member states in the Domain of Information Society" Study Final Report, December 2006.]*



More and more studies are revealing that companies with more senior female managers are making more money. A woman's management style is suddenly seen as valuable, rather than soft. Female right-brain skills like *inclusiveness, a focus on compromise* and *aversion to risk* are now being seen as necessary for a profitable business.

More companies are recognising that *flexible time schedules* offer employees the ability to manage and balance their own careers and lives, which in turn *improves productivity* and *employee morale*. And that's the key: Employing women is no longer a politically correct palliative to diversity. **It's a good business strategy.**

The Consortium of the BRIGHTER project, recognising the equal importance of male and female researcher participation in the project, has developed a specific Gender Action Plan. The Consortium has also nominated a Gender Manager, Professor Dido Yova, to lead and monitor all gender issues throughout the duration of the project.

The Gender Action Plan states that the Consortium will:

- *Monitor gender aspects of the project*
- *Identify and promote best practices*
- *Network with national gender and scientific related networks*
- *Promote opportunities for women in science*
- *Raise gender awareness in the ICT research arena*

*** The title is a rephrase of Prof. Dr. Ada Yonath, Structural Biology Department at the Weizmann Institute of Science in Rehovot, Israel and L'Oréal-UNESCO Laureate For Women in Science, Life Science Europe 2008 presentation "Climbing scientific Everests against all odds while being a loving parent".***

In order to monitor gender aspects of the project, the Gender Manager developed a specific monitoring document with detailed indicators that partners were asked to fill in every six months. This document monitors the number of women in both the academic and business sectors. It also deals with both horizontal and vertical segregation of the researchers within the project (i.e. the different roles of women within different sectors of the project).

The European Commission had set a 40% target for women's representation in FP6 committees, groups and panels. However, according to the European Union document "She Figures 2006", regarding Women and Science, Statistics and Indicators:

- *Across the EU as a whole, only 29% of researchers are women*
- *Only 18% of researchers in the business and enterprise sector are women, even though this is the largest R&D sector in most countries*
- *The gender imbalance at senior grades is even greater in engineering and technology, where the proportion of women is just 5.8%*

The total numbers of female and male researchers that are involved in the academic and business sectors of the WWW.BRIGHTER.EU project are presented in the table below.

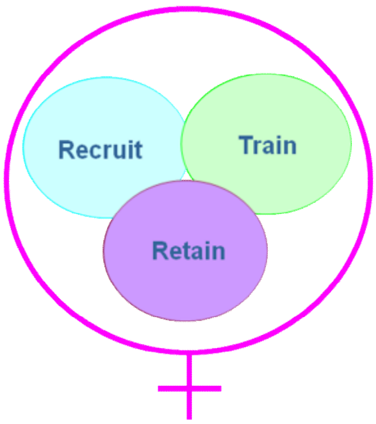
	Women	**Men**	**Total**	**% Women**	**% Men**
Total Researchers	29	90	119	24.4	75.6
Academic sector	17	62	79	21.5	78.5
Business sector	12	28	40	30.0	70.0

It is clear from these results that WWW. BRIGHTER.EU (like the Commission) falls short of the target with the proportion of female researchers involved in the project at the end of the 2nd year being only 25%. However, in comparison with Europe-wide figures on the gender balance in science and engineering, we see that the BRIGHTER project is achieving better than the "average" of the wider European scientific community.

During the duration of the BRIGHTER project, there were only minor changes to the number of researchers involved in the project. The main reason behind this is that researchers are usually appointed at the beginning of the project. As it was not easy to affect recruitment at the beginning of the project, the Consortium focused on supporting and promoting opportunities for women researchers during execution of the project.

In brief, the gender actions of the project can be summarized in the following list:

- *Continuous monitoring of the female researchers participation in the project*
- *Promotion of equal opportunities in recruitment of researchers and PhD students*
- *Flexible hours of work and childcare facilities are offered by many of the partners*
- *Female participation in tutorials, exchange visits and other training activities*
- *Offering of internships for female researchers*
- *Mentorship activities for young researchers*
- *Participation in national Girl's Days*
- *Organisation of workshops*



In conclusion, our experience from the gender management of the WWW.BRIGHTER.EU project reveals the importance of increasing gender awareness at the Consortium level.

Under this framework, universities, institutes and companies, *recruit, train and retain* women in order to be able to tap into an increasingly highly educated and skilled talent pool.

It is simply a different way of looking at *success, priorities and possibilities!*

A Fluorescence Imaging Application for Tumour Diagnosis with Tissue Surface 3D Reconstruction

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Abstract

Although fluorescence imaging has been applied in tumour diagnosis since the early 90s, it has only become of increasing scientific interest over the last few years. This is due to the advances in biophotonics and the combined technological progress of the excitation, acquisition and computation systems. In addition, it is expected that fluorescence imaging will be further developed and applied in deep tumour diagnosis in the years to come.

Introduction

Fluorescence imaging is expected to play a major role in diagnosis and molecular drug development within the next few years. Nevertheless, fluorescence signal processing still presents increased complexity and lacks the time efficacy, because of the enormous amount of recorded data and the required computational processes [1]. One of the major scopes of fluorescence imaging is to "see" tumours embedded into tissue by quantifying the spatial distribution of specific fluorescence markers of the tumour, under the premise that the excitation source and the emission signal at the boundaries are known. By using excitation light in the NIR region, the light penetrates several millimetres, exciting the fluorophores and labelling relatively deep tumours. However, light scattering in this region is dominant and advanced techniques are required to describe the tissue and light interactions.

This problem is modelled as a system of integro-differential equations, which mathematically consists of an ill-posed inversion problem. Due to the absence of direct methods, this problem is usually solved via its transformation to an optimization problem [2-4]. The current state-of-the-art in fluorescence imaging requires parallel programming and computational times of the order of hours. The most important reason for this lack of time efficacy is the non-linear nature of the inverse problem, which necessitates the use of iterative techniques for convergence [1] and the pixel-to-pixel comparison between measured and computed data [5]. One of the fluorescence imaging approaches, which presents increased scientific interest nowadays, is epi-illumination fluorescence imaging. According to this planar imaging technique, the excitation light is incident on the tissue surface, which is also the boundary from where the emitted fluorescence is detected [6]. Figure 1 depicts an epi-illumination system.

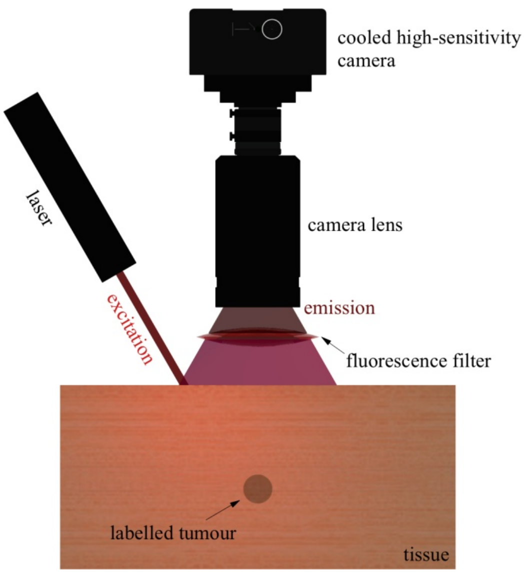

Figure 1: Architecture of a NIR epi-illumination system

Epi-illumination systems using <u>area</u> excitation source

One of the first approaches to estimate the 3D geometry of the fluorophores is the area excitation mode [7]. This approach presents increased time efficacy in data acquisition, since usually one measurement is required. According to this approach, the excitation source is expanded over an area that corresponds to the inspected area and the emitted fluorescence signal is detected by using very sensitive cameras.

Nevertheless, this technique presents some major drawbacks and is usually applicable to phantom experiments. The intensity profile of the excitation should be known with increased levels of accuracy, in order to successfully model it. However, this is possible only when the inspected area is smooth or even the smallest roughness will differentiate the source intensity profile from the modelled one. Furthermore, as data differentiation is limited, the solution is prone to converge to a false distribution.

Epi-illumination systems using <u>point</u> excitation source

One alternative approach, which confronts most of the inherited problems of area excitation schemes, is the application of a point source [8,9]. On the one hand, a point source presents an increased degree of modelling accuracy, leading to truthful correlation between measurements and simulations.

On the other hand, although this approach provides good data differentiation, one measurement is not adequate for the solution of the inverse problem. Thus, a two-dimensional scanning module is usually included in these systems. The accuracy of the solution is strongly dependent on the scanning step and the number of excitation points. These systems, however, require an increased time for data acquisition, while a dense excitation matrix would lead to the formulation of a huge system, not easily solved even with high-end multiprocessor computational systems.

Epi-illumination systems using a <u>structured</u> excitation source

Within the last few years, there has been increased scientific interest in epi-illumination systems using structured light as the excitation source. The most commonly applied pattern is the line source, a laser projecting a thin light on the tissue surface, although other patterns have also been tested [10].

This excitation method preserves the modelling accuracy of the point sources, while it significantly reduces the required data acquisition times. With structured excitation sources, a one-dimensional scanning module is required, needing approximately the square root of the time that a point excitation source would require for measurements over the same tissue area. Furthermore, the recorded data formulate smaller systems, without affecting the reconstruction accuracy, when compared with the point source systems.

However, even the use of a structured light excitation source presents some major drawbacks, mostly because of the required scanning process. First of all, the projected pattern such as a line from a laser is highly dependent on the surface geometry of the tissue surface. Without this knowledge, the length of the excitation line cannot be approximated and the modelling could fail. Furthermore, any random intensity fluctuations of the laser source would uncorrelate the measurements from the simulations, affecting the reconstruction outcomes.

Detection techniques

The detection techniques that are mainly used in fluorescence imaging can be distinguished into three categories; continuous wave, frequency domain and time domain techniques [1,2]. The comparison of these three techniques does not lead to safe conclusions, since each one is characterized by unique particularities towards the computational implementation, the data processing and the development of the corresponding hardware system.

However, the latter two techniques, frequency and time domain, are capable of higher accuracy in the discrimination between absorption and scattering and can independently solve for the fluorescence intensity and lifetime. On the other hand, continuous wave technology is a more accurate approach for spatial distribution studies of the fluorophores, as it is characterized by higher signal-to-noise ratios and an increased spatial resolution of the recorded signal.

Excitation sources in fluorescence imaging

The excitation source in fluorescence imaging applications plays a major role in the successful solution of the inverse problem, regardless the technological approach. Besides the obvious reason, which is the selection of the proper NIR wavelength that corresponds to the absorption maxima of the fluorophores used, there are also qualitative characteristics of the laser beam that influence the overall functionality of the fluorescence imaging system.

The laser beam profile is a very important for two reasons: firstly, as a mathematical model of the excitation source is required, an accurate description of it will help to correlate the real beam with the simulated one. Secondly, as most of the approaches to the solution of the inverse problem require a dense region discretization and sources with acute incident area, a high beam quality laser with M^2 as close to unity as possible is a very important prerequisite for adequate data differentiation, in order to confront the ill-posed optimization process.

Fluorescence imaging is prone to various noise sources, related both to the acquisition and the image formulation procedures, and thus presenting low signal-to-noise ratios. These random and small-scale artefacts decrease the time efficacy and the reconstruction accuracy of fluorescence imaging, and it is not always possible to reduce them through algorithmic processes. The intensity fluctuation of the excitation laser is a major source of such noise components during an image acquisition process. In addition, the random intensity fluctuations between consecutive measurements could uncorrelate the measured data from the simulated data, leading the inverse problem either to an increased number of iterations or to convergence at a false fluorophore distribution. Thus, optimum intensity stabilization of the excitation source is also required.

Inspected region surface reconstruction

Most of the fluorescence imaging approaches that are studied nowadays ignore the real surface geometry of the inspected region. The lack of this information is responsible for the inaccurate and unstable convergence of the inverse problem in an increasing number of experiments. This is due to the fact that the solution of the inverse problem is actually an effort to match the recorded and the simulated fluorescence data from planar measurements. However, if the surface geometry is not available, the simulation outcomes will not correspond to the actual inspected region and the matching process will be applied between two different areas.

There exists a limited number of efforts, mostly in transillumination approaches [6], that partially confront this problem, where only the excitation light projection surface is considered, but not the detection one. As for the epi-illumination approaches, to the authors knowledge, no such reference exists, but only the necessity of this information is highlighted [8].

Fluorescence imaging system using a BRIGHTER project NIR laser

Within the framework of the BRIGHTER project (IST-511722), the ICCS group has developed a robust epi-illumination fluorescence imaging system, which is based on the 1D spatial scanning of the tissue, by using an excitation laser sheet. The laser source of this system, along with the micro-optics, have been designed and developed within the BRIGHTER project and consist of a 670nm highly reliable, high-brightness laser diode provided by the Ferdinand-Braun-Institute (Germany), with the micro-optics and the diode mount provided by Fisba Optik AG (Switzerland). Using these, the final module was developed by ICCS. The block diagram of the developed system is shown in Figure 2.

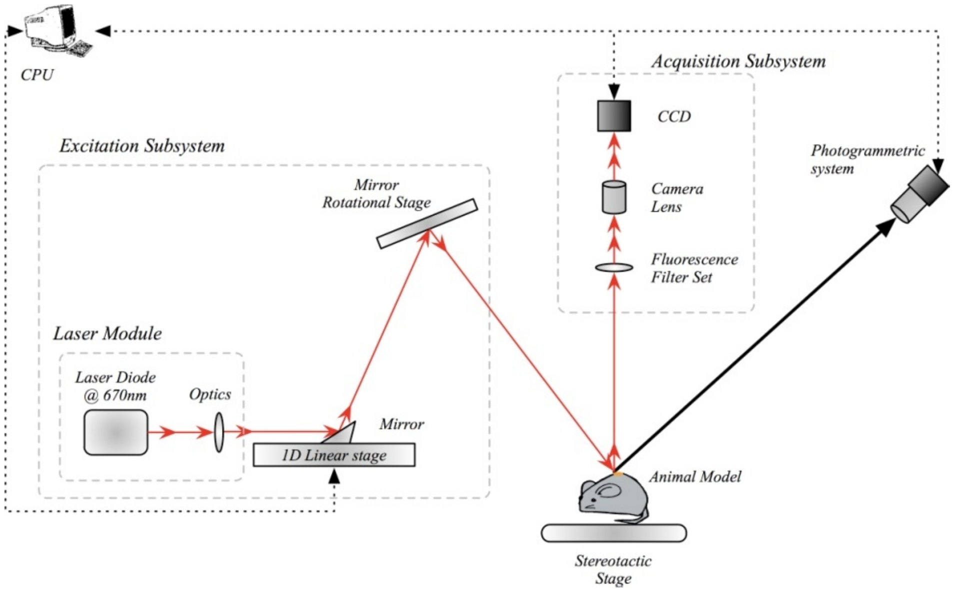

Figure 2: Block diagram of the fluorescence imaging system developed by ICCS

This system combines the advantages of epi-illumination with the structured light excitation source scheme, projecting on the tissue surface a laser line that scans the entire region-of-interest. Furthermore, by using a BRIGHTER laser diode at 670nm with 0.5W output power, the mathematical modelling is correlated with the actual measurements, leading to more realistic simulation results.

Finally, another very important problem that is solved by the system of Fig. 2 is the simultaneous reconstruction of the 3D geometry of the inspected tissue surface. A binocular machine vision sub-system has been developed, which is based on an M-array coded structured light pattern for the solution of the matching problem and the identification of the conjugate points. The light source of the structured light projector is a high power LED, with a dominant wavelength of 455nm for decreased back-scattering.

The forward and inverse problems

The solution of the 3D reconstruction problem in fluorescence imaging requires a computationally feasible and accurate mathematical model, which can describe the interaction of the excitation and emission radiations with the inspected tissue. At the same time, it requires an iterative optimization method, which can accurately and rapidly converge to the real 3D distribution of fluorophores. These two processes constitute the well-known forward and inverse problems in 3D reconstruction [2,3].

(1) The forward problem

The forward problem, in the framework of fluorescence imaging, is the theoretical computation of the fluorescence signal at the tissue boundaries, which corresponds to the measurand, when the optical properties of the medium and of the excitation source are known [11]. Transport theory well describes light propagation through biological media and numerous models have been developed based on this theory for the expression and solution of the forward problem [12].

The model that most accurately describes the transport theory is the radiation transport equation (RTE), which is an energy balance formulation of the radiance that is expressed by the Boltzmann transport equation [12]. The RTE assumes that the energy of particles does not change in collisions and that the refractive index is constant within the medium. Due to the large computational power that such a model requires, the attempts to use it as a forward solver are very limited. However, this is not the case for the diffusion approximation (DA), a deterministic simplification of the RTE [12]. The DA is among the most common models applied for the solution of the forward problem, mainly due to its rapid convergence to a solution. However, this model presents two major drawbacks, which are the failure of the model close to the source and low accuracy levels at the boundaries. These are the reasons, that although this model is very often used, it has not been recognised as the "gold standard" of the forward solvers.

The method that has been recognised as the "gold standard" of all the forward solvers is the Monte Carlo method, more specifically an algorithm that has been developed by Wang *et al.* and is known as Monte Carlo for Multi-Layered media (MCML) [13,14]. This algorithm, although available from the early 90s and is indeed a 3D approach, has been mainly used for 2D simulations, as its computational cost is strongly related to the number of photons considered.

(2) The inverse problem

The inverse problem in the context of fluorescence imaging involves the reconstruction of a region, which has been labelled with fluorophores and is embedded into the inspected tissue [1]. Being a non-linear, ill-posed inversion problem, regularization techniques are required for succeeding sufficient matrix inversions. In any case, the prior knowledge of the model and the expected solution, leads to a more accurate solution of the inverse problem.

Most of the reconstruction algorithms are trying to minimize an objective function, which depends on the difference between the measured data and the data computed from the forward solver [8,15]. One of the most common methods for the minimization of the objective function is the iterative Levenberg-Marquardt method [16]. As an optimization process, the solution accuracy and the number of iterations required for a successful convergence are strictly related to the accurate the solution of the forward solver. This is actually one major problem of fluorescence imaging, as *a priori* information of the fluorophore distribution is not available, and only a few attempts have been implemented towards solving this problem [17].

(3) A coupled RTE-DA approach

The solution of the forward and inverse problems still encounters a series of difficulties. The "gold standard" Monte Carlo methodology is mainly applicable in 2D schemes, due to the heavy computational requirements. On the other hand, although the DA accurately describes light propagation in tissues, it fails close to their boundaries and the sources. Finally, the RTE remains under investigation, in the most part because of its complexity driven from the angular dependence.

ICCS, working towards the implementation of the BRIGHTER project objectives, has developed a new methodology to confront these problems in fluorescence imaging. This method is based on the coupled RTE-DA model [18], which combines the feasibility and time efficacy of the DA with the accuracy of the RTE close to the tissue boundaries and sources. Furthermore, by utilizing super-ellipsoid models and through a data fitting process, the initial fluorophore distribution becomes available, leading either to less iterations or to the direct solution of the inverse problem, in cases where the data fitting provides increased matching accuracy.

Summary

Although fluorescence imaging is among the most promising fields in optical imaging with numerous potential applications, it is still considered to lie mainly within the framework of basic research and very few systems are currently available.

Nevertheless, fluorescence imaging is expected to play a major role within the next few years in diagnosis. Towards this expectation, important International Centres, like the Centre for Molecular Imaging Research (CMIR) at Massachusetts General Hospital, in collaboration with the Harvard Medical School, have developed systems for small animal fluorescence imaging, scoping to the quantification of various characteristics that are related to tumours [19]. On the other hand, Research Centres also exist, like the Baylor College of Medicine at Houston, which are mainly targeting different types of tissue phantoms [8,20], with the human breast being among the most common applications [19,21]. However, the vast majority of the approaches are still trying to solve the forward and/or inverse problems using different tissue phantoms or simulation-only experiments [22-24].

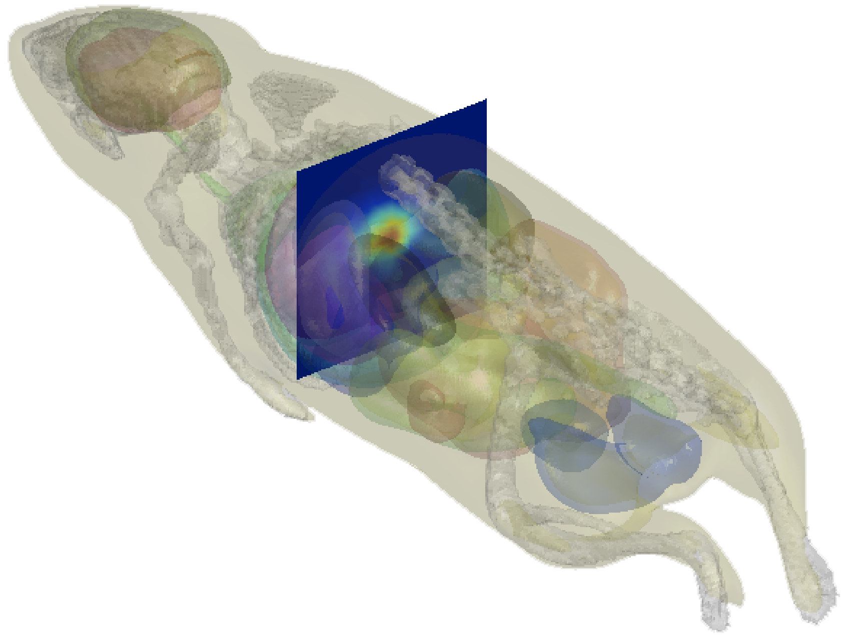

Figure 3: An x-z slice of the simulated fluorescence signal emitted from a labelled region inside the MOBY phantom

Within the framework of the BRIGHTER project, in collaboration with the Consortium, the ICCS group has developed and currently is evaluating a robust epi-illumination fluorescence imaging system, which is based on a scanning system for the excitation source and incorporates a photogrammetric sub-system for the tissue surface 3D reconstruction. Furthermore, the same group has developed a novel approach for the solution of the forward problem [25]. This approach is based on the coupled RTE-DA model [18] and for the first time this model is three-dimensionally solved [25,26]. Figure 3 presents the simulated emitted fluorescence signal from a labelled tumour inside the MOBY phantom. Finally, a new methodology for the *a-priori* estimation of the fluorophore distribution has been proposed, in order to increase the time feasibility and spatial reconstruction accuracy of the iterative inverse problem solution.

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Laser Diodes: Brightness & Beam Quality

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BRIGHTER is a project about developing high-brightness laser diodes and often we also talk about laser diodes with a high beam quality – but, what exactly are brightness and beam quality and how do we define and measure them? This article aims to answer these important questions and will provide a short overview of the definitions of brightness and beam quality (and other commonly used metrics) and take a look at how to measure / determine them.

Brightness and Beam Quality

The major performance target for high-power diode lasers continues to be the combination of output power and beam quality – this is known as brightness. The brightness B of a laser beam is defined as

$$B = \frac{P}{A \cdot \Omega},$$

where P is the optical output power, A is the emission area and Ω is the solid angle into which the power is emitted. The units of brightness are usually written as $\mathrm{W \cdot cm^{-2} \cdot sr^{-1}}$.

<u>*Gaussian beams*</u>

If the laser output is a single spatial mode of the lowest order and is predominantly single-lobed in the far field, then such a laser is said to be diffraction-limited. For a diffraction-limited beam with moderate divergence (such that the paraxial approximation is valid), the relationship between the radius w_0 and divergence θ of a Gaussian beam

$$\theta = \frac{\lambda}{\pi \cdot w_0},$$

can be used to obtain

$$B = \frac{P}{A \cdot \Omega} = \frac{P}{\pi w_0^2 \cdot \pi \theta^2} = \frac{P}{\pi w_0^2 \cdot \pi \left(\frac{\lambda}{\pi \cdot w_0} \right)^2} = \frac{P}{\lambda^2}.$$

The above expression shows that apart from the power and beam parameters, the brightness depends on the wavelength λ.

Another important and commonly used parameter is the Beam Parameter Product (BPP) Q, which is defined as the product of the beam radius (measured at the beam waist) and the beam divergence half-angle (measured in the far-field), i.e.

$$Q = w_0 \cdot \theta.$$

The usual units of Q are mm·mrad (i.e. millimetres times milliradians). The brightness can also be written in terms of the BPP as

$$B = \frac{1}{\pi^2} \cdot \frac{P}{Q^2}.$$

Realistic beams

In practice, and particularly in the case of high-power laser diodes, output beams are not diffraction-limited. In this case, the divergence of the beam (in each axis) is reduced by a factor known as M^2 or the beam quality or the beam propagation factor. M^2 is defined as the BPP divided by λ/π, the latter being the BPP for a diffraction-limited Gaussian beam of the same wavelength. The relationship between the radius w_0 and divergence θ then becomes

$$\theta = M^2\left(\frac{\lambda}{\pi \cdot w_0}\right).$$

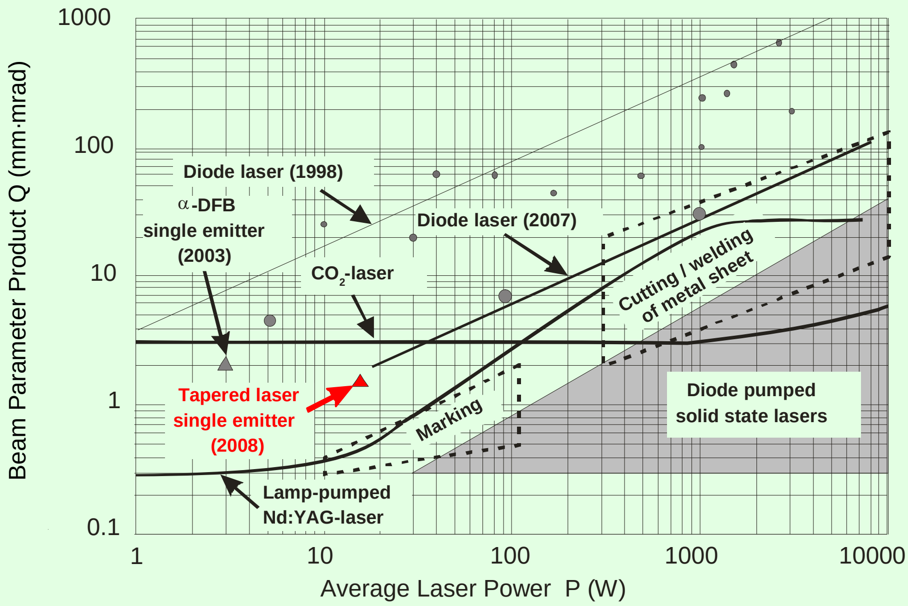
Laser beams are often said to be "M^2 times diffraction-limited". A diffraction-limited beam has an $M^2=1$ and is a Gaussian beam. Smaller values of M^2 are physically not possible. Values of M^2 for real laser beams are ≥ 1 and indicate the degree to which the beam can be focused.

For non-circularly symmetric beams, where the beam waists and divergences are different in each of the two directions orthogonal to the beam axis, the M^2 factors are also different in each direction. This is notably the case for high power diode laser bars where, where the M^2 factor is fairly low for the fast axis and much higher for the slow axis. These M^2 factors are then commonly denoted M^2_{fast} and M^2_{slow}.

Returning to the definition of brightness and incorporating M^2, it follows that for a non diffraction-limited beam the brightness is reduced by the product of the M^2 factors and is therefore given by

$$B = \frac{P}{\lambda^2 \cdot M^2_{fast} \cdot M^2_{slow}}.$$

Instead of using the brightness value, lasers are often compared with each other using their power and beam parameter product. One way of doing this is on a graph such as that in Fig. 1, which shows the parameters for several different lasers and also the requirements for a range of high-power laser diode applications. The comparison with other high-power lasers (e.g. CO_2 & solid-state lasers) shows that diode lasers are approaching the levels of power and beam quality achievable with other laser systems.



"Tapered laser single emitter (2008)" refers to a laser diode from the Ferdinand Braun Institute (FBH), which was developed during BRIGHTER. This is a 1060 nm laser with an output power of 12 W and Q = 1.5 mm·mrad.

Fig. 1: Typical beam parameters for different laser systems and for materials processing applications.
(Figure courtesy of Prof. Peter Loosen, Fraunhofer Institute for Laser Technology, ILT)

Practical Measurements

In the previous section, the brightness of a laser was shown depend upon the optical output power, the wavelength and the beam propagation factors M^2. If these quantities are known, then the brightness B can be calculated from

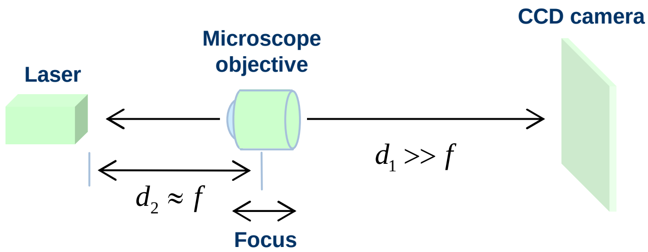
$$B = \frac{P}{\lambda^2 \cdot M^2_{fast} \cdot M^2_{slow}} \left[W \cdot cm^{-2} \cdot sr^{-1} \right].$$

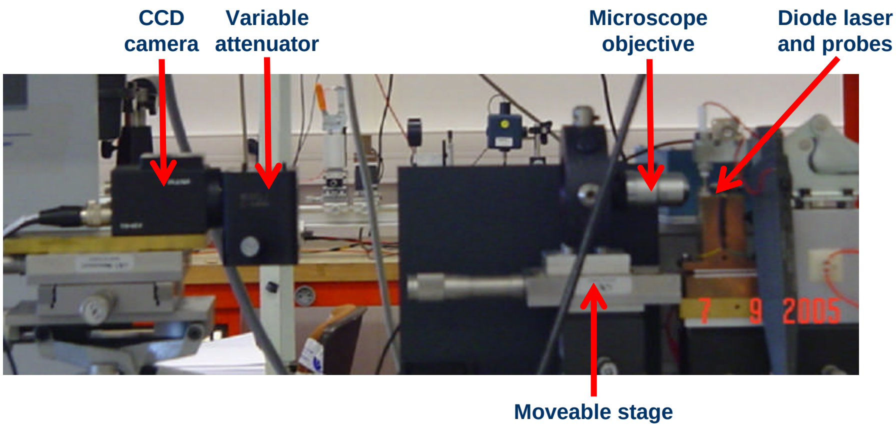
Power and wavelength measurements are relatively straightforward and only the measurement of M^2 is discussed here. M^2 requires the beam waist and far field divergence to be measured. The beam parameter product can also be calculated from the measured beam waist and divergence. A brief overview of near- and far-field measurements is given below and this is followed by the presentation of two popular techniques for determining M^2.

Measuring the near-field at the beam waist

- Install the laser, objective lens and camera as shown opposite
- Move lens & focus on the beam waist
- Know the magnification factor:

$$MF \sim d_1/f$$





Practical near-field measurement setup at III-V Lab

III-V lab
ALCATEL-THALES

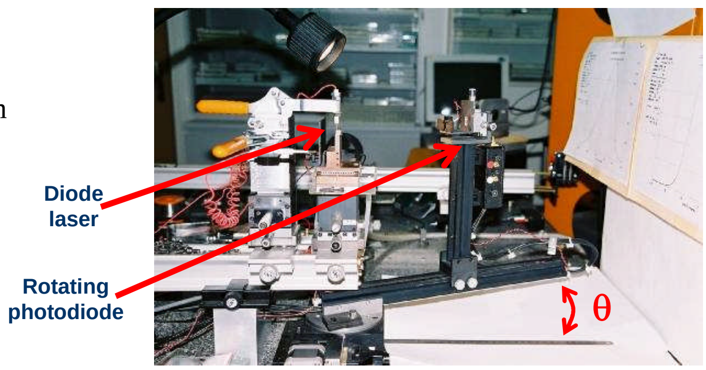
Measuring the far-field

- Extremely simple setup
- Rotate a detector around the beam
- Arm length must be longer than:

$$z_r = \pi \frac{w_0^2}{\lambda}$$

III-V lab
ALCATEL-THALES

Practical far-field measurement setup at III-V Lab



Determining *M²*

Method 1: Measuring *M²* at *1/e²* – fast and easy to perform, but does not conform to the International Standards Organisation (ISO) method for determining M^2 and also does not take all of the beam profile into account. Despite this, it is still widely used and reported in the literature.

Method 2: Second-moment method according to ISO 11146 – time consuming, unless an automated setup is available, but conforms to the ISO international standards for determining M^2.

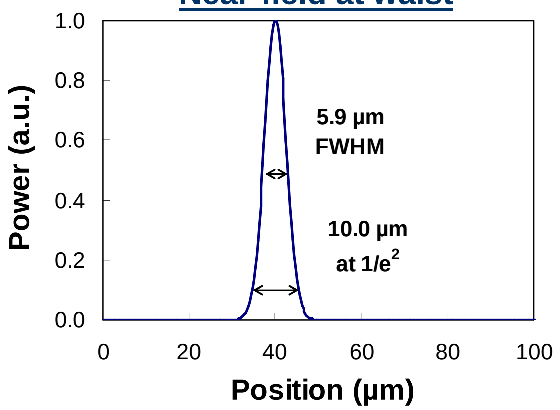
Measuring *M²* at *1/e²*

Here we present theoretical and experimental results for this often used method of determining M^2.

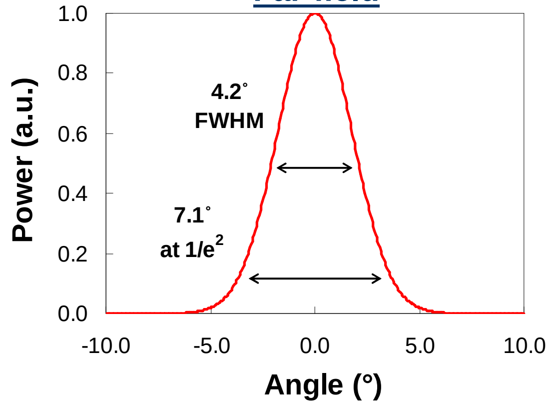
Example with a Gaussian beam

- Assume a perfect beam at 975 nm
- Simulate near-field at waist
- Simulate far-field

Near-field at waist



Far-field



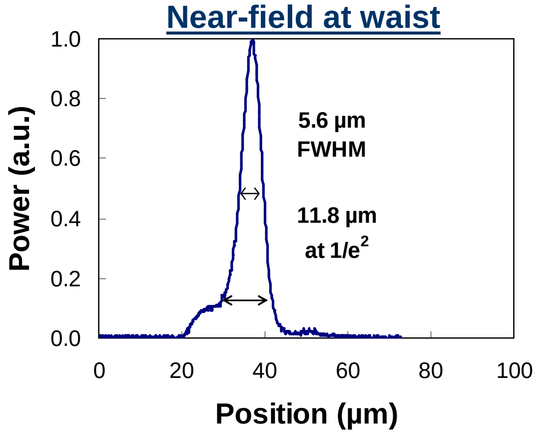
Apply formula to calculate *M²*

$$M^2_{1/e^2} = \frac{\pi}{4\lambda} w_{1/e^2} \theta_{1/e^2} = 1.0$$

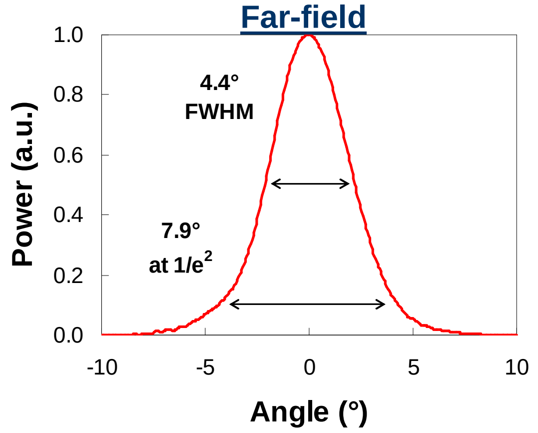
Example with a real beam

- Measure actual laser at 975 nm
- Measure near-field at waist
- Measure far-field

Near-field at waist



Far-field



Apply formula to calculate *M²*

$$M^2_{1/e^2} = \frac{\pi}{4\lambda} w_{1/e^2} \theta_{1/e^2} = 1.3 \pm 0.2$$

Measuring M^2 using ISO 11146

In this part, a brief overview is given of the ISO 11146 standard for measuring M^2 – often referred to as the second moment method. The ISO 11146 method requires the user to measure the cross-sectional power density distribution at a number of axial locations (> 10) along the beam propagation axis (approximately half of the measurements distributed within one Rayleigh length on either side of the beam waist and approximately half distributed beyond two Rayleigh lengths from the beam waist).

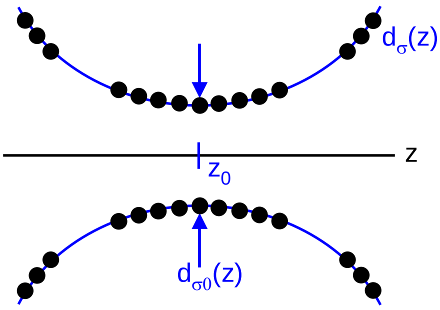
At each *z*-axis measurement position, the second moment beam width $d_\sigma(z)$ must be determined.

A hyperbolic fit of $d_\sigma(z)$ is then made to $d_\sigma(z) = \sqrt{a + bz + cz^2}$.

From the *a*, *b* and *c* coefficients of the fit, the beam waist location and width and the beam propagation factor are determined from

$$z_0 = \frac{-b}{2c}, \quad d_{\sigma 0} = \frac{1}{2\sqrt{c}}\sqrt{4ac - b^2}, \quad M^2 = \frac{\pi}{8\lambda}\sqrt{4ac - b^2}.$$

For simple astigmatic beams, this procedure should be applied separately to both principal directions.



As can be seen from the above discussion, this method is time consuming unless an automated setup is available. However, if measurement equipment with a sufficiently high signal-to-noise ratio and a simultaneously high spatial resolution is not available, the ISO standard allows for alternative methods, known as the variable aperture, moving knife-edge and moving slit methods, to be used. For detailed instructions, it is recommended that the reader consults the ISO 11146 documentation.

Summary

This article has given a brief overview of laser diode brightness and beam quality. Definitions of these quantities, together with other commonly used metrics, have been presented. Practical laser beam measurements have also been discussed. The principal relationships between brightness, beam parameter product, beam propagation factor, beam waist and divergence can be summarised as:

$$B = \frac{P}{A \cdot \Omega} = \frac{1}{\pi^2}\frac{P}{(w_0 \cdot \theta)^2} = \frac{1}{\pi^2}\frac{P}{Q^2} = \frac{P}{\lambda^2 \cdot M^2_{fast} \cdot M^2_{slow}}.$$

Further Information

- The main parts of this article were adapted from a tutorial developed in the BRIGHER project:
  N. Michel, ***Recent Solutions for Higher-Brightness Laser Sources,*** BRIGHTER Technical Tutorial, available online at http://www.ist-brighter.eu/tutorial.htm, 2009.
- A excellent reference on high-power diode laser technology and applications:
  F. Bachmann, P. Loosen and R. Poprawe, ***High-Power Diode Lasers: Technology and Applications***, Springer-Verlag, 2007.
- A recent invited paper on high-brightness lasers with 20 authors from the BRIGHTER project:
  J.J. Lim *et al.*, ***Design and simulation of next-generation high-power, high-brightness laser diodes,*** IEEE J. Select. Topics Quantum Electron. Vol. 15, pp. 993-1008, 2009 (invited).
- The relevant international standard for the measurement of laser beams:
  ISO Standard 11146, ***Lasers and laser-related equipment – Test methods for laser beam widths, divergence angles and beam propagation ratios***, 2005.

Gigabit/s direct data modulation of a two-electrode high brightness tapered laser with high modulation efficiency

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This article reports on the high modulation efficiency of a two-electrode high brightness tapered laser at high bandwidth. This is realised by separate excitation of the two sections in a tapered laser, whereby a modulated current is applied to the ridge section and a constant current to the tapered section. Under dynamic operation, the ridge section is driven by a non-return-to-zero data pattern using a standard low cost laser diode driver with < 100 mA maximum drive current swing. Despite using this low modulation current, a 0.95 W optical modulation amplitude is obtained at a data rate up to 1 Gb/s with error free operation.

1. Introduction

To date, high brightness diode lasers have found numerous applications, such as free-space communications, high brightness displays, and medical treatment. Several of these applications require high power pulsed or modulated signals with some requiring high modulation speed. This requirement poses special challenges for conventional high power laser diodes, as the long chip length needed to provide sufficient single mode power limits the high modulation speed. Moreover, a large current swing, well beyond the capability of common commercial current driver chips, is required to control the optical output power for this large laser chip. This situation is often overcome by high power external amplification of a low power directly-modulated laser or via incoherent power combining of several devices to provide the required high optical power [1], [2]. However, a single chip high power laser diode with high modulation bandwidth and low modulation current drive would be a more compact and less complex solution. In particular, the use of separate current drives for two-electrode tapered lasers [3], [4] adds versatility for efficient light modulation.

The idea of a two-electrode laser arises from the highly sub-linear nature of the gain versus carrier density characteristics of semiconductor lasers [5], [6]. Here, one can obtain a large change in the carrier density in one section of the laser by a small change in injection current in the other [5]–[11]. This mechanism is referred to as the “gain lever” effect [6] and can provide an output power variation with at least ten times lower drive current swing than for a single contact device. Based on this gain-levering approach and a tapered structure for high optical power operation, we have demonstrated a 4 W/A dynamic modulation efficiency for 1 Gb/s non-return-to-zero signal modulation using a high brightness tapered laser [12]. By optimizing the laser structure and design, in this paper we report a two-electrode tapered laser with the highest dynamic modulation efficiency to date, at data modulation rates up to 1 Gb/s. The methods for achieving this high bit rate operation for the high power two-electrode tapered laser are discussed, and its dynamic behaviour characterized.

2. Operating Principle

Fig. 1 shows a schematic illustration of a two-electrode high brightness tapered laser. It consists of a ridge section and a tapered section. Light in the ridge section is index-guided within a ridge waveguide and then amplified in the gain-guided tapered section. The single-transverse mode ridge waveguide provides spatial transverse mode filtering to the back reflected wave, so that only the Gaussian fundamental mode is preferentially excited and oscillates within the laser cavity for a good beam profile at the output. The tapered section amplifies the optical power by providing gain across the expanding Gaussian beam. Hence, high brightness operation can be realized by this tapered laser structure.

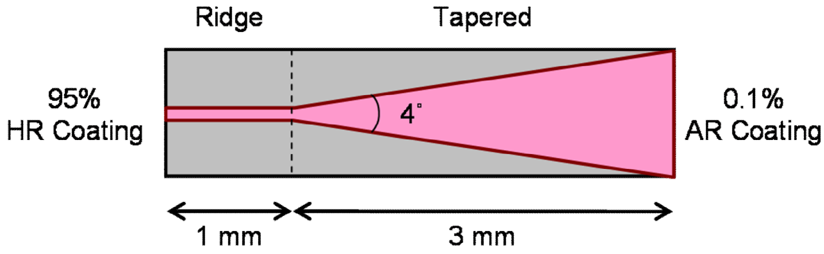

Fig. 1: Schematic illustration of a high power tapered laser with separate electrodes for individual excitation of the ridge and tapered sections.

The large laser dimensions required to achieve high power and brightness operation, however, limit the speed under direct modulation due to the long photon lifetime of the device. High speed operation can be quantified by a modulation current efficiency factor $(g/\tau_p)^{0.5}$, where g is the differential gain and τ_p is the photon lifetime.

Under gain-levering operation, the larger tapered section is biased to operate in a high net gain but low differential gain regime, whereas the shorter ridge section is biased to operate in a low net gain but high differential gain regime. Assuming the photon density remains lower than the saturation density in each section, the differential gain of the ridge section g_r is larger than that of the tapered section g_t. As a result, the displacement along the gain curve in the ridge section induced by current injection causes an enhanced reaction in the laser net gain, as illustrated in Fig. 2, and minimizes the input current swing required for modulating the output optical power [3].

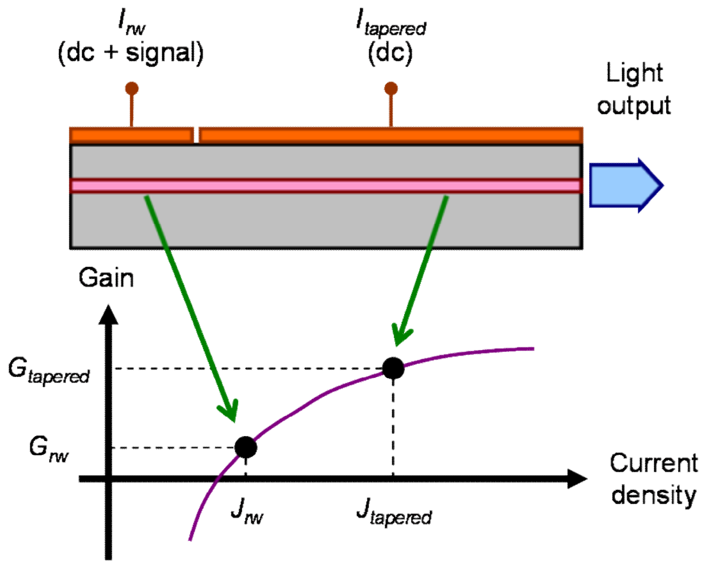

Fig. 2: Gain versus carrier density curve showing the bias operating points of each section.

3. Two-Electrode Tapered Laser

(A) Laser Structure

The device used in this work has a total length of 4 mm, with 1 mm for the ridge section and 3 mm for the tapered section. The full angle of the tapered section is 4° and the lateral width of the output facet is 210 µm. An Al-free active region containing a single GaInAs quantum well is used to provide optical gain to the laser cavity at an operating wavelength of 1060 nm.

The front facet is coated with a multilayer TiO_2/SiO_2 antireflection coating, which has a very low reflectivity of 0.1%; whereas a high reflectivity multilayer Al_2O_3/Si stack is used on the back facet to provide a reflectivity of 95%. The low output reflectivity minimizes the back reflected power and leads to an enhanced effect for the cavity gain and the output power control [13].

(B) Static Laser Characterization

Fig. 3 plots the measured output optical power of this separately excited tapered laser at different constant drive currents for these two sections. Fig. 3(a) shows the light-current (L-I) characteristics of the continuous wave (CW) output power as a function of the tapered section current, with contours of different ridge drive currents. The curves indicate that this device has a threshold current of 450 mA and reaches a CW output power of 1.1 W with 100 mA and 2 A drive current to the ridge and the tapered sections, respectively. The results show clearly that this device with separate electrodes allows a small current swing to be used for controlling the output optical power.

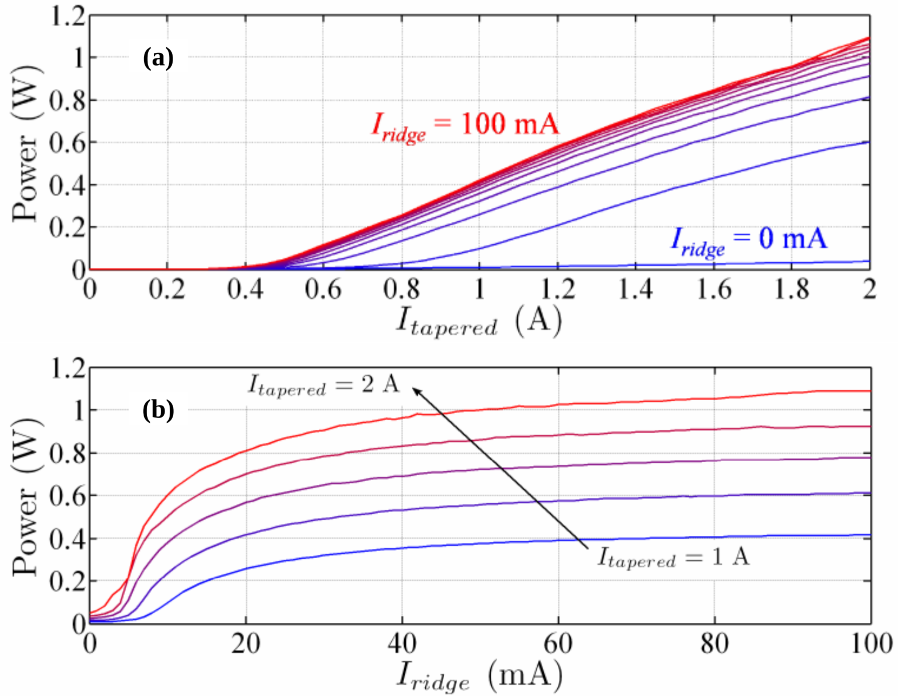

Fig. 3: Plot of (a) the CW L-I characteristics of the two-electrode tapered laser versus the tapered drive current with different ridge drive currents ranged from 0 to 100 mA in 10 mA steps and (b) output optical power versus the ridge current with the tapered drive currents ranged from 1 to 2 A in 0.25 A steps.

The effectiveness of controlling the output optical power with the ridge current is quantified in Fig. 3(b) which shows a plot of the output optical power versus the drive current to the ridge section. The plot shows two physical operating regimes of this two-electrode tapered laser: 1) high modulation extinction when the ridge current is near the threshold (<20 mA); and 2) lower modulation extinction for ridge currents above this point. The ridge section turn-on drive current is found to be ~5 mA for tapered section currents greater than 1 A. By driving the laser near its threshold using the ridge current, a strong modulation can be achieved though with a slower response time. In contrast, the modulation response time of the laser can be reduced by shifting the operating point to above the laser threshold through a dc-bias current combined with an ac-coupled modulation signal. This dc-bias leads to a lower modulation extinction but a faster modulation speed by avoiding the long laser turn-on time.

Here, we define the modulation efficiency as the modulated optical output power versus input modulation current, and find it a useful way of evaluating the performance of this two electrode laser. This modulation efficiency is the same as the slope efficiency when a slowly modulating drive current is applied to a single electrode laser. The measured results show that the average modulation efficiency varies nonlinearly with the tapered drive current and the current swing at the ridge section and reaches a maximum value of 40.5 W/A when the ridge current is varied from 0 to 20 mA for a tapered drive current of 2 A. This compares with 0.62 W/A slope efficiency for a single electrode laser with the same structure. Under the single electrode modulation, this low modulation efficiency of 0.62 W/A leads to a small optical modulation amplitude (OMA) for the same input current swing. Consequently, this high modulation efficiency substantially reduces the necessary performance of the current driver for broad-band data modulation by reducing the current swing required to achieve the same OMA. The maximum OMA under static operation with 2 A tapered drive current and 100 mA ridge current swing is measured to be 1.06 W.

(C) Dynamic Laser Characterization

Fig. 4 plots the measured frequency response of the two-electrode tapered laser under small-signal ridge current excitation for different direct ridge bias currents to illustrate the two operating regimes. A constant 2 A current is applied to the tapered section.

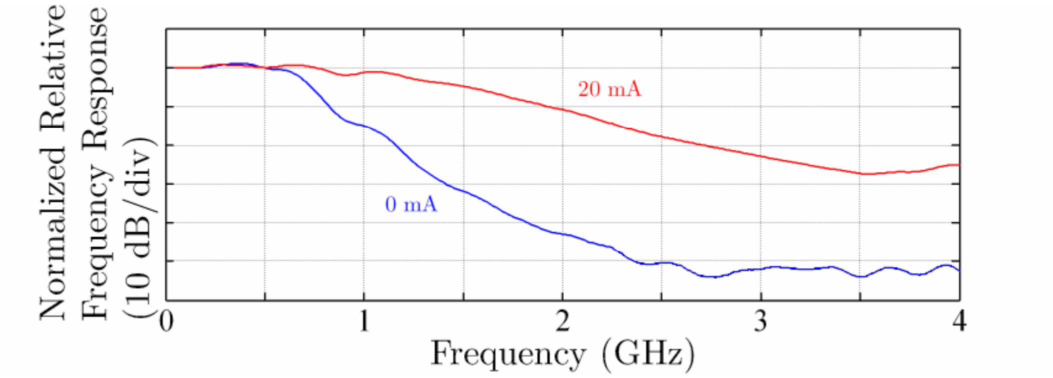

Fig. 4: Measured frequency responses under a 2 A tapered drive current with different direct ridge section bias currents.

4. Signal Modulation

The aforementioned two-electrode tapered laser is tested under data modulation with standard telecom drivers through an impedance-matched 50-ohm load network using a 2^{31}-1 pseudo-random bit sequence length. The dynamic behaviour of the device is characterized by measuring the OMA, the eye diagram and the back-to-back bit error ratio (BER) under data modulation at 100 and 700 Mb/s for the high modulation extinction regime; and at 1 Gb/s for the high speed regime. The results are shown in Fig. 5.

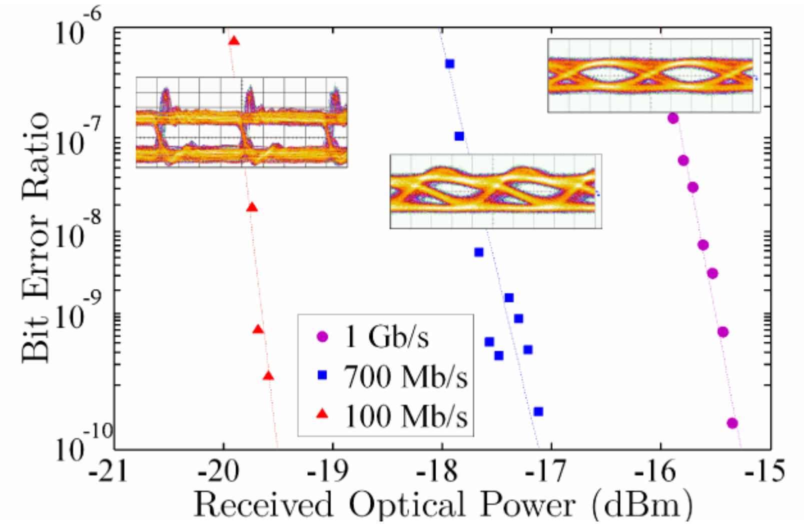

Fig. 5: Plot of the measured BERs versus the received optical power at different bit rates. The insets show the corresponding measured eye diagrams.

In the high modulation extinction regime, the device operates with a 2 A tapered drive current and with a 70 mA current swing on a dc-bias at the ridge section, and the resultant modulated output signal has a 0.81 W OMA corresponding to an averaged modulation efficiency of ~12 W/A at a bit rate of 700 Mb/s, but the eye has begun to close.

When the drive conditions are altered to operate well above the threshold with a 43 mA bias, a higher modulation speed of 1 Gb/s can be achieved though with a degradation of the modulation extinction to ~3 dB. Nevertheless, a record 0.95 W OMA is generated with a 68 mA current swing at the ridge section and 3 A tapered drive current corresponding to a modulation efficiency of 14 W/A at 1 Gb/s under these drive conditions.

The back-to-back BER performance of a non-return-to-zero signal at different bit rates is plotted in Fig. 5 with the measured eye diagrams shown inset. The receiver used in this BER measurement composes of a multimode fibre-coupled photodetector, a linear rf amplifier and a low pass filter with a 0.85 GHz 3 dB bandwidth. The BERs are, therefore, thermal noise limited. The required received optical power to achieve 10^{-9} BER is measured to be ≤-18.5 dBm for bit rates ≤700 Mb/s and ≤-15.8 dBm at 1 Gb/s. This relative receiver sensitivity degradation takes into account the operating bandwidth at different bit rates. By comparing this receiver sensitivity level with the output OMA (29 dBm at 700 Mb/s and 29.7 dBm at 1 Gb/s), we project a power budget of >45 dB over the measured operating bit rates. Specifically, the power budget is ~47.5 dB at 700 Mb/s and ~45.5 dB at 1 Gb/s.

5. Conclusion

We have reported a simple two-electrode gain-levered high power tapered laser design with the maximum 40.5 W/A static average modulation efficiency, corresponding to a 65 times improvement in equivalent over the 0.62 W/A slope efficiency observed for a single contact laser. With a 2 A tapered drive current and a dc-biased 70 mA current swing, a 0.81 W OMA optical signal is generated at 700 Mb/s. An operating bit rate of 1 Gb/s operation is achieved with a 43 mA current bias and 68 mA drive current to the ridge at 3 A tapered drive current for a 14 W/A modulation efficiency. Both values are the highest ever reported. A comparison between the output OMA and the thermal noise limited receiver sensitivity at 10^{-9} BER implies a power budget of >45 dB for a bit rate of 1 Gb/s. The power budget is even greater at lower bit rates.

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Large Spot Size Lasers

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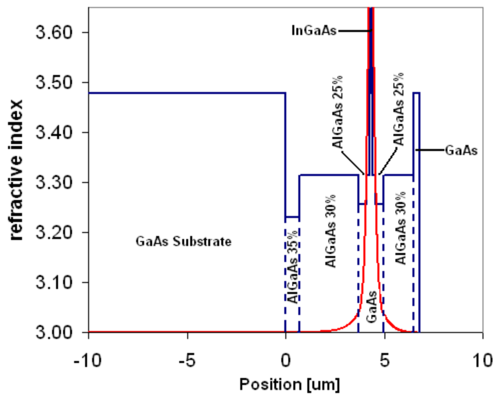
Introduction

Semiconductor lasers are highly versatile devices with wide wavelength ranges, wide power ranges and specific frequency and spatial properties that can be obtained and thus enable widespread applications. Most applications require that the semiconductor light be carefully managed and delivered to the point of use with a tightly controlled spot size for the laser beam and with a controlled incident angular range. The optical lenses used in this light management will have finite apertures, while optical fibres have finite numerical apertures (NA). Thus, any use of lasers must take into account that highly divergent beams are more difficult to manage, even if those beams have a high beam quality (low M^2 values).

The BRIGHTER project has demonstrated many advances in controlling the lateral beam from a semiconductor laser resulting in high power output with low lateral M^2 values. In the transverse or fast-axis dimension, the M^2 value is essentially 1 by virtue of the design of the epitaxial layer structure, which results in a well controlled refractive index profile. However, as is well known, the emission from a semiconductor laser is highly divergent in this direction. This is because the requirement for a single transverse mode leads to the tight confinement of light in a submicron thick waveguide. Through the Fourier relationship, a large divergence angle results. Thus, while the beam is well behaved, it requires high NA lenses to collect the light efficiently. These aspheric lenses must be made with high precision resulting in higher cost components, which must be placed with high precision and maintained in position over the device lifetime. It would be better to have a lower divergence to start with.



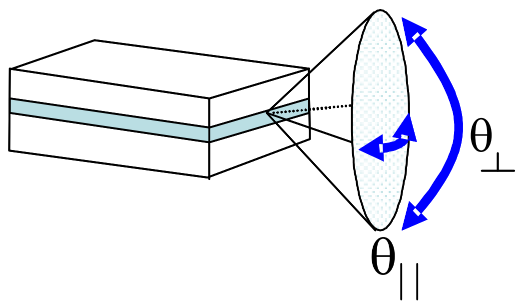


Fig. 1: (a) Typical refractive index profile (blue) and fundamental mode (red) for a GaAs/AlGaAs semiconductor laser along the fast axis direction, (b) Diagram showing the transverse & lateral beam divergences from a semiconductor laser.

Design

In terms of divergence, the slow axis direction does not present a major problem because the electromagnetic field envelop can easily spread laterally, thus giving rise to a narrow far field pattern. The issue is to keep the mono-modality condition along this direction, along with ideally a Gaussian profile. This further condition guarantees that the far field pattern is mono-modal, because the Fourier transform of a Gaussian function is also a Gaussian function.

Along the transverse (fast axis) direction, the problem is the extreme confinement of the field into a very thin region, usually a fraction of the laser wavelength within the high refractive index material. This relatively high confinement results in the broadening of the transverse far field (TFF) that can be >40° at the full width at half maximum (FWHM) and >60° at the $1/e^2$ width. A laser with such a large difference between the lateral far field (LFF) and TFF divergence results in an elliptical far field that needs to be circularly re-shaped with external optics in order to be coupled efficiently, for example, to an optical fibre.

In high power lasers such as tapered designs [1], a high confinement of the field within the thin active region may be detrimental to the device. Catastrophic optical damage (COD) at the laser facet can be enhanced by the high power density, while the beam quality may be degraded due to the interaction between the optical field and the carriers. The interaction increases strongly (quadratically) with the confinement factor [2] and can thus create non-linear effects such as spatial hole burning and filamentation. These effects result in a limited focusing capacity of the laser beam along the lateral direction, leading to a large M^2 factor.

Advantages of a large transverse mode size

1. Reduction in power density on the laser facet
   Reduce the probability of COD (catastrophic optical damage)
2. Reduction in transverse far-field
   Simplify the optics to control the laser emission
3. Symmetrisation of beam
   Simplify the optics and improved coupling to applications
4. Reduction in generation of nonlinearities
   Low modal gain reduces filamentation and self focusing

From the above, it is seen that a reduction in the confinement of the light within the active region, due to a transverse mode expansion, is advantageous both for a reduction in the TFF divergence and for the beam quality. However, a very small confinement factor reduces the modal gain. Thus, a careful balance needs to be found in the design that satisfies all the main design requirements, such as threshold gain, beam divergence and ellipticity. An additional restriction is imposed by the range of compatible materials and their associated refractive indices. For lasers emitting in the 900 – 1100 nm range, the gain material will be based on InGaAs quantum wells or on quantum dot layers while using a GaAs substrate. The compatible materials are based on $Al_xGa_{1-x}As$ and compositions of the quaternary alloy InGaAsP that are lattice matched to GaAs. The available refractive indices are shown in Fig. 2. Further restrictions are imposed by, for example, the need to have low oxidation rates, especially at the laser facet, which requires keeping the Al content low.

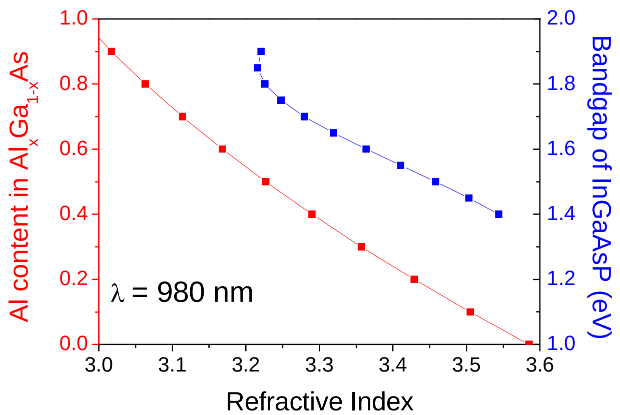


Fig. 2: Refractive index values at a wavelength of 980nm for AlGaAs and InGaAsP compositions lattice matched to GaAs.

There are a number of strategies to increase the mode size. Here, we consider those based on the design of the epitaxial structure, rather than mode expansion techniques that can be achieved, for example, by tapered mode coupling between waveguides or by overgrowth which are more complex to produce and not very compatible with GaAs based materials. Examples include:

1) Reduction of the refractive index difference between the core active layer and the border layers

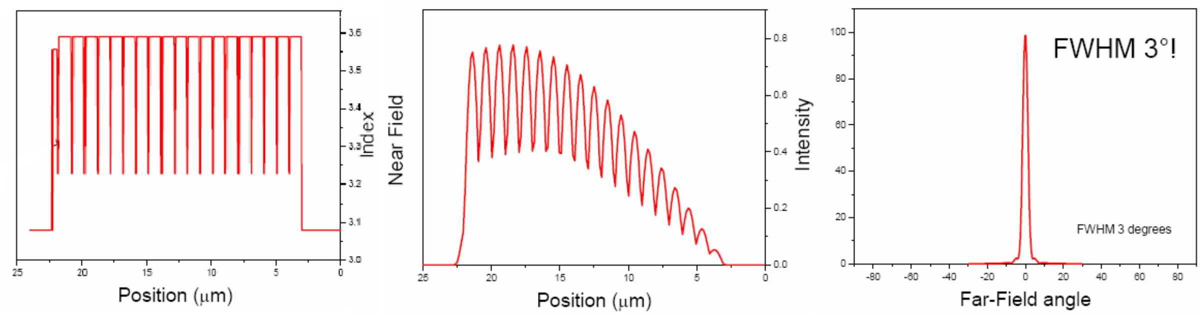
2) Mode expansion using low-refractive index layers close to the active region

3) Photonic bandgap crystal (PBC) structures [3]

4) Slab coupled optical waveguides (SCOWL) [4]

The PBC and SCOWL methods can provide TFF divergences less than 10º. The PBC consists of a quasi-periodic alternation of thin layers with a high refractive index contrast in such a way as to obtain a photonic bandgap structure along the fast axis direction. The gain providing layer(s) are located as the “defect” of the structure.

The growth of the epitaxial structure is complex and requires an extremely high control of the interfaces to reduce the potential series resistance associated with the hetero-barriers between the alternating layers of the quasi-periodic structure. Nevertheless, Fig. 3 shows an example PBC structure with 19 periods and a thickness of >20µm, which can achieve a remarkably low divergence of only 3 degrees.



(a) (b) (c)

Fig. 3: Example of a PBC laser, (a) refractive index profile, (b) calculated electric field profile, (c) corresponding far field.

For all approaches, it is important to consider carefully the penetration of the field inside the n-doped substrate and especially the overlap with the heavily p-doped layers [5]. These layers are significant sources of unsaturable free carrier absorption (FCA) losses. The typical values that we considered for the FCA cross sections, for the range of wavelengths of our interest, are $\sigma_p = 1 \times 10^{-17}$ cm^{-2} for the p-doped layers and $\sigma_n = 5 \times 10^{-18}$ cm^{-2} for the n-doped layers. We designed a number of large spot size lasers. In particular, we designed single quantum well structures (SQW) and multiple quantum dot layer structures (MQD) for use in the 900 – 1060 nm wavelength range. Moreover, a new concept of a Single Mode Intense Laser Emitter (SMILE) structure [6] that is based on the exponential expansion of the mode was introduced. All designs were modelled using FIMMWAVE, a Photon Design CAD tool capable of simulating optical passive devices both in 2D and 3D. The materials used for these devices are InGaAs for the active regions and AlGaAs/GaAs for the cladding layers.

Large spot size single quantum well design

The strategy for mode expansion in this design is obtained by inserting a low refractive index layer between the active region and the substrate. The resultant laser performance can be strongly dependent on the thickness of this layer. In Fig. 4, we show how the thickness of this layer can modify both the confinement factor and the transverse divergence. Thus, it is very important to realise a design that takes into account the possible variations during the growth of the epitaxial layers both in terms of refractive index (material composition) and thickness. A safe design is, for example, one that is able to provide similar performance even considering variations of layer thickness of ±10% and of aluminium content of ±2%. The epitaxial structure realized provides a mode confinement factor 1.2% and a far-field divergence of 12º at FWHM and <35º at $1/e^2$, as shown in Fig. 4. The optical losses, if just due to FCA, are estimated to be less than 1.8 cm^{-1}. This is a result of a design where the field penetration into the substrate and heavily doped layers is limited.

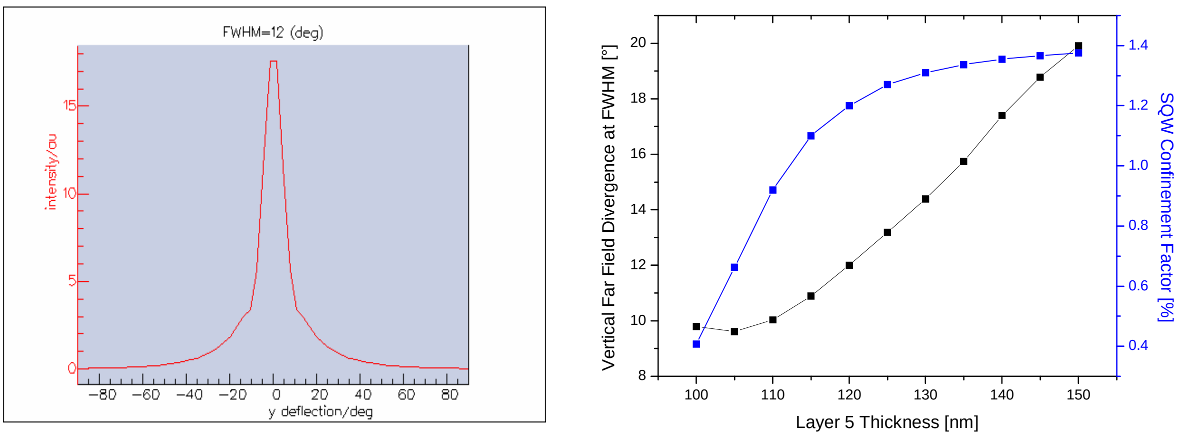


Fig. 4: Vertical far field divergence and anti-guiding layer thickness analysis for the SQW structure.

Large spot size multiple quantum dot structures

There are additional challenges in the design of large spot size quantum dot lasers. The finite dot density results in a diluted modal gain. Thus, careful management of the gain is required through low waveguide losses and long cavities. However, quantum dots present many advantageous properties, including the ability to engineer the dots to reduce the wavelength shift with temperature, a broad gain spectrum for tunability, access to a wide wavelength range by changing dot dimensions and a single platform especially suitable for frequency doubling.

The design principle of the MQD structure is similar to the one used for the SQW, but in this case we used two low-refractive index layers to expand the mode, as can be seen in the refractive index profile shown in Fig. 5(a). This structure is able to provide a TFF divergence of 15º at FWHM and <40º at $1/e^2$, as shown in Fig. 5(b), with a confinement factor of 1.28%. The core region consists of 3 InGaAs QD layers spaced by 50 nm thick GaAs barriers, sandwiched between 2 AlGaAs low refractive index layers. The FCA losses are estimated to be lower than 3.7 cm^{-1}. Fig. 5(a) also shows how the electric field of the fundamental mode is distributed along the transverse direction, with its peak maximally overlapped with the active region and the tail expanded broadly into the substrate. Transverse cavity designs based on an anti-guiding concept, as in this case, are generally quite thick when compared to conventional designs. This is because it is necessary that the mode is well expanded in the waveguide region avoiding its coupling with the substrate. As it is possible to see in Figs. 5(c) & 5(d), the absence of the two low refractive index layers results in a broadening of the fast axis far field pattern from 16º to 34º at FWHM, mainly because the mode is more confined in the core region of the cavity. However, the advantage of a reduction of the TFF divergence is greater than the disadvantage of a lower confinement factor. In fact, the large spot size structure has a confinement factor of Γ_1 = 1.28%, which is very close to the Γ_2 = 1.58% of the structure without anti-guiding layers. This reduction of just 20% in the confinement is much lower than the reduction of more than 50% in the far field divergence ($\Gamma_1 / \Gamma_2 = 0.8$; $TFF_1 / TFF_2 = 0.43$).

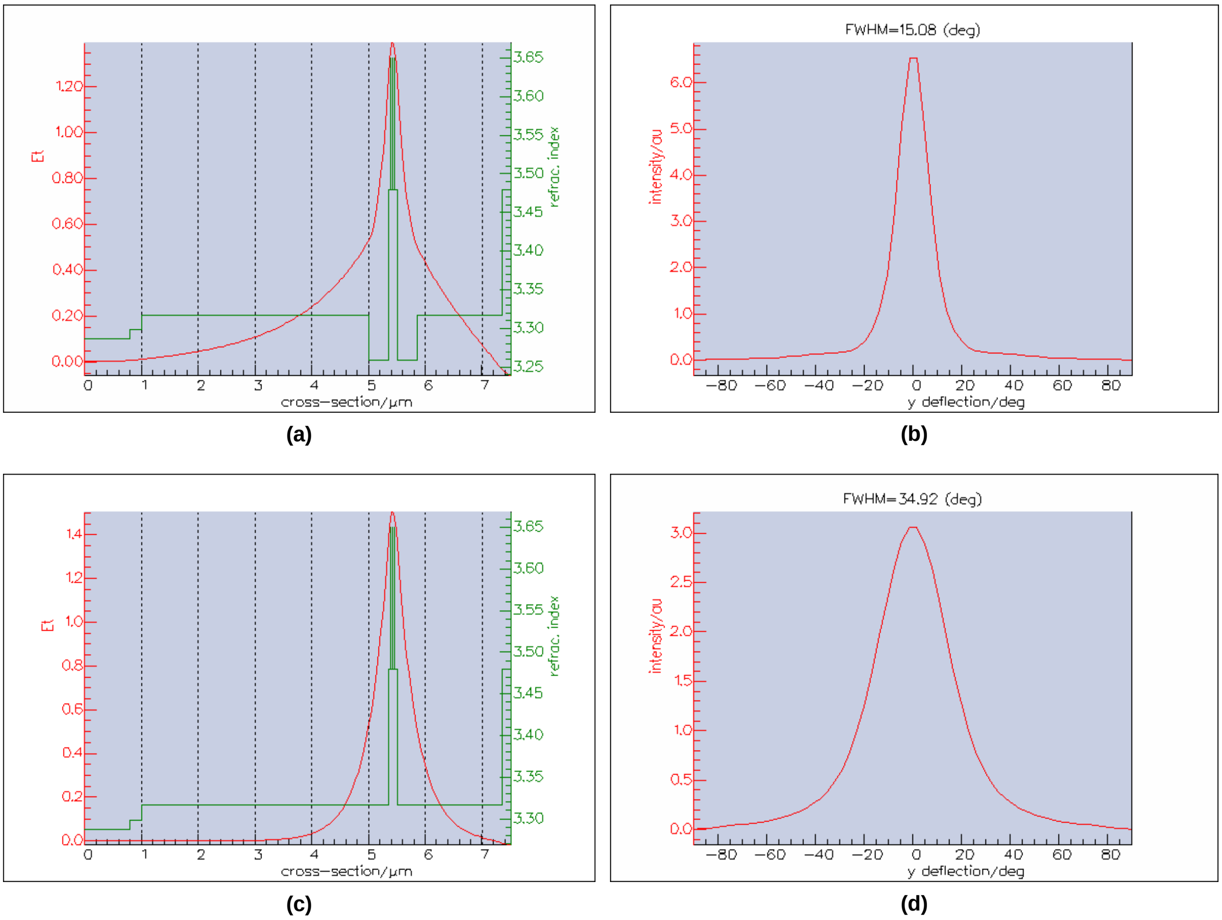


Fig. 5: Fundamental transverse mode envelope, refractive index profile and fast axis far field for a MQD structure with anti-guiding layers (a) & (b) and without anti-guiding layers (c) & (d).

The Single Mode Intense Laser Emitter (SMILE) structure

A different approach to design a large spot size laser has been used in the case of the SMILE structure. To obtain a narrow TFF, the principle exploited is the exponential expansion of the electric field inside the waveguide, as shown in Fig. 6. The active region in this case consists of a single InGaAs QD layer, engineered for 980 nm emission. The design is able to provide a very narrow TFF divergence of 12º at the FWHM, and <30º at $1/e^2$. It is noted that the fraction of the mode penetrating into the substrate is significant. In order to provide sufficient gain, 3 InGaAs QD layers are used which reduces this substrate penetration. The additional 2 QD layers increase the fraction of the mode confined into the active region, which increases the TFF divergence to 20º at the FWHM.

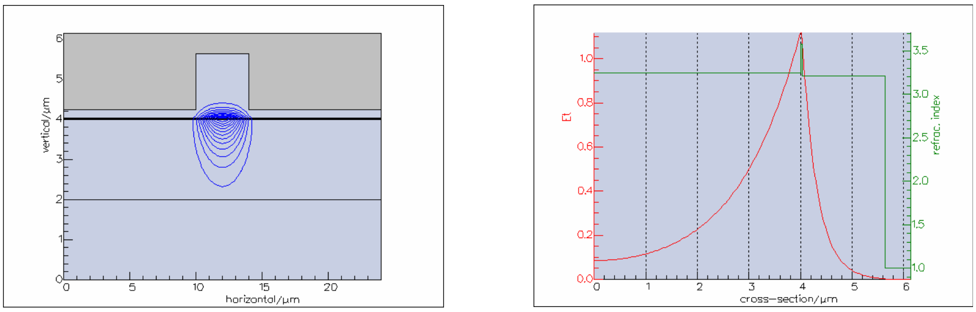


Fig. 6: Fundamental mode 2D intensity contour plot, transverse envelope & refractive index profile for a SMILE structure.

Ridge waveguide lasers based on the SMILE quantum dot active region were fabricated with epitaxial material from the University of Würzburg. Figure 7 shows the device characteristics where a threshold current density of J_{th} = 0.6 kA/cm^2 was obtained for a 3 mm long device with a slope efficiency of close to 1 W/A indicating low waveguide losses. Of special interest is the very low FWHM vertical divergence of 20º matching that of the lateral direction. An interesting match between simulation and experiment is seen in Fig. 7, where we compare the modelled intensity profile in a RW laser and a SEM image of an uncoated facet which has been driven to COD. The close match also shows the quasi-circular near field mode of the laser matching the far field results.

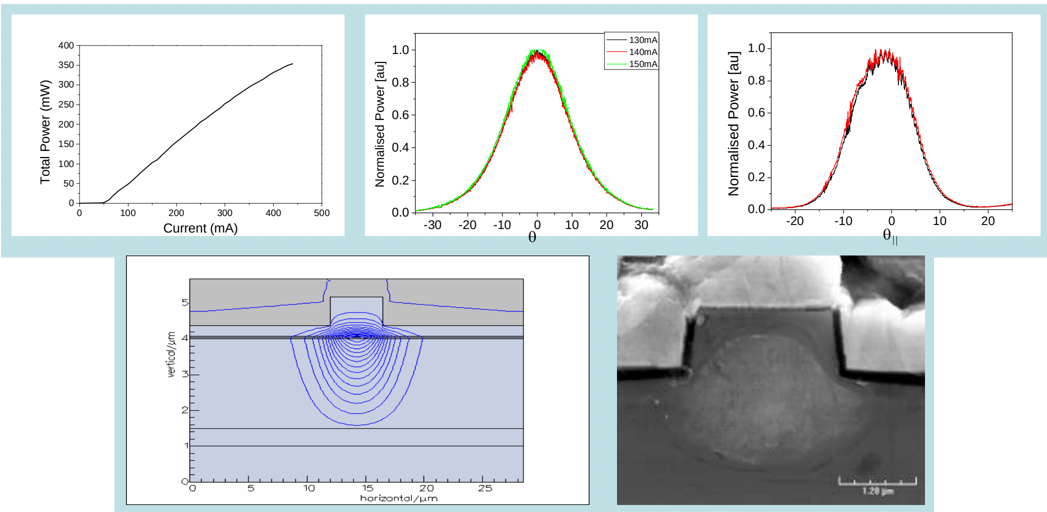


Fig. 7: Basic characteristics of the quantum dot SMILE structure showing high slope efficiency and near circular output. The lower panel shows the simulated and actual near field as obtained by driving the laser to catastrophic optical damage.

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[2] M. Mikulla *et al.*, "High-brightness tapered semiconductor laser oscillators & amplifiers" *Photon. Tech. Lett.* **10,** 654, 1998.
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[4] J.P. Donnelly *et al.*, "AlGaAs–InGaAs slab-coupled optical waveguide lasers" *J. Quantum Electron.* **39,** 289, 2003.
[5] B. Corbett *et al.*, "Engineering of InGaAsP layer structures for low divergent long-λ lasers" *Electron. Lett.* **38,** 515, 2002.
[6] B. Corbett *et al.*, "Modal analysis of large spot size, low beam divergence QD lasers" *Photon. Tech. Lett.* **19,** 916, 2007.

BIOPHOTONICS '09 – SUMMER SCHOOL

The 4th International Graduate Summer School Biophotonics '09, in collaboration between the Technical University of Denmark, Lund University in Sweden and Photonics for Life (P4L), a European network of excellence for biophotonics, was held on the island of Ven, Sweden from 6th to 13th June 2009. The main purpose of this biennial summer school is to provide education within biophotonics for students and young scientists at the highest international level.

The format of the school is a combination of lectures, student poster presentations – and leisure time. However, the leisure time is also spent discussing, learning and exchanging new scientific ideas. The school targets graduate students and postdoctoral fellows with a limit of about 70 participants. Application to attend the summer school is by peer review of a summary of the participants' research & results or planned research project.

During the school, successful applicants present their research during three poster sessions. The posters are evaluated by the lecturers and a best poster prize awarded. Following the school, the posters and summaries are available online at http://www.biop.dk/biophotonics09. The lectures are also made available online following the summer school.

The 4th International Graduate Summer School Biophotonics '09 had 74 participants from 21 different countries worldwide with 48 male and 26 female students mainly ranging in age from 25 to 35 years. Approximately 25% of the participants came from outside the EU – the majority (16%) of these coming from the US and Canada. The school had 11 lecturers representing 6 countries – 5 lecturers from the US and 6 from the EU.

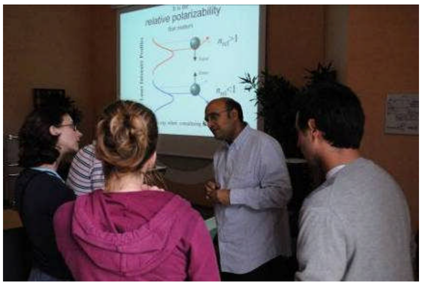
The Biophotonics '09 school covered the basics of lasers and their application in medicine, tissue optics, photodynamic therapy (PDT), optical tweezers and their applications in biophotonics, optical biosensors, molecular imaging based on optical methods and optical coherence tomography (OCT). These topics were covered by internationally renowned lecturers:

- *Prof. Darryl J. Bornhop, Chemistry Department, Vanderbilt University, USA*
- *Prof. Kishan Dholakia, School of Physics & Astronomy, University of St. Andrews, UK*
- *Prof. Stefan W. Hell, Department of NanoBiophotonics, Max-Planck-Institute for Biophysical Chemistry, Germany*
- *Prof. Joseph Izatt, Department of Biomedical Engineering, Duke University, USA*
- *Prof. Steven Jacques, Oregon Health & Science University, USA*
- *Prof. Eva Sevick-Muraca, Brown Institute of Molecular Medicine, Univ. of Texas, USA*
- *Prof. MD Katarina Svanberg, Dept. of Oncology, Lund University Hospital, Sweden*
- *Prof. Sune Svanberg, Department of Physics, Lund University, Sweden*
- *Prof. Roy Taylor, Department, of Physics, Imperial College London, UK*
- *Prof. Bruce Tromberg, Beckman Laser Institute, University of California, USA*
- *Prof. Hubert van den Bergh, Ecole Polytechnique Fédérale de Lausanne, Institut de l'environnement, Switzerland*

Biophotonics '11

The 5th school, Biophotonics '11, is already scheduled for May 2011. To receive more information, please visit http://www.biop.dk/biophotonics09 and join our mailing list.

Biophotonics '09: Class of 2009



Poster session at Biophotonics '09

Prof. Joseph Izatt during his OCT lectures

Prof. Kishan Dholakia (middle) discussing with students during a break in his lectures

Prof. Bruce Tromberg (right) discussing with students during a break in his lectures

HIGH POWER DIODE LASERS & SYSTEMS

Diode lasers lie at the heart of most laser systems today. Advances in the capabilities of both conventional solid state lasers and fibre lasers are being driven by improvements in power, mode structure, brightness and reliability of high-power diode pump lasers. This meeting, being held at Photonex for the second time and this year co-sponsored by the WWW.BRIGHTER.EU project, will investigate the capabilities of diode lasers, what they can do now and what they might be able to do in the future.

This meeting will comprise an ***invited programme*** of speakers, all leaders in High Power Diode Lasers from around Europe, followed by an ***evening poster session of contributed papers***. Time and opportunity has been built into the day to visit the PHOTONEX exhibition and also to listen to the PHOTONEX annual executive panel discussion.

Please join us and present your research at this leading event. The main timings of the meeting are given opposite and the full programme of speakers can be found on the next page.

High Power Diode Lasers & Systems Meeting – Agenda	
09.00	Coffee & Registration
09.55	Introduction by Prof John Marsh
10.00	SESSION 1: Advances in High Power Diode Lasers
12.10	Lunch and Exhibition
13.30	Keynote Address
14.00	SESSION 2: Beam Control and Delivery
15.00	Tea
15.20	SESSION 3: Novel Diode Lasers and Arrays
17.00	Oral Session Ends
17.15	Executive Panel Discussion Forum
18.15	Poster Session Starts

www.photonex.org/hpdls.php

HIGH POWER DIODE LASERS & SYSTEMS
Programme of Speakers

SESSION 1: ADVANCES IN HIGH POWER DIODE LASERS	
10.00	**Recent developments on high-power and high-brightness diodes at Coherent** Dr Mario Auerbach, Coherent GmbH, Germany
10.20	**Wavelength stabilized high-power diode lasers and modules** Dr Jörg Neukum, DILAS Diodenlaser GmbH, Germany
10.40	**Ultra-large optical cavity diode lasers for high power, high efficiency, narrow linewidth applications** Dr Paul Crump, Ferdinand-Braun-Institute, Germany
11.00	**Numerical emulation of the degradation of 975nm high power tapered laser bars** Prof Eric Larkins, University of Nottingham, UK
11.20	**Design and realisation of high power semiconductor lasers** Dr Norbert Lichtenstein, Oclaro, Switzerland
11.40	**High power diode lasers for future applications** Dr Detlev Wolff, JENOPTIK Laserdiode GmbH, Germany
11.55	**Stack designs for high brightness, highly reliable QCW pump sources** Dr Andreas Kohl, Quantel Laser Diodes, France
KEYNOTE ADDRESS	
13.30	**HiPER and ELI: Multi-kilojoule-class DPSSLs for laser fusion and ultra high intensity research** Dr Klaus Ertel, Rutherford Appleton Laboratory, UK
SESSION 2: BEAM CONTROL AND DELIVERY	
14.00	**Fast axis lens collimators for high power diode lasers** Dr Martin Forrer, FISBA OPTIK AG, Switzerland
14.20	**Beam conditioning of high power lasers** Dr Roy McBride, Power Photonic, UK
14.40	**Advanced fibre designs for high power laser beam delivery and generation** Mr John Hayes, University of Southampton, UK
SESSION 3: NOVEL DIODE LASERS AND ARRAYS	
15.20	**Very high modulation efficiency, high bandwidth, high power, two contacts tapered laser** Dr Michel Krakowski, THALES Research and Technology, France
15.40	**External-cavity designs for phase-coupled laser diode arrays** Prof Gaëlle Lucas-Leclin, CNRS/LCFIO Université Paris-Sud, France
16.00	**Multimode interference coupled array lasers** Prof Catrina Bryce, University of Glasgow, UK
16.20	**Recent developments in QCW bar and stacks fabricated with QWI enhanced bars** Dr Gianluca Bacchin, Intense, UK
16.40	**Low fill factor diode laser bars with high brilliance from 808nm to 1020nm for fibre coupling** Dr Robin Fehse, OSRAM Opto Semiconductors GmbH, Germany

www.photonex.org/hpdls.php

ONLINE PROJECT RESOURCES

Over the course of the project, the Consortium has produced a wide range of informational and teaching/training resources, all of which can be found on our project website http://www.ist-brighter.eu/. These resources include:

- A 15 minute film clip about the different aspects of the project
  http://www.ist-brighter.eu/clip.htm
- Presentations and videos from a project workshop on toxicology & safety
  http://www.ist-brighter.eu/toxicology.htm
- Video recorded technical tutorials on key project topics and technologies
  http://www.ist-brighter.eu/tutorial.htm
- Presentations from a workshop dedicated to high brightness laser sources
  http://www.ist-brighter.eu/laser2007.htm
- Our series of e-Newsletters from both the BRIGHT & BRIGHTER projects
  http://www.ist-brighter.eu/news.htm

Project Film Clip — *www.ist-brighter.eu/clip.htm*

BRIGHTER Film Segments

1. **Brighter: Project Introduction**
2. **What is a laser?**
3. **Laser Structures & Processing**
4. **Laser Modelling**
5. **Frequency Doubling**
6. **Reliability & Degradation**
7. **Laser Packaging**
8. **Display Applications**
9. **Medical Applications**
10. **Telecom Applications**
11. **Dissemination**

The film is divided into 11 short segments as listed opposite. Just click on the video camera to watch a clip (see screenshot above). The videos can also be viewed in full screen mode if you wish.

Workshop Presentations — *www.ist-brighter.eu/toxicology.htm*

Video recordings (RichMedia presentations) and slides are available to download for the following:

1. **Toxicology: A basic introduction** – Dr. J.H. Duffus, *The Edinburgh Centre for Toxicology (Scotland)*
2. **Toxicology: Examples related to As, Al, Be, Ga and In compounds** – Nicole Proust, *TRT (France)*
3. **MBE maintenance: Safety management** – Prof. Johann Peter Reithmaier, *University of Kassel (Germany)*
4. **Nanotoxicology: The nanoparticles example** – Dr. A. Lombard, *Alotoxconsulting (France)*

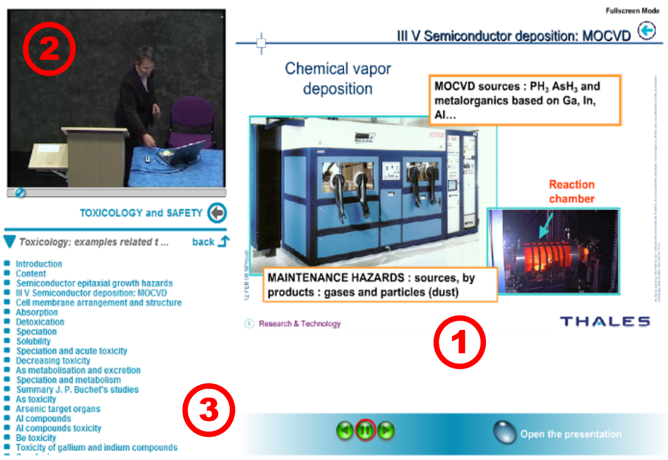
Technical Tutorials

www.ist-brighter.eu/tutorial.htm

Throughout BRIGHTER, the Consortium have developed a series of technical tutorials, each of which have been produced in the RichMedia CD format and are now available free online.

More about RichMedia CDs…

RichMedia CDs are an innovative way of attending a virtual presentation, which include the transparencies of the presentation, together with synchronised video and audio of the presenter. The screen is divided in to 3 parts: (1) the presentation slides, (2) the video of the presenter, and (3) a contents and navigation panel (see example opposite). The video, audio and slide changes are all synchronised and a PDF file of the presentation is also available.



BRIGHTER Tutorials – Available online in RichMedia format

1. **Toxicology and safety in III-V epitaxy**
2. **Quantum dot lasers**
3. **Mirror heating and COD in high-power lasers**
4. **Efficiency of diode lasers: Basics and principles of optimisation**
5. **High-power high-brightness tapered diode lasers and amplifiers**
6. **The major changes affecting the physical layer of optical networks**
7. **By emitter degradation analysis of high-power diode laser bars**
8. **Raman amplification for telecom optical networks**
9. **Analysis of diode lasers by near-field scanning optical microscopy**
10. **An overview of large spot size laser structures**
11. **Frequency doubling and second order nonlinear optics**
12. **Recent solutions for higher-brightness laser sources**
13. **Modelling of external cavity laser diodes**
14. **Medical fluorescence imaging**

Did you know?

There are even more resources online from the earlier BRIGHT.eu project. These include 11 extra tutorials, 11 more workshop presentations & 3 e-Newsletters. Find them all online now at:

http://www.bright-eu.org

On the BRIGHTER website, you have four options:

1. Stream the full RichMedia presentation (slides, video, audio) from the website
2. Stream just the video recording of the presentation from the website
3. Download an *iso* image file of the RichMedia presentation from which to make your own CD
4. Download a PDF copy of the presentation slides

Workshop Presentations — *www.ist-brighter.eu/laser2007.htm*

The High Brightness Diode Laser Sources Workshop was hosted by the BRIGHTER Consortium during the World of Photonics Congress (Laser2007) in Munich in June 2007 (more details were given in e-Newsletter #2).

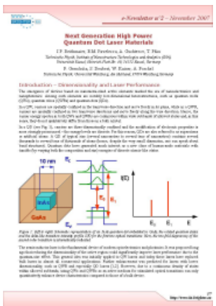
It was a busy one-day workshop with speakers presenting on a wide variety of topics including high-brightness laser technology, frequency-doubled lasers, laser packaging, micro-optics and reliability, as well as important medical, telecom and display applications of high brightness laser diodes.

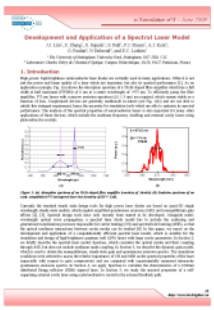
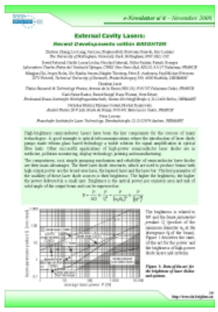
The following presentations are now available to download from our project website:

1. **External cavities for controlling spatial & spectral properties of semiconductor lasers**
   Jean-Pierre Huignard, *Thales Research and Technology*
2. **Reliable high-power red-emitting laser diodes**
   Bernd Sumpf, *Ferdinand Braun Institute*
3. **Wavelength stabilised high-power quantum dot lasers**
   Hans Peter Reithmaier, *University of Kassel*
4. **Quantum dot lasers & new device concepts for high-brightness applications**
   Nikolai Ledentsov, *Technical University of Berlin*
5. **High-power laser for surgical applications (cutting and ablation)**
   Ronald Sroka, *LFL Munich*
6. **How to measure packaging-induced strain in high-brightness diode lasers?**
   Jens Tomm, *Max Born Institute*
7. **High-power laser modules and their applications**
   Jörg Neukum, *DILAS*
8. **Second harmonic generation of external cavity tapered diode lasers**
   Ole Bjarlin Jensen, *Risoe National Laboratory*
9. **High-power semiconductor VECSELs**
   Anne Tropper, *University of Southampton*
10. **Fluorescence diagnostics in medicine: The need for improved light sources**
    Stefan Andersson-Engels, *Lund University*
11. **Laser fluorescence spectroscopy & molecular imaging as tools for tumour detection**
    Bernd Ebert, *Physikalisch-Technische Bundesanstalt*

e-Newsletters — *www.ist-brighter.eu/news.htm*

Sadly, this is the final edition of our e-Newsletter series for the BRIGHTER project. We hope you have enjoyed this edition and indeed all of our previous e-Newsletter editions. If you have missed any of the previous five e-Newsletters, or would like to see our three e-Newsletters from the earlier WWW.BRIGHT.EU project, these can all be found online on our website http://www.ist-brighter.eu, where you can download your personal copy.

SELECTED RECENT PUBLICATIONS

Laser Diode Technology

- P. Weinmann, C. Zimmermann, T.W. Schlereth, C. Schneider, S. Hoefling, M. Kamp, A. Forchel, "Mode-controlled tapered lasers based on quantum dots," IEEE J. Select. Topics Quantum Electron. Vol. 15, pp. 780-784, 2009.
- E.-M. Pavelescu, C. Gilfert, J.P. Reithmaier, A. Martin-Minquez, I. Esquivias, "High-power 1060nm tunnel-injection InGaAs-(Al)GaAs quantum-dot lasers," IEEE Photon. Technol. Lett. Vol. 21, pp. 999-1001, 2009.
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- B. Piechal, J.W. Tomm, A. Bercha, W. Trzeciakowski, M. Reufer, A. Gomez-Iglesias, "Mounting-induced strains in red emitting (Al)InGaP laser diodes tuned by pressure," Appl. Phys. A Vol. 97, pp. 179-184, 2009.
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CALENDAR OF EVENTS

2009

4th – 8th October

IEEE Photonics Society Annual Meeting, *Belek-Antalya, Turkey*

14th October *[See pages 35-36]*

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*

18th – 21st November

World Forum for Medicine – Medica.de, *Düsseldorf, Germany*

30th November – 4th December

Materials Research Society (MRS) – Fall Meeting, *Boston, MA, USA*

2010

23rd – 28th January

SPIE Photonics West – Conference and Exhibition, *San Francisco, CA, USA*

13th – 18th February

SPIE Medical Imaging – Conference and Exhibition, *San Diego, CA, USA*

21st – 25th March

Optical Fiber Communication Conference (OFC), *San Diego, CA, USA*

5th – 9th April

Materials Research Society (MRS) – Spring Meeting, *San Francisco, CA, USA*

7th – 9th April

European Conference on Integrated Optics (ECIO), *Cambridge, UK*

12th – 16th April

SPIE Photonics Europe – Conference and Exhibition, *Brussels, Belgium*

16th – 21st May

Conference on Lasers and Electro-Optics (CLEO), *San Jose, CA, USA*

7th – 11th June

European Materials Research Society (EMRS) – Spring Meeting, *Strasbourg, France*

28th June – 1st July

International Conference on Transparent Optical Networks (ICTON) , *Munich, Germany*

5th – 9th July

Optoelectronics and Communications Conference (OECC) , *Sapporo, Japan*

1st – 5th August

SPIE Optics + Photonics – Conference and Exhibition, *San Diego, CA, USA*