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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 2nd 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 the 1st edition of our e-Newsletter in June, please visit our website to download a copy. The next e-Newsletter will be published in March 2008.

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

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GREETINGS FROM THE PROJECT COORDINATOR

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Dear Reader,

Welcome to the second 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.

In the year since the WWW.BRIGHTER.EU Project began, our Consortium has been working hard towards the project objectives and have already achieved many successes.

Examples of our technological successes include: improved power and reliability from both red-emitting single emitters and laser bars for use in display and photodynamic cancer therapy applications; a frequency-doubled blue laser for fluorescence imaging; infrared laser diodes ready for frequency-doubling to achieve the green lasers required for laser displays; high-brightness infrared lasers for free space optical communications and demonstration of high-speed data modulation; and the beginning of clinical tests using the new blue laser source and fluorescence imaging system.

In addition to these impressive achievements, the Consortium has been making a focussed effort on providing training opportunities for young researchers – through technical tutorials and personnel training exchange visits – and on disseminating the results of the project – through the project website (http://www.ist-brighter.eu), workshops, papers, conferences and the e-Newsletters.

Inside this e-Newsletter you'll find a review of the latest technical achievements, a report on the extensive training activities in the project, in particular for young scientists, and profiles of three more project partners. There are also three extended articles in this e-Newsletter. Two applications topics cover the design of collimating lenses for high power diode lasers and the pumping of fibre lasers using high-brightness diodes. A technical review article discusses next generation quantum dot materials for high-brightness laser diodes. There are also reports on some of our project dissemination and popularisation activities including workshops, conferences and summer schools held in recent months. At the end of this edition, you can find details of some of our recent publications, a calendar of forthcoming events and a preview of the next e-Newsletter.

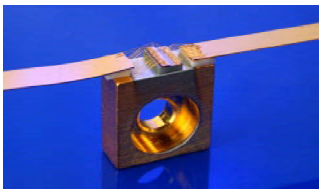
TECHNICAL ACHIEVEMENTS

Towards the Project Objectives

During the first year of WWW.BRIHGTER.EU, the Project Consortium has had many technological successes. Here, we present a short review of some of the highlights from the past year. These range from improved laser sources for a wide range of applications to the demonstration of a high-speed modulated source and the first clinical tests of a fluorescence imaging system using a blue laser source developed by the Project Consortium.

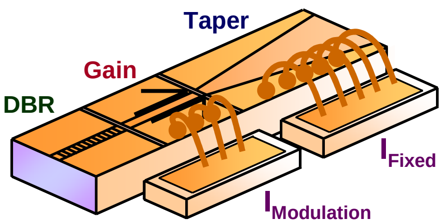
Improved diode laser sources for a wide range of applications

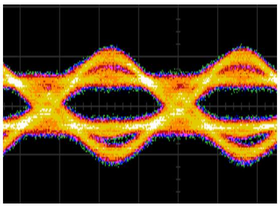
Red-emitting single chips and laser bars for medical and display applications have both been demonstrated with over 10,000 hours of operation at powers of 1W and 7W, respectively. Wavelength stabilised 1060nm laser diodes have been produced with output powers of >3W, suitable for frequency-doubling to achieve green display lasers. High-brightness lasers at 975nm for telecom pumps have been realised – tapered single emitters with output powers of >15W and 100W tapered laser bars. New modules with 4W of 976nm wavelength-stabilised output have been produced using a tapered laser and a holographic volume grating written into the fast axis collimator.



High-speed source for optical wireless and display applications

Using a multi-section DBR tapered laser operating at 1060nm, direct data modulation of up to 1Gb/s has been demonstrated for use in optical wireless applications and laser projection displays. An optical modulation amplitude of 0.4W was achieved with a dc bias of 2A applied to the taper and a 100mA ac bias applied to the ridge waveguide. The average power output was 0.75W.

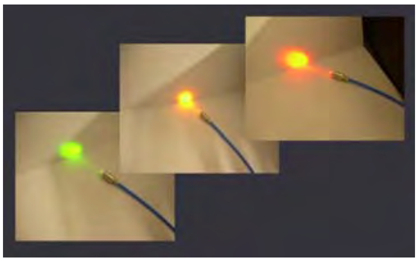




Pressure and temperature tuning provides yellow-green laser diodes

Through pressure and temperature tuning of high-power red lasers, emission in the yellow-green region has been demonstrated.

Using a red laser (640nm), orange emission (600nm) could be achieved through temperature tuning alone. By operating the laser at -150ºC, the emission from the fibre coupled to the laser could be tuned through orange to yellow and then green with increasing pressure.



As shown above the emission from the fibre coupled to the red laser was tuned to orange (610nm) at 1 kbar, yellow (590nm) at 10 kbar and then towards green (575nm) at 17 kbar. At 575nm, the power out of the 200µm fibre was 280mW.

From the development of a blue laser source and fluorescence imaging system to the first clinical tests

A pulsed blue source for laser-induced fluorescence imaging has been realised, based on frequency-doubling a cw 808nm laser in an external cavity being scanned across the peak of resonance. At 404nm, peak powers of 720mW were achieved. The system was then transferred from Risoe to the Lund Laser Centre to be used in their fluorescence imaging system.

Fluorescence imaging assists physicians with detecting legions and determining their extent and type. In initial clinical tests, skin malignancies are being imaged by detecting the fluorescence from a marker drug (e.g. ALA-induced PpIX).

TRAINING ACTIVITIES

Training the Researchers of Tomorrow

The WWW.BRIGHTER.EU Project Consortium has established specific mechanisms for promoting effective communication and closer interactions both within the Consortium and within the wider European high-power and high-brightness laser diode community. We have taken a pro-active position with respect to attracting and training young scientists and engineers to pursue careers in lasers and optical systems. Specific activities are devoted to the training and mobility of young scientists and engineers within the Consortium. Towards the end of this edition you will find information on our recent project dissemination and popularisation activities.

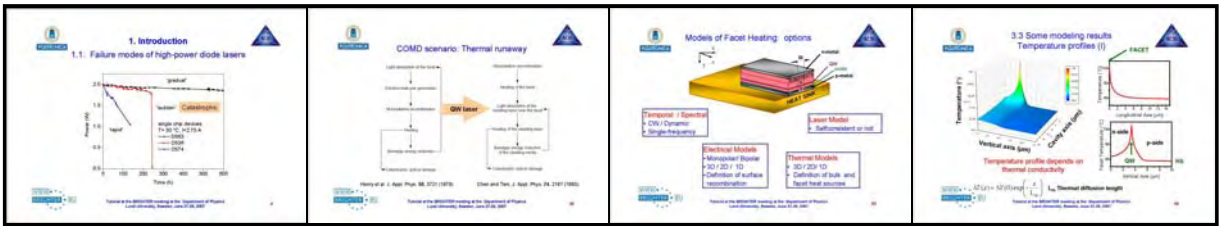
Technical Tutorials

This activity establishes a forum for the training of researchers and technicians in specific skills and technologies by means of tutorials given by senior scientists. At each project meeting, two 1-hour tutorials are normally given. Following their presentation within the Consortium, the tutorials are made available for public download on the project website, http://www.ist-brighter.eu.

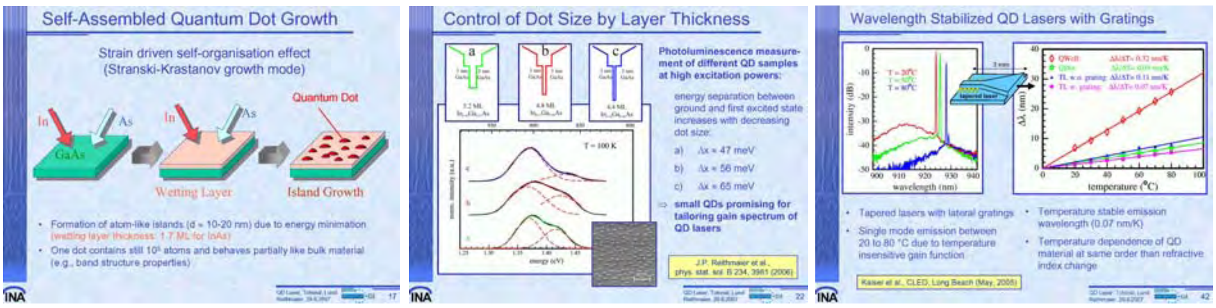
Currently Available Tutorials

- Toxicology & Safety in III-V Epitaxy
- Quantum Dot Lasers
- Mirror Heating and COD in High-Power Lasers
- Fibre Laser Pumping with High-Brightness Pump Sources
- Diode Laser Design for Very High Wall-Plug Efficiency

For more tutorials from our earlier WWW.BRIGHT.EU project, please visit the website http://www.bright-eu.org.



Examples taken from the tutorial "Mirror Heating and COD in High-Power Lasers" – Dr. Jens W. Tomm (Max-Born-Institute, Berlin, Germany) and Prof. Ignacio Esquivias (Universidad Politécnica de Madrid, Madrid, Spain).



Examples taken from the tutorial "Quantum Dot Lasers" – Prof. Hans Peter Reithmaier (University of Kassel, Germany).

Watch out for the following future tutorials…

- By Emitter Degradation Analysis of High-Power Laser Bars
- Analysis of Diode Lasers by Near-Field Optical Microscopy
- Beam Quality of High-Brightness Laser
- Modelling of External Cavity Lasers
- Fluorescence Diagnostic Imaging
- Erbium Amplifiers
- Raman Amplifiers
- Large Spot-Size Lasers
- Frequency Doubling

TRAINING ACTIVITIES

Training the Researchers of Tomorrow

Personnel Training Exchange Visits

This activity promotes the interchange of young scientists and/or PhD students between partners. The main aims are to provide additional training and to promote increased cooperation between partners. The host provides each visitor with a personal "coach" who works closely with the visitor to ensure that the resulting interaction is both educational and productive. Reviews of some of visits are given here.

In May 2007, Milan Mrozowicz of UNIPRESS in Warsaw, Poland visited the Laboratoire Charles Fabry de l'Institut d'Optique (LCFIO) in Paris. The purpose of this visit was to gain experience in building self-organising external cavity lasers with different materials used for the photorefractive crystal. The various cavity setups and crystals were tested to confirm if self-organising behaviour occurred. Beam quality measurements were made on the external cavity and the free-running laser.

In August 2007, Gilles Pauliat of LCFIO visited the University of Nottingham, U.K for the first of two planned exchange visits. The purpose of the visit was to begin developing models for self-organising external cavity laser diodes. A clear route has now been defined for the model development and the construction of new self-organising cavity lasers.

In June 2007, Jose Manuel Garcia Tijero of the University of Madrid visited the Max-Born-Institute in Berlin. The purpose of this visit was to begin a new interaction between the two partners on the modelling and characterisation of facet heating in laser diodes.

During the exchange, Jose Manuel was coached by Jens W. Tomm and introduced to the experimental techniques available at MBI. After initial training, he performed measurements of the facet temperature of laser diodes as a function of the injection current by spatially resolved micro-Raman spectroscopy. He also participated in temperature measurements using a micro-thermography system based upon a thermal camera sensitive in the 1.5µm-5.5µm spectral range.

In June 2007, Bernard Piechal of UNIPRESS in Warsaw, Poland visited the Max-Born-Institute in Berlin in order to bring together MBI's expertise in photocurrent spectroscopy and UNIPRESS's expertise in measuring devices under high pressure conditions. During the exchange, a range of lasers mounted in different ways and using various heatsink materials were studied using differential photocurrent. The results have led to better understanding of the strain caused during the mounting of the lasers and also when the lasers are operated under high pressure conditions.

In September 2007, Monika Maziarz of UNIPRESS in Warsaw, Poland visited the University of Madrid. The purpose of this visit was to begin an interaction between the two partners on the modelling of pressure and temperature effects in laser diodes. During the visit, Monika became with familiar with the current features of the software and defined the changes that are needed to correctly model pressure and temperature effects in laser diodes. Over the next year, the two groups will work closely together to implement these enhancements. Monika is pictured opposite with her coaches at the University of Madrid, Dr. Jose Manuel Garcia Tijero and Prof. Ignacio Esquivias.

PARTNER PRESENTATIONS

In this section of the e-Newsletter, we introduce some of the partners in the project Consortium. In this edition, profiles are presented for the Fraunhofer Institute (Institute for Applied Solid State Physics and Institute for Laser Technology) and Fisba Opitk AG.

Fraunhofer-Gesellschaft

The "Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V." (FhG) carries out applied research for private and public enterprises and to the benefit of society. It is a link between science and industry, between research and application of results. The employees carry out research and development projects on a contract basis on behalf of industry, the service sector and government. Future-oriented strategic research commissioned by the government and public authorities are carried out with the aim of promoting innovations in key technologies with an economic and social relevance during the next five to ten years.

The FhG was founded in 1949 in Munich as a non-profit registered association. It is autonomous organised with a decentralised structure and operates from 40 different locations across Germany. The Fraunhofer-Gesellschaft currently maintains 56 research institutes. A staff of approximately 13,000, with the majority being qualified scientists and engineers, work with an annual research budget of about 1.2 billion € .

The Fraunhofer-Gesellschaft is also active on an international level: Affiliated research centres and representative offices provide contact with the regions of greatest importance to present and future scientific progress and economic development. Working within the framework of the European Union's research and technological development programs, the Fraunhofer-Gesellschaft collaborates in industrial consortia on technical issues ultimately destined to improve the competitiveness of European industry.

Commissioned by customers in industry, Fraunhofer scientists provide rapid, economical and immediately applicable solutions.

Fraunhofer Institute for Applied Solid State Physics (FHG IAF)

Fraunhofer IAF is a gateway between state-of-the-art research and industrial implementation of novel micro- and nano-electronic circuits and optoelectronic devices. We are focused on III-V compound semiconductors and their heterostructures for advanced transistors and optoelectronic devices. Epitaxial growth in atomic dimensions and device structures of less than 50 nm are the daily used essentials of our technology. We offer epitaxial and technology services, design, prototyping and small volume production for civilian, security and defence applications.

The research and development work is done in close cooperation with national and international partners including the Federal Ministry of Defence, the Federal Ministry of Education and Research, national state governments, the European Commission and industry.

The Institute was founded in 1957 and celebrates its 50th anniversary this year. Today a total staff of 200 scientists, engineers and technicians are working at the IAF. Our annual budget amounts to 20 million €.

The Fraunhofer IAF in Freiburg, Germany.

The research at the IAF covers:

- Microwave and millimetre wave monolithic integrated circuits (MMICs) for radars, sensors and communication up to 220 GHz
- Mixed-signal and multifunctional ICs for high bit rate communications up to 100 GBit/s
- Infrared sensors in the 3-5 µm and 8-12 µm spectral regions for thermal imaging
- Lasers and LEDs for sensing, communication, material processing, and lightning from UV (350 nm) to the mid-IR (12 µm)
- CVD diamond for optical, thermal and mechanical components

In the field of semiconductor lasers, IAF focuses on the development and fabrication of novel devices for customer specific applications. Based on the III-V compound semiconductors GaAs, AlGaAs and GaInAs, high-power, high-brightness diode lasers are realised. Infrared diode lasers based on group III-antimonides such as GaSb and AlGaAsSb emitting at $\lambda > 2$ µm, and quantum cascade lasers for even longer wavelengths are also available at the IAF.

Activities within WWW.BRIGHTER.EU

In the BRIGHTER project Fraunhofer IAF will aim at high-brightness tapered devices with doubled output power in comparison to the BRIGHT project to address the new applications “high-efficiency laser modules” and “display systems”.

At 975 nm, tapered laser bars with 5 W per emitter and tapered single emitters with 10 W of nearly diffraction limited output power are very innovative and ambitious goals.

For display applications, tapered amplifiers for external cavity setups emitting at 1060 nm with 4 W of output power constitutes a remarkable improvement within the amplifier market.

In addition, tapered amplifiers at 975 nm with twice the output power of commercially available laser chips for external cavity approaches are being developed.

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Fraunhofer Institute for Laser Technology (FHG ILT)

With more than 250 employees and 10,000 m^2 of usable floor space, the Fraunhofer Institute for Laser Technology, located in Aachen, is one of the most important development and contract research institutes of its specific field worldwide. The activities cover a wide range of areas such as the development of new laser beam sources and components, the use of modern laser measurement and testing technology and laser-supported manufacturing including laser cutting, caving, drilling, welding and soldering as well as surface treatment, micro-processing and rapid-prototyping.

In the field of high-power diode lasers, ILT works on principal technologies such as cooling and packaging technology, micro-optics and waveguides, special beam shaping optics, fibre coupling and wavelength multi-plexing techniques, as well as on the development of application-specific diode laser modules and systems. Furthermore, ILT is developing mounting and testing equipment for diode lasers and micro-optical elements.

Currently, a staff of approximately 270 people are working at ILT, approximately 25 of them in the field of high-power diode lasers. The Institute is certified according to DIN EN ISO 9001.

The Fraunhofer ILT in Aachen, Germany (left), Wavelength stabilised pump module (right).

Activities within WWW.BRIGHTER.EU

Within the project, the Fraunhofer Institute for Laser Technology is involved in the design assembly and characterisation of various kinds of laser diode modules.

These modules are applied as pump sources for fibre amplifiers in the telecom field and as infrared beam sources for frequency doubling (second harmonic generation) for laser display applications. All modules are based on lasers, amplifiers or micro-optics developed within the project by other project partners.

Additionally, Fraunhofer ILT mounts laser bars and develops packages according to the specific needs of high brightness bars. For reliability testing, Fraunhofer ILT performs electro-optical characterisations and aging tests on laser bars from project partners.

Modules being developed within the project include:

- 30 W high brightness fibre coupled module in a 50 µm NA 0.22 fibre
- 12 W telecom pump module with a NA 0.12 fibre of 100 µm
- Coolerless 15 W pump module based upon quantum dot lasers (200 µm NA 0.22 fibre)
- Single mode/single frequency pump module for frequency doubling, based on 1060 nm tapered amplifier, output power 5 W

Further Information

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FISBA OPTIK AG

Putting Optics into Focus for 50 years

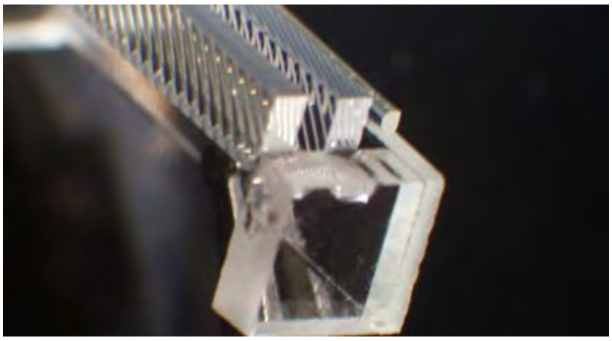
Intelligent solutions rely on a widespread competence in the field of high-precision optics. For over 50 years, FISBA OPTIK offers its customers comprehensive services, from the optical design, through integrated project management to the production of customised sub-assemblies and components for system integrators.

With the company mission *"Spirit of Partnership"* in mind, FISBA's dedicated staff works hand in hand with the customer to develop and produce optical components or systems according to the customer's specifications. Well accounted skills in the areas of optic and mechanic workshops, as well as production and assembly processes give FISBA the leading edge when it comes to developing optimised and cost-efficient solutions for its customers.

FISBA was founded 50 years ago by Christian H. Fischbacher, a textile entrepreneur, and optic designer Waldemar Strietzel in St. Gallen, Switzerland. Originally the company planned to design optical systems and build specialized optical instruments. Very soon afterwards, the program was extended to include the fabrication of lenses, prisms, optical components, complete optical systems as well as the specialisation on precision optics and mechanics in small to medium sized series. In addition, FISBA developed and manufactured its own assortment of ophthalmic instruments. Later the firm concentrated on calculating, constructing and manufacturing optical systems according to customer specifications. Towards the end of the 90's FISBA began the sales and distribution of its own digital interferometers and diode laser systems for plastic moulding.

Following the millennium, FISBA has now also set a focus on the development and manufacturing of advanced optical components. Building on the know-how and expertise gained in the past, FISBA now offers its customers a large variety of micro optical components and arrays, such as FAC's (Fast Axis Collimators) or the FISBA Beam Twister™ with outstanding performance features.

FISBA has grown considerably in the past 50 years. Starting out with approximately 30 employees in 1958, the firm counted more than 90 staff members in 1976 and so FISBA moved from its first site, an old brewery in the City of St. Gallen, to the Eastern part of the town. In 1998 a further building was built to create additional space for the ever growing company. With almost 380 employees today, FISBA is again facing the need to increase its production capacities.



Top: Semi-automated assembly area for the active alignment of cylindrical lenses. Positioning and bonding accuracy are smaller than 0.001 mm. Bottom: The FISBA Beam Twister™ provides up to 80% coupling efficiency of broad area diode laser bars in a 400 µm fibre (NA 0.22).

Activities within WWW.BRIGHTER.EU

FISBA will provide beam shaping solutions, optic design and fabrication, and beam characterisation methods for tapered laser based modules.

Some of the specific tasks being carried out by FISBA:

- Development of a 5 W single mode fibre coupled module based on a single 975 nm tapered device
- Development of a micro-optical solution for coupling multiple tapered lasers into a 50 µm fibre (solution includes optic design, assembly, technology and production)
- Design and production of optics for display applications

Further Information

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High Power Diode Laser Collimators

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Abstract: High power diode lasers are anisotropic light emitters with high aperture angles in the plane perpendicular to the semiconductor plane. The collimation of this radiation with different cylindrical collimator types is discussed in this article. Special attention is paid to the usable numerical aperture, the offence against Abbe's sine condition (OSC) and production constraints.

Introduction

High power diode lasers are anisotropic light emitters. Within the semiconductor chip plane (x-z-plane) of today's diode chips with several tens of Watts of optical output power, the aperture size is typically 10 mm and the beam divergence is only ±5º…7º. The resulting beam parameter product is several orders of magnitude larger than for low order Gaussian beams. In the perpendicular plane (y-z-plane), the light has a ±30º…50º divergence angle, but due to the 1 μm aperture size the beam is diffraction limited.

The collimation of this radiation requires an anamorphic optical system to achieve equal exit pupil dimensions in both symmetry planes, which is essential for applications like material processing, longitudinal solid state laser pumping or medical applications. Two different cylindrical optical systems collimate the emitted light in both planes independently. The low aperture angle and the high beam parameter product in the x-z-plane allow the use of simple optical systems — often single cylindrical lenses are sufficient — as a collimator for this plane without a significant loss of beam quality. The opposite is true for the y-z-collimator, which shall be discussed in more detail.

Collimator Designs

Several designs of realised optical systems with cylindrical symmetry are compared below:

1. Single refractive surface:

A single hyperbolic air–glass surface is used as the collimator. Such elements are commercially available as plano-convex cylindrical lenses. The curved surface faces the diode laser and bends the light rays parallel to the symmetry plane of the system. The planar exit surface does not influence the ray direction.

2. Single aspherical lens:

In a reversed plano-convex cylindrical lens, where the planar surface is used first, both surfaces share the refractive power. The curved surface has a non-circular cylinder geometry. This is the design used for most commercially available fast-axis collimators – so called "FAC lenses" – today, including those fabricated by FISBA OPTIK AG. (See examples in remainder of article)

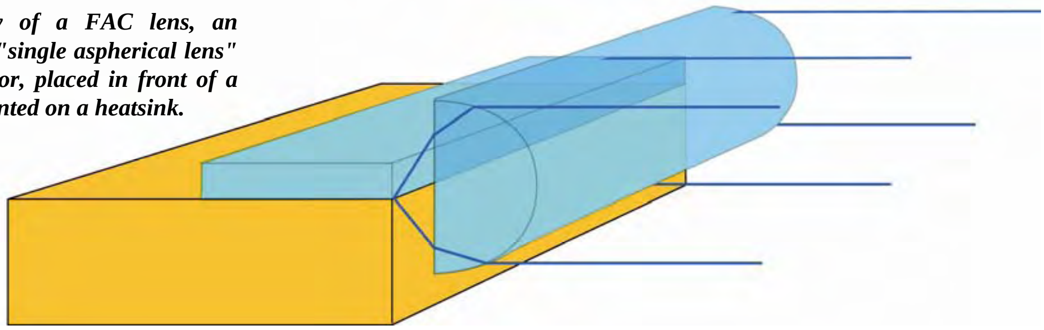
3. Circular cylindrical lens doublet:

This design has two plano-convex cylindrical surfaces. The curved surfaces are now circular cylinders.

4. Hybrid optics:

A combination of a refractive and a diffractive optical element. This is a modification of the previous layout. The second cylindrical lens is replaced by a fused silica flat with a diffraction grating structure on one surface. This structure is produced by four etching steps of binary patterns in photoresist. The patterns are generated with an electron beam writer that allows ~0.1 μm resolution. With this technique 2^4=16 phase levels are achieved. The theoretical diffraction efficiency is η>98%. The power of the optical system is mainly concentrated in the refractive lens. The diffractive element is used similarly to a free form aspherical surface to correct aberrations.

Schematic view of a FAC lens, an example of the "single aspherical lens" type of collimator, placed in front of a laser diode mounted on a heatsink.



Aberrations

The correction of aberrations for laser light collimators differs from the typical visual systems' needs. No colour correction is necessary, and only a small field of view is required. However, the monochromatic correction in the near-field of the optical axis must be very good. The following sections discuss the most important aberrations of the four collimator designs.

Spherical Aberration

The usable numerical aperture of the collimators is limited by the spherical aberration. The three designs

- single refractive surface
- single aspherical lens
- hybrid optics

with their free form aspherical surfaces allow the complete correction of the spherical aberration for the intended aperture angle ~±45º. The circular cylindrical lens doublet has low spherical aberration only up to ~±35º. Above this the theoretical wavefront aberration is larger than $\lambda/2$.

Coma

Only a rather small field of view is used in the laser collimators, due to the diode's tiny emitting surface, but a good correction in the vicinity of the optical axis is necessary for a comfortable alignment of the optical elements during the assembly of real optical systems.

Coma is the main aberration that limits the field of view. It can be estimated by tracing only rays for an on-axis field point by calculating the offence against Abbe's sine condition, OSC. For afocal optical systems:

$$\mathbf{OSC(\varphi) = y(\varphi) / f - \sin(\varphi)}$$

where f is the effective focal length

y is the image ray height

φ is the object aperture angle.

A comparison of the OSC for the four collimator designs gives the following ranking:

1. circular cylindrical lens doublet
2. hybrid optics
3. single aspherical lens
4. single refractive surface

On one hand, the circular cylindrical lens doublet has nearly perfect coma correction and the alignment of the optical elements relative to the diode laser is not critical. On the other hand, the single aspherical surface has a very large OSC, which significantly complicates the assembly process of the complete optical system.

"Azimuth Aberration"

A new type of aberration, that is unknown in optical systems with rotational symmetry, occurs in cylindrical systems.

The focus and spherical aberration change when the rays leave the plane perpendicular to the cylinder axis and the azimuth angle α in the x-z-plane becomes non-zero.

This aberration can not be corrected with pure cylinder optics. All four of the collimators that have been described here show several 0.1λ of wavefront aberration over the used ±5°…7° aperture angle in the x-z-plane. Again, the single refractive surface has the largest aberrations.

Photograph of a variety of FISBA's FAC lenses.

Summary

Four different types of collimators for diode lasers have been compared. The most significant aberrations — spherical aberration, coma and the "azimuth aberration" — are summarised in the table below.

	Spherical Aberration	Aperture Angle	Coma	"Azimuth Aberration"
Single Aspherical Surface	++	±45°	--	--
Single Aspherical Lens	++	±45°	+-	-
Spherical Doublet	+	±35°	++	+-
Hybrid Doublet	++	±45°	+	+-

The main restriction of the spherical doublet is its large spherical aberration, which reduces the aperture angle. The hybrid doublet has low aberrations, and is the best choice for high performance diode laser collimators.

However, in recent years, the singe aspherical lens has gained popularity because the fabrication costs of this design have kept up with the rapidly increasing volumes and lower costs of the laser diodes themselves.

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Pumping of Fibre Lasers

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Introduction

Fibre lasers have attracted considerable attention during recent years because of their excellent properties in terms of output power, efficiency, beam quality and production costs. Six years ago, fibre lasers played basically no role in high power application fields such as materials processing, marking, printing or medicine. This has changed significantly due to the rapid development of fibre technologies and the respective optical pumping technologies. Figure 1 illustrates this development by displaying the achieved maximum single mode output power from fibre lasers during recent years. Since 2000, the output power has increased from 100 W to 3,000 W for cw fibre lasers. In the meantime, diverse pulsed fibre lasers have also been developed, e.g. achieving nanosecond pulses with several tens of kW peak power. Today, nearly all major laser manufacturers have fibre lasers in their product portfolio or are developing such lasers.

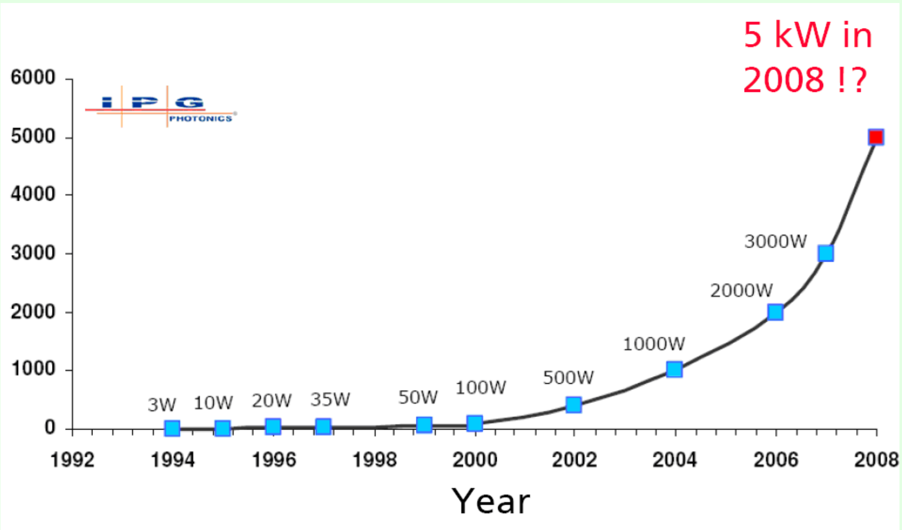


Figure 1: Development of cw output power from single mode fibre lasers.

In addition to the fibre components themselves, pump sources for fibre lasers play a critical role. Today, there are several pumping concepts employed or under investigation, some using pigtailed single emitters for pumping and others using laser bars or even stacked laser bars to achieve maximum power. In any case, the pump light has to be concentrated into the active fibre – thus a certain level of brightness is required.

Fibre Laser Principles

In a fibre laser the active gain medium is an optical fibre doped with rare-earth elements such as erbium, ytterbium, thulium and others. Fibre nonlinearities, such as Stimulated Raman Scattering or Four Wave Mixing can also provide gain, and thus in an appropriate configuration even an undoped fibre can serve as a gain medium. However, for high-power applications only doped fibres are used as a gain medium.

Unlike most other types of lasers, the laser cavity in fibre lasers is constructed monolithically by either integrating the cavity mirrors into the fibre (fibre Bragg gratings) or by appropriate coating of the fibre end facets. In fibre lasers, the active fibre can have a length of several tens of meters and provides very high optical gain. Due to the large ratio of the surface to the active volume, fibre lasers have excellent heat dissipation. The mode structure and thus the beam quality is defined by the refractive index profile of the active core and is therefore independent of the pump power.

Typically high-power fibre lasers are based on double-clad fibres. The gain medium forms the core of the fibre (with a diameter of around 20 µm), which is surrounded by two layers of cladding. The lasing mode propagates in the core, while a multimode pump beam propagates in the inner cladding layer. The diameter of this so-called pump cladding is typically between 200 and 400 µm and has a large numerical aperture (e.g. 0.45). The outer cladding finally confines the pump light in the pump cladding (see Fig. 2). This arrangement allows the core to be pumped with a much higher power beam than could otherwise be made to propagate in it. It also allows the conversion of pump light with a relatively low brightness into a beam with a much higher brightness.

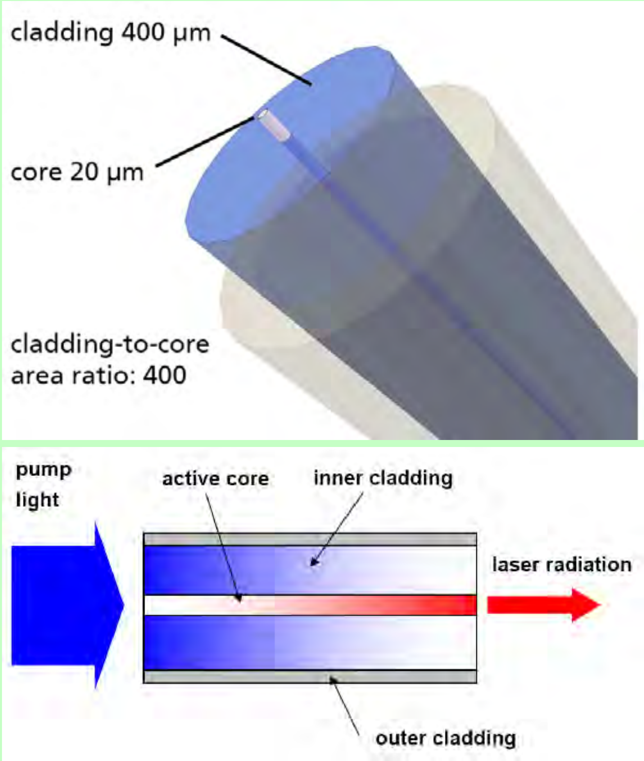


Figure 2: Schematic of a double-clad fibre.

An important factor for the design of the fibre laser is the cladding / core ratio, determining the ratio between the pump cladding area and the core area, e.g. for a core diameter of 20 µm and a cladding diameter of 400 µm, the cladding / core ratio is 400. Together with the absorption cross section of the dopant and the dopant concentration in the active core, the cladding / core ratio determines the effective absorption length of the pump light in the active core of the double-clad fibre. The effective absorption length is the most important factor determining the length of the active fibre. If the fibre is too short, not all pump light is absorbed. If it is too long, re-absorption of the laser light in unpumped regions leads to reduced efficiency and thermal limitations. The fibre length influences many properties of the fibre laser such as achievable output power, pulse duration and repetition rates. It also has an impact on the general laser design, e.g. the thermal design of the laser. Typical fibre lengths for high average power fibre lasers are in the range of several meters.

Although in general different rare-earth ions can be used as a dopant for active fibres, in the high-power regime nearly all fibres are doped with Ytterbium (Yb) ions, because Yb provides a high conversion efficiency of the pump light into the laser light and thus reduces the thermal load on the fibre (see Fig. 2). Yb doped fibres exhibit a broad emission spectrum in the range of 1040-1100 nm. The main pump lines are around 915 nm (broad pump band with weaker absorption) and 976 nm (narrow pump band with strong absorption). For high-power operation the 976 nm pump band is preferred because it provides the highest possible conversion efficiency due to the small wavelength difference between pump and laser light. However, this pump band has a width of only ~6 nm. Therefore, the wavelength of the pump source has to be well controlled. To further increase the pump power, pump sources with 915 nm and 976 nm wavelength can be combined. In this case the different absorption lengths of these two wavelengths in the active fibre have to be taken into account in the design.

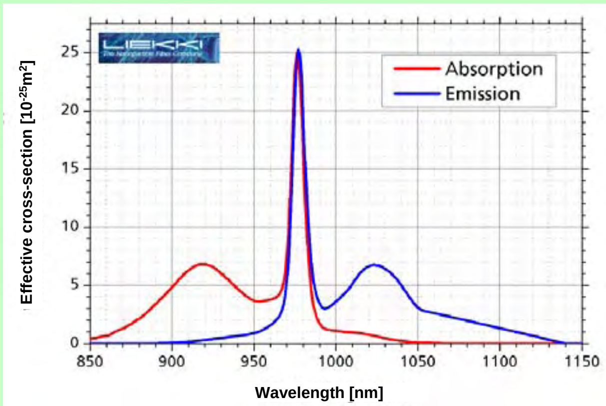


Figure 3: Absorption and emission spectra of Yb-doped fibre.

Fibre Laser Pump Concepts

For effective pumping of a fibre laser as much pump light of the desired wavelength as possible has to be coupled into the pump cladding of the active fibre. As already mentioned, typical dimensions of the pump cladding are a diameter of 200-400 µm and a numerical aperture (NA) of 0.45. Two main concepts for the pumping can be identified: 1) concentrated pumping and 2) distributed pumping.

Option 1: Concentrated Pumping

For concentrated pumping, the pump light is coupled into the active fibre via the fibre end facets, meaning the pump power is concentrated in large pump units at the two ends of the fibre (see Fig. 4). The light from the pump units is either directly coupled into the active fibre using appropriate beam shaping and focusing optics or – which is in many cases more convenient – it is first coupled into a passive transport fibre with the same dimensions as the pump cladding and the transport fibre is then fusion spliced to the active fibre.

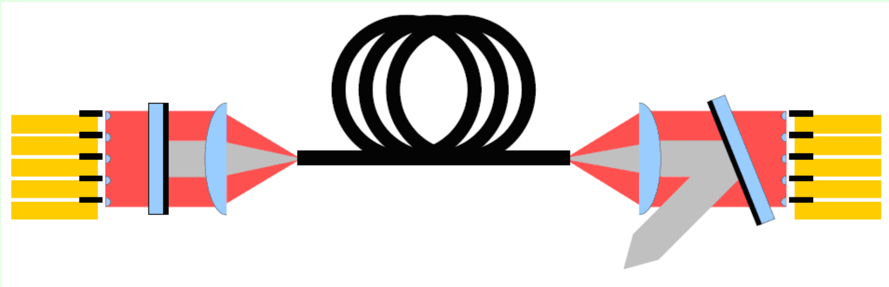


Figure 4: Schematic overview of concentrated pumping.

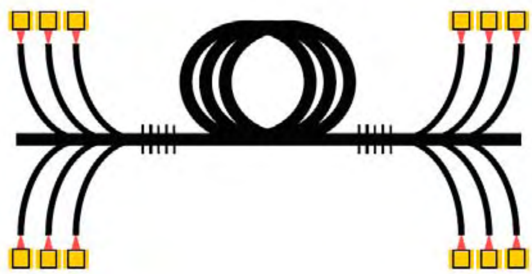
In either case, the beam from each pump unit has to be concentrated into the diameter and NA of the pump cladding. When, for example, a fibre laser output power of 1 kW has to be achieved, a total pump power of ~1.5 kW is required. With concentrated pumping the pump power has to be coupled into the fibre via the two end facets of the fibre and thus 750 W have to be coupled into each end of the fibre. Such high-power pump units, coupled to 400 µm or 600 µm fibres, are available (e.g. from the companies Laserline and Nuvonyx). They typically consist of two or more stacks of laser diode bars and make use of polarisation coupling to increase the achievable power within a certain spot size. For dual-wavelength pumping (at 976 nm and 915 nm) additional stacks are coupled by wavelength multiplexing. A 750 W pump unit at 976nm may for instance consist of two polarisation coupled stacks, each stack comprising of 7 laser bars with 80 W of output power per bar. With an overall optical efficiency of 75% such a pump unit is able to deliver 840 W at the beginning of its life, leaving room for a 10% degradation of the laser bars over the lifetime of the pump unit. Pump units in this output power class are typically water-cooled. However, water-cooling is not always acceptable for a customers' application.

For the concentrated pumping scheme it is obvious that an increased pump power for a given fibre geometry is only achievable by increasing the brightness of the pump source. However, for a given pump power, an increased brightness of the pump sources is also advantageous because it allows a reduction in the diameter or numerical aperture of the pump cladding. This increases the cladding / core ratio and allows a reduced fibre length. In a shorter fibre, nonlinear effects and the sensitivity to back reflections are reduced.

Option 2: Distributed Pumping

In the distributed pumping concept, the pump light is not coupled into the active fibre via the fibre end facets but via special fibre couplers that can be attached to the double-clad fibre at intermediate positions (see Fig. 5).

Figure 5 (opposite): Schematic overview of distributed pumping.



Typically for distributed pumping, fibre-coupled (pigtailed) single emitters are used. Such single emitters, packaged in small hermetically sealed housings, are available from companies such as Bookham or JDSU with output powers of 6-10 W from a fibre with ~100 µm core diameter and a numerical aperture of 0.12-0.15. The total pump power is scaled up by adding more and more of these single emitter pumps. To obtain the 1.5 kW pump power required for a 1 kW fibre laser, 150-300 pump modules are therefore necessary.

For the efficient coupling of many single emitter pumps to the active fibre, special fibre couplers have been developed. Although there are different detailed approaches, the general principle of the most familiar couplers is the same. By appropriate fusion of a bundle of pump fibres a fused taper is produced that effectively guides all light from the individual pump fibres into a single fibre core that is designed to match the pump cladding of the active double-clad fibre (see Fig. 6).

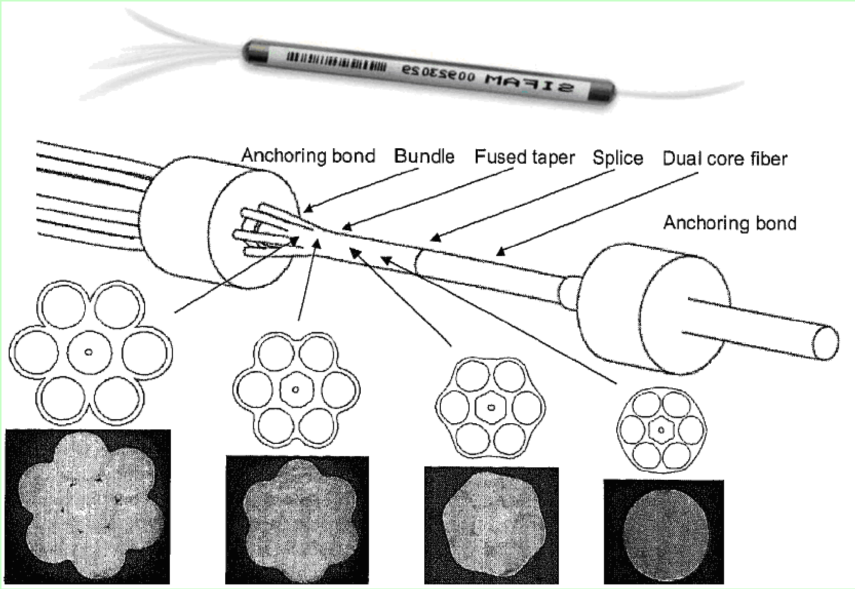


Figure 6: Sample schematic of a fused fibre bundle.

By this technique it is not possible to increase the overall brightness of the laser beam – the total beam parameter product of the incoming beams must not exceed the beam parameter product of the outgoing beam. Expressed in fibre core diameters and numerical apertures, the following rule must apply:

$$d_{in} \times NA_{in} \times n_{fibres} \leq d_{out} \times NA_{out}$$

As a consequence, for given core diameters and numerical apertures of the incoming pump fibres and the outgoing signal fibre, only a certain number of pump fibres can be combined in one step without severely increasing the coupling losses. Additionally, a rotationally symmetric arrangement of equal diameter pump fibres can only be achieved with certain numbers of pump fibres. Therefore, combiners are typically available as 7 to 1 or 19 to 1 combiners (see Fig. 7). The central fibre is either a pump fibre or a signal feed-through fibre.

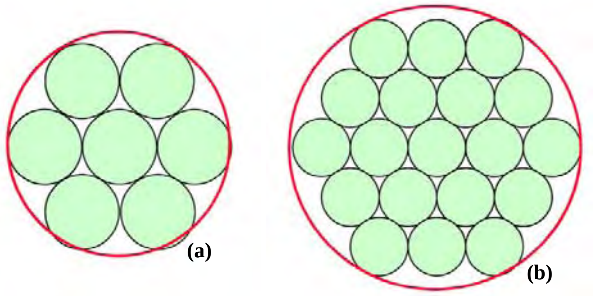


Figure 7 (opposite): Rotationally symmetric arrangements of pump fibres for fused fibre combiners.

a) 7 to 1 coupler

b) 19 to 1 coupler

With a signal feed-through, several of these fibre combiners can be cascaded on a single active fibre to scale the number of attached pump diodes and thus the pump power. The distance between the couplers has to be in the order of the absorption length of the pump light because the signal feed-through is not double-clad and therefore does not transport the pump light.

The main advantages of the distributed pumping technique are that mature technologies such as hermetically housed single emitters and fusion splicing of fibres are used to set up an “all-fibre” laser system. The individual pump modules are comparably simple and cheap. For the pigtailing of the single emitters, either no optics or only a single and simple fast axis collimation is required and the slow axis of the emitter is coupled into the fibre without any transformation. Additionally, cooling aspects are simplified by the fact that the heat generating pump diodes can be distributed over an area of suitable size.

The disadvantages of this pumping technique are that the system complexity is increased by the large number of required pump modules and that in these pump modules the brightness conservation is low. While in the pigtailed single emitter module the beam parameter product of the attached fibre is well filled by the laser light in the slow axis direction:

$$d_{core} \times NA_{fibre} \approx w_{slowaxis} \times \theta_{slowaxis},$$

it is strongly under filled in fast axis direction:

$$d_{core} \times NA_{fibre} >> w_{fastaxis} \times \theta_{fastaxis}.$$

This means that each pump fibre delivers less power and as a consequence more pump fibres and more fibre combiners are required than expected from a theoretical point of view. This in turn has consequences for the fibre laser design – more coupled pump fibres per combiner (19 instead of 7) lead to a larger cladding / core ratio, a lower effective absorption rate and a longer fibre. Also additional fibre combiners make it necessary to increase the fibre length. However, the maximum fibre length is determined by nonlinear effects such as stimulated Raman scattering. Thus, also for this pumping concept, pump power scaling is not infinitely possible by adding pump sources. At a certain point, a further increase of the fibre laser output power is only possible by increasing the pump power per attached pigtailed pump module, which is equivalent to an increase in brightness.

Summary

Fibre laser technology is advancing rapidly and is expected to provide the next generation lasers to many application fields. The main advantages of the fibre laser technology are the possibilities to produce compact and rugged laser systems at comparably low costs and because the optical path of the laser light, the laser system can be completely realised in fibre technology (“all fibre” designs). This reduces the mechanical complexity of the laser and the correlated assembly and adjustment effort as well as the number of discrete components such as optics, mirrors etc.

A crucial point for the technical realisation and also the production costs is the optical pumping concept of the fibre laser. Today, no general decision can be made between the two principal pumping schemes, the concentrated pumping, using high-power laser array based pumps on the fibre ends, and the distributed pumping, using a large number of comparably low-power single emitter pumps coupled to the active fibre via pump fibre combiners.

In both pump concepts, increased brightness of the pump sources is necessary to achieve the maximum output power from the fibre laser. Also in both concepts, an increased brightness of the pump sources enhances the possibilities to optimise the fibre laser for specific parameters, such as pulse duration, repetition rate, peak output power, insensitivity to back-reflections etc., by allowing reduced fibre lengths, smaller cladding / core ratios and thus also different dopant concentrations. However, these advantages can only be exploited when the increase in brightness does not lead to large increases in the complexity and costs of the pump modules. Therefore, further increases in brightness should – as far as is possible – be built into the pump lasers themselves and in such a way that additional expensive optics are not required. High-brightness tapered laser arrays may be a good approach to achieving increased brightness.

Next Generation High Power Quantum Dot Laser Materials

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Introduction – Dimensionality and Laser Performance

The emergence of devices based on nanometre-sized active elements marked the era of nanoelectronics and nanophotonics. Among such elements are notably low-dimensional heterostructures, such as quantum wells (QWs), quantum wires (QWRs) and quantum dots (QDs).

In a QW, carriers are spatially confined in the transverse direction and move freely in its plane, while in a QWR, carriers are spatially confined in two transverse directions and move freely along the wire direction. Hence, the carrier energy spectra in both QWs and QWRs are continuous within wide subbands of allowed states and, in this sense, they do not qualitatively differ from those in a bulk crystal.

In a QD (see Fig. 1), carriers are three-dimensionally confined and the modification of electronic properties is more strongly pronounced – the energy levels are discrete. For this reason, QDs are also referred to as superatoms or artificial atoms. A QD of typical size (several nanometres to several tens of nanometres) contains several thousands to several tens of thousands of atoms (hence, despite the very small dimension, one can speak about band structures). Quantum dots have generated much interest as a new class of human-made materials with tunable (by varying both the composition and size) energies of discrete atomic-like states.

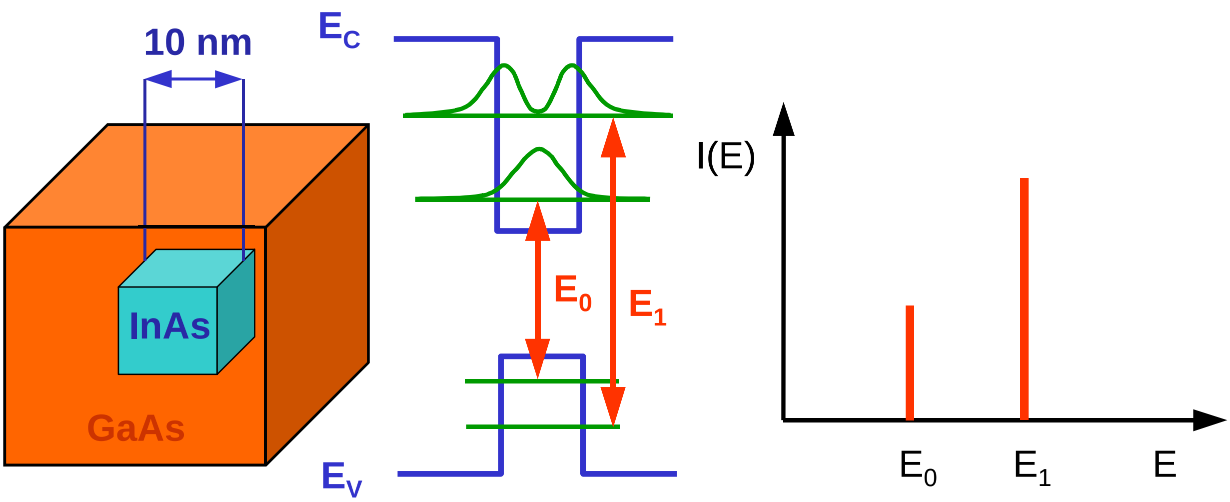


Figure 1: (left to right) Schematic representation of an InAs quantum dot embedded in GaAs, the related quantum states and the delta-like transition intensity profile I(E) for the first two optical transitions. Here, the two-fold degeneracy of the second order transition is schematically indicated.

The semiconductor laser is the fundamental device of modern optoelectronics and photonics. It was proposed long ago that reducing the dimensionality of the active region could significantly improve laser performance due to the quantum-size effect. This general idea was initially applied to QW lasers and today these lasers have replaced bulk lasers in almost all commercial applications. Further enhancement was predicted for lasers with lower dimensionality, such as QWR and especially QD lasers [1,2]. However, due to a continuous density of states within allowed subbands, using QWs and QWRs as an active medium for stimulated optical transitions can only quantitatively enhance device characteristics compared to those of a bulk device.

Advantages of an Ideal QD Laser

As the density of states narrows, following the reduction in the dimension of the active region, one needs a smaller number of states to be filled to attain transparency of the active region and thus lasing. As a result, both the transparency current (injection current required for zero gain) and the threshold current (current at which the gain equals the loss and lasing starts) decrease, and also their temperature dependences become less pronounced [3]. Lowering the threshold current and improving its temperature stability are both important objectives in the development of diode lasers, especially for telecom applications. Since QD lasers possess the lowest threshold currents among all current semiconductor lasers [4], these results suggest, knowing that the power performance of a laser is strongly linked to its threshold characteristics, their other potential advantage, namely, the possibility of achieving higher output powers.

The principal advantages of QD lasers over conventional QW lasers can be summarised as follows: significantly lower threshold current density, significantly weaker temperature dependence of the threshold current, ideally (discrete energy levels – high density of states – no temperature dependence) temperature-insensitive threshold current, superior opportunity for tuning the gain spectrum width and the emission wavelength (colour of light), low chirp (shift of the lasing wavelength with injection current), ideally zero α-factor (refractive index decoupled from the carrier density) [5,6]. In the ongoing improvement of semiconductor lasers, each of the above areas has always been on the high-priority list and indeed originally motivated the very idea of heterostructure lasers.

Fabrication of QD Lasers

Initial attempts to fabricate QD devices relied on traditional means, such as selective etching of QW structures or QW intermixing, growth on profiled substrates and on cleaved facets, or condensation in glassy matrices. These efforts, however, did not produce device-oriented structures due to the high density of surface states created during etching.

A breakthrough in fabricating QD lasers came with the use of self-organising effects in heteroepitaxial systems [3]. The non-planar 3D growth, which had been traditionally considered undesirable, has led to the direct formation of QDs. Highly strained semiconductors grow epitaxially on mismatched substrates in the Stranski-Krastanow growth mode, wherein islands are formed after a few monolayers of layer-by-layer growth. Elastic relaxation on the facet edges, renormalisation of the surface energy of the facets and interaction between neighbouring islands via the substrate are the driving forces for the self-organised growth. The use of strain to produce self-organised quantum dots has now become a well-accepted approach and is widely used in III-V semiconductors and other material systems.

The most extensively studied heterosystems for QD lasers are (In,Ga,Al)As on GaAs [7] and (In,Ga,Al)As on InP substrates [8]. Using these materials one can vary the lasing wavelength in a wide spectral range from 0.87 to more than 2.0 µm including 920, 980 and 1060 nm for high-power and high-brightness applications as well as 1.3 and 1.55 µm, the most desirable wavelengths for telecom devices. The use of GaInP/InP and InAlAs/GaAs QDs has extended the range into the visible (red) spectrum [9,10].

Impact of QD Size and Distribution

As discussed earlier, the advantages of QD lasers stem from a δ-function-like density of states. If all QDs were identical, the gain spectrum would also be a δ-function. However, the QDs in actual structures vary, primarily in size and shape, but also in composition and the local strain. The differences in QD parameters cause fluctuations in the quantised energy levels, leading to an inhomogeneous broadening in the optical transition energy and hence a broadening of the gain spectrum. This dispersion is hardly avoidable during the growth of QD structures: size fluctuations are inherent in self-organised QD ensembles, which are fabricated either by molecular-beam epitaxy (MBE) or metal-organic chemical vapour deposition (MOCVD).

Inhomogeneous line broadening is the key factor, among others such as parasitic recombination outside QDs, violation of local neutrality in QDs and spatial hole burning due to local gain saturation, which degrades the characteristics of a QD laser. It adversely affects the operating characteristics of a laser by decreasing the maximum gain, by increasing the threshold current and its temperature sensitivity (i.e. the characteristic temperature decreases), by decreasing the internal differential efficiency and output power as well increasing the threshold for multi-mode generation.

The threshold current density (j_{th}) of a QD laser theoretically diverges to ∞ as the dispersion of QD size (δ) increases and approaches a certain critical value. The temperature dependence of the threshold current is usually described by the characteristic temperature T_0. The higher this parameter, the less sensitive the threshold current density is to temperature. Non-uniformity of QDs has twofold effects on the temperature dependence of j_{th}. The main effect is through thermal population of the optical confinement layer (OCL), which controls the parasitic recombination current outside QDs. The more uniform the QD ensemble, the lower the carrier density and the recombination current in the OCL and therefore the higher the T_0 value. The second effect is through the thermal population of non-lasing QDs, which gives rise to a parasitic recombination current. Because of inhomogeneous broadening, a certain fraction of the QDs do not contribute to the lasing transitions while still adding to the parasitic recombination. As far as T_0 is concerned, the effect of thermal population of non-lasing QDs is in principal similar, but not as strong due to carriers residing in the OCL. It is worth mentioning that T_0 could decrease at small δ due to the increasing thermal population of non-lasing QDs. Also, at large QD size dispersion, full occupancy of QDs leads to higher T_0 at the expense of an increase in the total threshold current.

On the other hand, the inhomogeneous size distribution can be an advantage and used as a new design parameter to tailor the spectral gain function to a broadband characteristic with a flat gain profile over a larger spectral range.

QD Lasers with Improved Thermal and Brightness Properties

The improvement of thermal properties is twofold. As mentioned above, the inhomogeneous line broadening is used for spectral gain engineering to stabilise the emission wavelength. Due to an increased occupation of higher energy states with increasing threshold current with temperature, the band gap shrinkage with temperature can be intrinsically compensated to a large extent. This design approach was already applied in the WWW.BRIGHT.EU project where the temperature coefficient could be reduced by more than a factor of 3.5 to 0.1 nm/K at an emission wavelength of 920 nm [11]. This approach will be further developed within the WWW.BRIGHTER.EU project to meet the final device performance necessary for the realisation of uncooled or passively-cooled pump sources for Yb fibre lasers.

With an alternative approach, the spectral gain profile would be optimised to get a narrow symmetric gain centred at the fundamental transition. In this case, the internal temperature compensation will be lost. However, the linewidth enhancement factor will be very low (ideally zero) and the T_0 value should be strongly improved (ideally infinite). This goal, which is in principal fully complementary to the goal of the first approach, will be realised by improving the dot geometry and by implementing a tunnel injection quantum well for cooled carrier injection into the lowest dot levels [12]. This approach will allow the realisation of high-power lasers with very temperature stable device performance (threshold current, differential efficiency) and higher single lobe output powers due to a reduced filamentation effect as a result of the low linewidth enhancement factor [5].

Epitaxy of High-Density Uniform QDs

It is obvious that the basic advantages of QD structures can only be utilised if the QDs are sufficiently uniform, defect free and have a high density. Many growth parameters influence the dot density, size and size distributions, like III-V ratio, growth rate, substrate temperature and material composition and related strain variations. In Fig. 2, the direct influence of the substrate temperature is shown by keeping all other parameters constant. By decreasing the temperature from 520 to 480 °C the low temperature photoluminescence (PL) linewidth decreases from 95 meV down to 45 meV. This linewidth is mainly determined by the height fluctuations. At the same time, the dot density also increases from about $1x10^{10}$ cm^{-2} to about $6x10^{10}$ cm^{-2}. A further improvement in the size homogeneity could be achieved by using a QD seeding layer. Here the position of the QDs and the QD size can be controlled in subsequent dot layers by strain coupling. Using this method, values < 11 meV have been shown [13].

The lateral ordering of self-assembled quantum dots has been under investigation for several years. The most promising approach to force QDs into lateral order seems to be the growth on patterned substrates. In Fig. 3, an example for QD stacks is shown, which is grown on a seed layer formed on a pre-patterned surface. A three-dimensionally ordered QD structure with 11 dot layers show a mean height variation of 7.2 % and a corresponding low-temperature PL linewidth of 23 meV [14]. However, these dot arrays are for the moment not dense enough (< $5x10^9$ cm^{-2}). New template preparation processes are under development to allow higher dot densities. In Fig. 4, scanning electron microscope (SEM) pictures are shown of wet chemically etched GaAs surfaces with hole densities of $2x10^{10}$ cm^{-2} and $4x10^{10}$ cm^{-2} that are high enough to create dot layers suitable for laser applications.

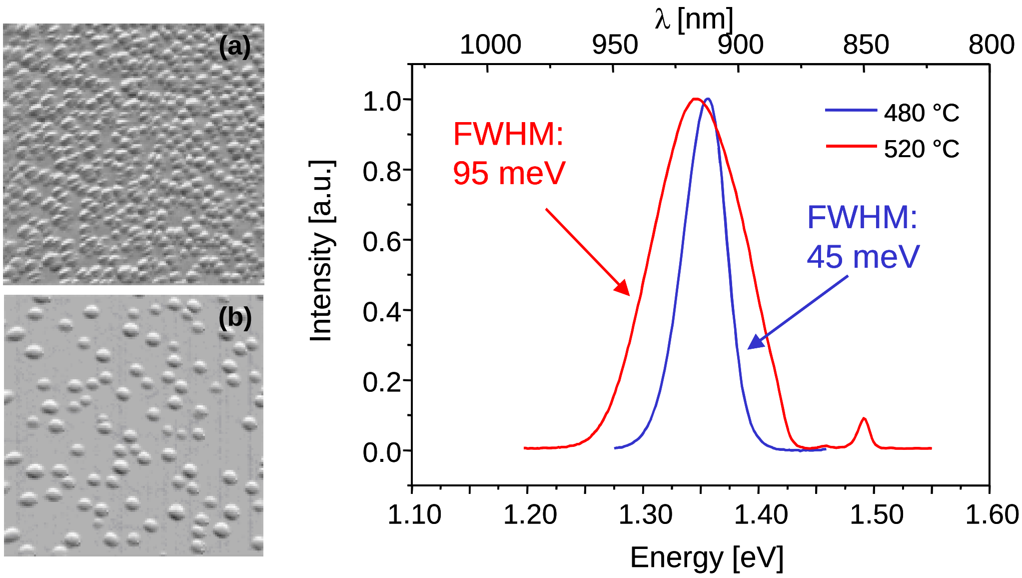


Figure 2: AFM images of uncovered $Ga_{0.4}In_{0.6}As$/GaAs QDs grown at (a) 480 °C and (b) 520 °C shown with their corresponding low temperature (T = 10 K) photoluminescence spectra.

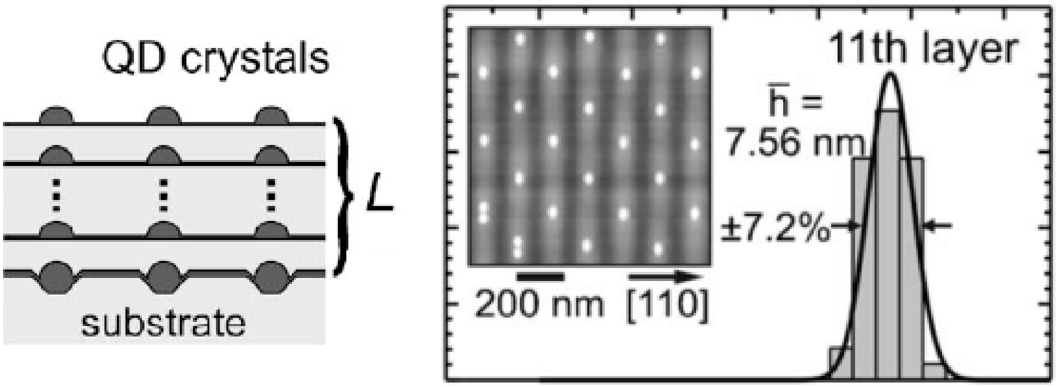


Figure 3: Schematic structure of a seeded dot array grown on a pre-patterned substrate (left) and the corresponding dot height distribution of a dot array with 11 dot layers (right) [14].

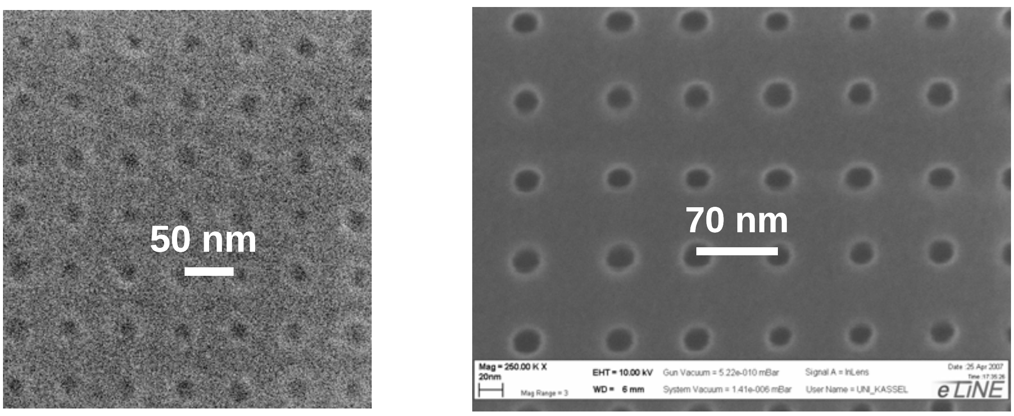
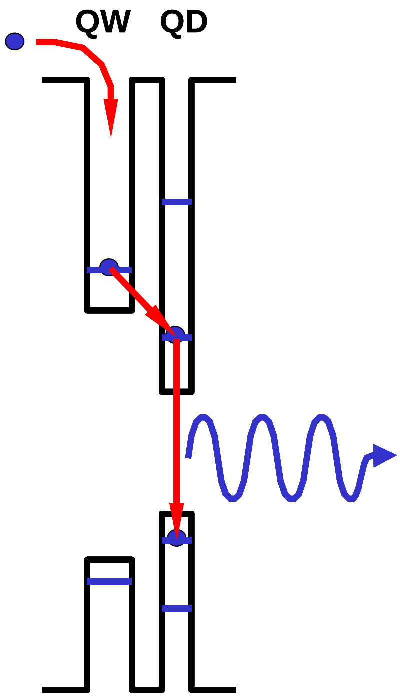


Figure 4: SEM images of pre-patterned substrates defined by e-beam lithography and wet chemical etching with hole densities of (a) $2x10^{10}$ cm^{-2} and (b) $4x10^{10}$ cm^{-2}. The hole diameters are about 30 and 20 nm, respectively.

Tunnelling-Injection QD Laser

A very promising design to improve the modal gain in a QD laser without degrading important dot properties (local recombination, δ-function like density of states and the related effects such as temperature stability of the threshold current and low linewidth enhancement factor) is the quantum well tunnel injection structure. In Fig. 5a, a schematic is shown for such a tunnelling injection quantum dot (TI-QD) structure. Here, the carrier capture process into quantum dot states takes place via a quantum well relaxation process and subsequent tunnel injection accompanied by a longitudinal optical (LO) phonon scattering process. The major advantages in this structure design are a fast and very efficient carrier capture and relaxation process in the quantum well to the lowest energy state. Due to the resonant tunnelling process via LO phonons only cooled carriers can be injected into the quantum dot, which have not enough energy to escape once again. Therefore the relaxation process and thermally activated escape process can be decoupled. As a consequence, the QD laser should be much less temperature sensitive in terms of threshold current density and efficiency and the modal gain should significantly increase. The latter will result in a more dominating fundamental transition in the quantum dot with a strongly reduced excitation of higher order states, i.e. the gain spectrum should be more symmetric leading to a low linewidth enhancement factor.

Figures 5b and 5c show room temperature electroluminescence spectra of a conventional QD and a TI-QD laser structure, respectively, for different current densities. The fundamental, i.e., longest wavelength transition of the QD structure (QD PL) already saturates at low current densities while for the TI-QD structure the fundamental QD transition could not be saturated even at the highest current density. In addition, the optical transition of the injection quantum well (QW PL) can be identified at the highest current density. This result shows clearly that a very efficient tunnelling process of cold carriers occurs without strong excitation of higher order quantum dot states. For future development, however, it will be important to increase the energy difference between the fundamental dot transition and QW transition, which might be possible by resonant tunnelling via LO phonon scattering into higher order quantum dot states. Further details of this will be published in the near future [15].



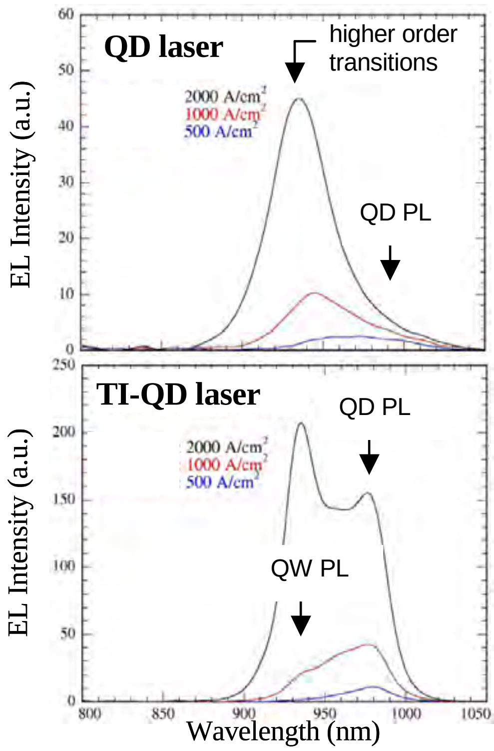


***Figure 5:** Schematic representation of a quantum dot structure with a tunnel injection quantum well (left) and electroluminescence measurements at different current densities for a QD laser structure with and without a tunnel injection design (right). While early saturation of the fundamental QD transition is observed in the QD structure, the fundamental QD transition in the TI-QD structure cannot be saturated even at the highest current density of 2 kA/cm^{-2} [15].*

In Fig. 6a, the light output characteristics of a 980 nm TI-QD laser are shown for different operation temperatures. High temperature stability of the threshold current can be observed with a T_0 value of about 180 K up to 50 °C. Laser operation in pulsed mode is possible up to at least 180 °C. By reducing the cavity length of a laser the losses and the threshold current density are increased. This effect results in an increased filling of higher order states, which is most pronounced for the QD laser due to the lower modal gain. As a consequence, the emission wavelengths shift to shorter values.

In Fig. 6b, a comparison is made between the cavity length dependence of the emission wavelengths of QD, QW and TI-QD lasers. As expected, the wavelength shift is the strongest for the QD laser while for the QW laser it is the weakest. The TI-QD laser is in between but very near to the QW laser characteristics confirming the much higher modal gain in comparison to the QD laser.

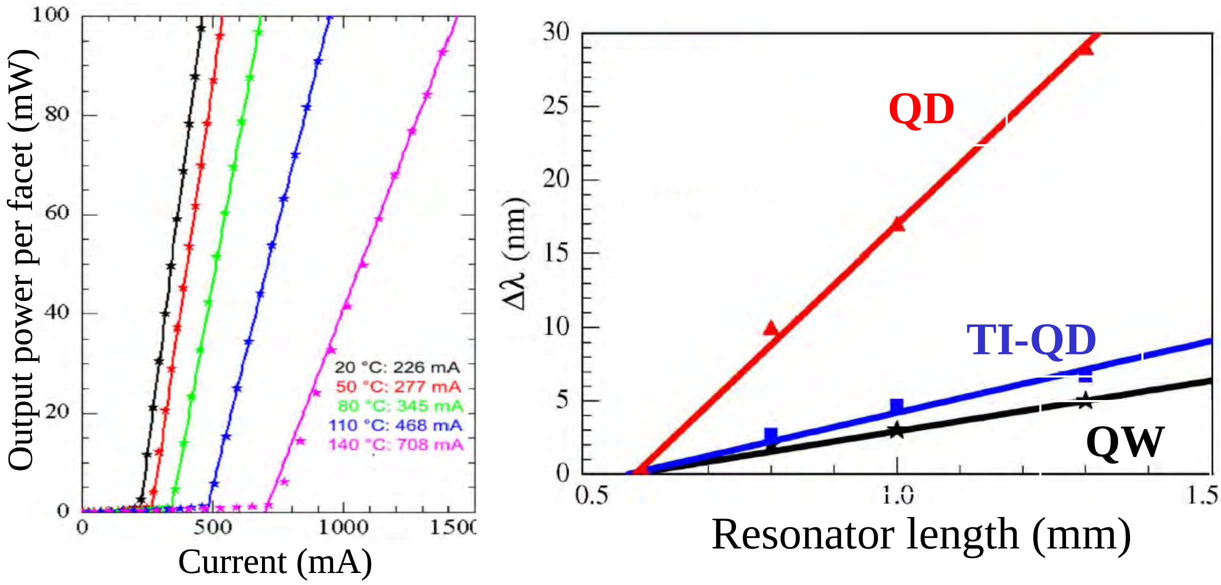


Figure 6: (left) Light output characteristics of a 980 nm TI-QD broad area laser (L = 1 mm, w = 100 µm) at different operation temperatures (pulsed measurements) and (right) Wavelength shift for 980 nm QD, TI-QD and QW lasers as function of the resonator length. Due to the much higher modal gain, the TI-QD laser shows very similar characteristics to the QW laser [15].

Summary and Conclusions

In this article, a general introduction to QD laser materials with their specific advantages and remaining challenges has been given. Two major challenges were highlighted, i.e., the problem of statistical dot size distribution and the inefficient carrier capture process, which leads to a limited modal gain. Several possible ways were discussed to address these challenges. In the case of size distribution, e.g., the formation of dot arrays with advanced growth parameters or/and the dot formation on pre-patterned surfaces are presented. Very promising is also the introduction of tunnel injection designs to overcome the carrier capture bottleneck in QDs. This should allow one to utilise dot specific properties, like a symmetric gain function for low linewidth enhancement factors and a high temperature stability of the laser performance, without suffering from the low modal gain typical of conventional QD lasers.

In Fig. 7, some device results of a currently state-of-the-art 920 nm tapered QD laser is shown with a very homogeneous near field intensity profile at 1 W cw output power. In addition, the light output characteristic and wall-plug efficiency are shown and demonstrate maximum values of 3 W cw output power and a 39 % wall-plug efficiency. More details are reported elsewhere [16]. In the next generation of quantum dot materials further improvements in the overall performance are expected especially addressing the reduction of the filamentation problem, which is currently one of the limiting factors for high-power, high-brightness lasers as well as the temperature stability of threshold current density and efficiency.

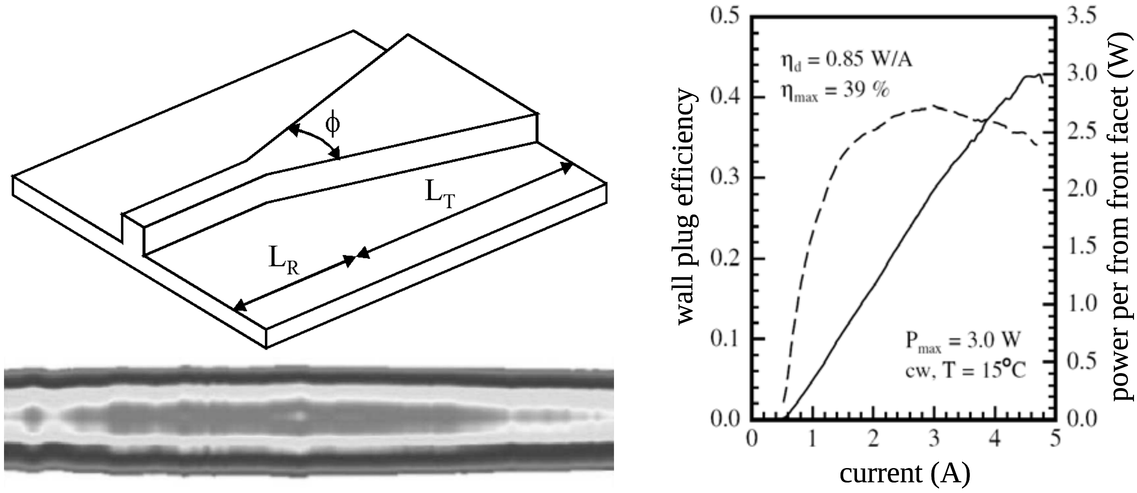


Figure 7: Schematic design of a tapered QD laser for high brightness applications (top left) together with the near-field characteristics at 1 W cw output power (bottom left) and the light output and wall plug efficiency characteristics (right) [16].

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PROJECT WORKSHOP @ CLEO-EUROPE

The WWW.BRIGHTER.EU Consortium organised and hosted a workshop in June this year entitled "High Brightness Diode Laser Sources". The workshop took place during the 2007 World of Photonics Congress and Laser Fair, which was held together with the CLEO-Europe Conference in Munich, Germany.

The one-day Workshop, attended by delegates from across Europe and beyond, included a program of 16 presentations – 9 given by invited speakers from outside the Consortium and 7 given by members from within the WWW.BRIGHTER.EU project team.

The program was divided into four topical sessions as shown opposite and the full program is given on the following page.

The high quality of presentations on state-of-the-art developments and techniques related to laser diodes and applications stimulated many enthusiastic discussions, resulting in an enjoyable and successful event.

A selection of the presentations from the workshop are now available on our project website, http://www.ist-brighter.eu.

Photographs of speakers at the "High Brightness Diode Laser Sources" Workshop – 18th June 2007, Munich
Top image: Hans Peter Reithmaier, University of Kassel. Bottom row (left to right): Jean-Pierre Huignard, Thales Research and Technology, Stefan Andersson-Engels, Lund University and Holger Mönch, Philips Research Laboratories.

PROJECT WORKSHOP @ CLEO-EUROPE

The workshop program was divided into 4 topical sessions. More details on the program are given below. Some of the presentations are available to view and download from the project website, http://www.ist-brighter.eu.

Session 1

High-Brightness Laser Technology

External cavities for controlling spatial & spectral properties of SC lasers
Jean-Pierre Huignard – *Thales Research and Technology*

Reliable high-power red-emitting laser diodes
Bernd Sumpf – *Ferdinand Braun Institute*

Wavelength stabilised high-power quantum dot lasers
Hans Peter Reithmaier – *University of Kassel*

Quantum dot lasers & new device concepts for high-brightness applications
Dieter Bimberg / Nikolai Ledentsov – *Technical University of Berlin*

High-power laser for surgical applications (cutting and ablation)
Ronald Sroka – *LFL Munich*

Session 2

Packaging, Micro-Optics and Reliability

Micro-optics and fibre coupling of high-brightness laser bars
Martin Forrer – *FISBA OPTIK*

How to measure packaging-induced strain in high-brightness diode lasers?
Jens Tomm – *Max Born Institute*

High-power laser modules and their applications
Jörg Neukum – *DILAS*

Session 3

Frequency-Doubled Lasers

Second harmonic generation of external cavity tapered diode lasers
Ole Bjarlin Jensen – *Risoe National Laboratory*

High-power Semiconductor VECSELs
Anne Tropper – *University of Southampton*

ps applications of diode lasers
Ranier Erdmann – *Picoquant*

Session 4

Medical, Telecom and Display Applications

Fluorescence diagnostics in medicine - there is a need for improved light sources
Stefan Andersson-Engels – *Lund University*

Diode lasers for photodynamic therapy
Tilmann Trebst – *Biolitec*

Laser-induced fluorescence spectroscopy & molecular imaging as tools for tumour detection in vivo
Bernd Ebert – *Physikalisch-Technische Bundesanstalt*

Laser display markets, technologies and requirements
Holger Mönch – *Philips Research Laboratories*

Making use of brighter lasers - Optical amplifiers in current and future WDM systems
Jörg Peter Ebers – *Ericsson*

DRIP-XII CONFERENCE – SEPTEMBER 2007

Two WWW.BRIGHTER.EU partners, the Max-Born-Institute (MBI) and the Ferdinand-Braun-Institute (FBH), jointly organised and hosted the recent DRIP-XII conference.

DRIP-XII – The 12th International Conference on Defects – Recognition, Imaging and Physics in Semiconductors took place in Berlin from the 9th to the 13th September 2007.

The conference was jointly chaired by Dr Jens W. Tomm (MBI) and Dr Ute Zeimer (FBH).

The proceedings of DRIP-XII will be published in a special issue of the Journal of Materials Science: Materials in Electronics.

DRIP-XII Conference – At a glance…

- 70 oral presentations (incl. 11 invited)
- 70 poster presentations
- 155 attendees from 28 countries

Overview of Conference Sessions

- Silicon Devices
- Defects in Group IV Materials
- Non-Polar GaN and GaN-Based Devices
- Advanced Analytical Methods & Devices
- Defects in Nitrides
- New Developments in III-V Materials
- Defects in Devices
- Advanced Analytical Methods
- Wide Bandgap and II-VI Materials

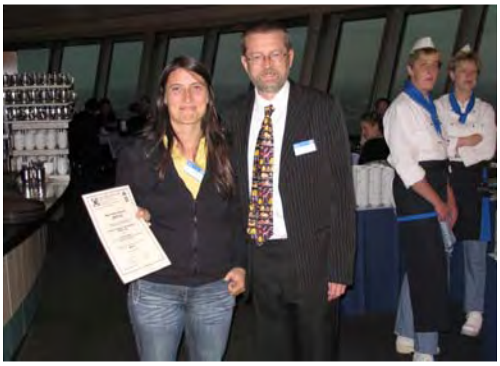
Conference Location - "Courtyard by Marriot" in Berlin Köpenick

Conference Chairs - Jens W. Tomm (MBI) and Ute Zeimer (FBH)

Invited Speakers

- Martin Albrecht, Institut für Kristallzüchtung (Germany)
- Tilo Baumbach, Universität Karlsruhe (Germany)
- Tonio Buonassisi, Massachusetts Institute of Technology (USA)
- Mark S. Goorsky, University of California, Los Angeles (USA)
- Colin Humphreys, University of Cambridge (UK)
- Martin Kuball, University of Bristol (UK)
- Abdelmadjid Mesli, Laboratoire InESS (France)
- Julien Nagle, Thales Research and Technology (France)
- James Speck, University of California, Santa Barbara (USA)
- Eicke Weber, Fraunhofer Institut für Solare Energiesysteme (Ger.)
- Hiroshi Yamada-Kaneta, Niigata University (Japan)

BEST POSTER AWARD



Winner of the Best Poster Award (500€) – Paola Altieri-Weimar (OSRAM Opto Semiconductors) for the poster entitled "Influence of doping on the reliability of AlGaInP LEDs" – Award presented by Jens W. Tomm (Max-Born-Institute)

13th DRIP Conference September 2009

The 13th DRIP Conference will be held in Pittsburgh, USA in 2009 and be organised by Prof. Marek Skowronski of the Department of Materials Science and Engineering, Carnegie Mellon University.

Many thanks to all the DRIP-XII sponsors!

DRIP-XII CONFERENCE – SEPTEMBER 2007

WWW.BRIGHTER.EU at DRIP

Two special sessions which were supported by the WWW.BRIGHTER.EU project and entitled “Defects in Devices” took place within the DRIP-XII conference. Twelve presentations were given within these special sessions (see below), with the opening invited talk given by Dr Julien Nagle of Thales Research and Technology, France. Several other members of the Consortium also contributed to the presentations within these sessions.

"Defects in Devices I"
“Defect impact and defect signatures in high power laser diodes” J. Nagle, M. Oudart *(Invited)*
“Reliability and failure mechanisms of 650 nm high-power diode lasers” B. Sumpf, U. Zeimer, K. Häusler, M. Zorn, G. Erbert
“Study of the degradation of AlGaAs-based high-power laser bars : V defects” M. Avella, M. Pommiès, J. Jiménez, A. Martín, P. Iñiguez, M. Oudart, J. Nagle
“Identification of degradation mechanisms in high-power laser bars using by-emitter degradation studies” S. Bull, J.W. Tomm, E.C. Larkins
“Spatially resolved thermo-reflectance analysis of thermal processes in high-power laser bars” D. Pierscinska, K. Pierscinski, A. Kozlowska, M. Bugajski, J.W. Tomm

WWW.BRIGHTER.EU Consortium Members at DRIP

Top (left to right): Marwan Bou Sanayeh (OSRAM Opto Semiconductors) and Steve Bull (University of Nottingham) Bottom (left to right) Jens W. Tomm (Max-Born-Institute) and Julien Nagle (Thales Research and Technology)

"Defects in Devices II"
“Micro-Raman thermography : Temperature, defects and time-resolved characteristics of semiconductor devices” M. Kuball, J.W. Pomeroy, A. Sarua, G.J. Riedel, R. Simms, H. Ji, M.J. Uren, T. Martin *(Invited)*
“Defect investigation and temperature analysis of high-power AlGaInP laser diodes during COD” M. Bou-Sanayeh, P. Brick, B. Mayer, M. Müller, M. Reufer, W. Schmid, K. Streubel, S. Schwirzke-Schaaf, J.W. Tomm, A. Danilewsky, G. Bacher
“Degradation model analysis of laser diodes” K. Häusler, U. Zeimer, B. Sumpf, G. Erbert, G. Tränkle
“Spatial variations of carrier and defect concentration in VGF GaAs:Si” M. Baeumler, J. Wagner, F. Börner, U. Kretzer, M. Scheffer-Czygan, T. Bünger
“Introduction of defects during the dry etching of InP photonic structures : A CL study” M. Avella, J. Jiménez, F. Pommereau, J.P. Landesman, A. Rhallabi
“SIMS depth profiling of Mg back diffusion in (AlGaIn)N light emitting diodes” L. Kirste, M. Maier, J. Wiegert, K. Köhler
“The evolution of the ion implantation damage in device processing” M.L. Polignano, I. Mica, V. Bontempo, M. Mariani, A. Mauri, G. Pavia, G. Spoldi

Full program details, including presentation abstracts, can be found on the conference website: http://www.drip12.de

BIOPHOTONICS '07 – SUMMER SCHOOL

The 3rd International Graduate Summer School Biophotonics '07, in collaboration between Risø National Laboratory in Denmark and Lund University in Sweden, was held on the island of Ven, Sweden from 9th to 16th June. 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 50 participants. Application to attend the summer school is by peer review of a summary of the participants' research and results or planned research project.

During the school, successful applicants present their research during two 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 the school website, http://www.biop.dk/biophotonics07. The lectures are also made available online following the summer school.

Biophotonics '07

The 3rd International Graduate Summer School Biophotonics '07 had 57 participants from 19 different countries worldwide with 37 male and 20 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 six different countries – 5 lecturers from the US and 6 from the EU.

The Biophotonics '07 school covered the basics of lasers and their application in medicine, tissue optics, photodynamic therapy, optical tweezers and their applications in biophotonics, optical biosensors, molecular imaging based on optical methods and optical coherence tomography. These topics were covered by internationally renowned lecturers:

- *Prof. Darryl Bornhop, Vanderbilt University, USA*
- *Prof. Kishan Dholakia, University of St. Andrews, UK*
- *Prof. James Fujimoto, Massachusetts Institute of Technology, USA*
- *Prof. Stefan Hell, Max-Planck-Institute for Biophysical Chemistry, Germany*
- *Prof. Steven Jacques, Oregon Health & Science University, USA*
- *Prof. Paul Michael Petersen, Risø National Laboratory, TU Denmark, Denmark*
- *Dr. Brian Pogue, Dartmouth College, USA*
- *Prof. Eva Sevick-Muraca, Baylor College of Medicine Houston, USA*
- *MD Katarina Svanberg, Lund University Hospital, Lund, Sweden*
- *Prof. Sune Svanberg, Lund University, Lund, Sweden*
- *Prof. Hubert van den Bergh, Ecole Poly. Fédérale de Lausanne, Switzerland*

Biophotonics '09

The 4th school, Biophotonics '09, is already scheduled for June 2009, tentatively 5th to 13th June. To receive more information, visit http://www.biop.dk/biophotonics07 and join our mailing list.

Lecture by Prof. Stefan Hell, Max-Planck-Institute for Biophysical Chemistry, Göttingen, Germany

Summer School participants during a lecture

Discussions during one of the posters sessions

Discussions continue during a coffee break

SELECTED PUBLICATIONS & PRESENTATIONS

Improvements in Diode Laser Performance

- B. Sumpf, M. Zorn, R. Staske, J. Fricke, P. Ressel, G. Erbert, M. Weyers, G. Tränkle, "5W reliable operation over 2000h of 5mm wide 650nm AlGaInP/GaInP/AlGaAs laser bars with asymmetric claddings," IEEE Photon. Technol. Lett., Vol. 18, 1955-1957, 2006.
- B. Sumpf, M. Zorn, R. Staske, J. Fricke, P. Ressel, A. Ginolas, K. Paschke, G. Erbert, M. Weyers, G. Tränkle, "3W broad area lasers and 12W bars with conversion efficiencies up to 40% at 650nm," Digest 20th IEEE Int. Semicond. Laser Conf., 37-38, 2006.
- F. Dittmar, A. Klehr, B. Sumpf, A. Knauer, J. Fricke, G. Erbert, G. Tränkle, "9W output power from an 808nm tapered diode laser in pulse mode operation with nearly diffraction-limited beam quality," Digest 20th IEEE Int. Semicond. Laser Conf., 35-36, 2006.
- B. Sumpf, M. Zorn, R. Staske, J. Fricke, A. Ginolas, K. Häusler, W. Pittroff, P. Ressel, G. Erbert, M. Weyers, G. Tränkle, "650nm InGaP broad area lasers with 5000h reliable operation at 600mW," IEEE Photon. Technol. Lett., Vol. 19, 118-120, 2007.
- R. Bohdan, A. Bercha, O. Mariani, M. Wojdak, F. Dybala P. Adamiec, W. Trzeciakowski, J. Weber, M.T. Kelemen, "Tuning of the high-brightness tapered laser and its applications," Phys. Stat. Sol. (b), Vol. 244, 213-218, 2007.
- W. Trzeciakowski, A. Bercha, F. Dybała, R. Bohdan, P. Adamiec, O. Mariani, "Pressure and temperature tuning of laser diodes," Phys. Stat. Sol. (b), Vol. 244, 179-186, 2007.
- F.K. Lau, C.W. Tee, R.V. Penty, I.H. White, N. Michel, M. Krakowski, "A novel intracavity lens design for compact and high efficiency tapered laser diode," IEEE Photon. Technol. Lett., Vol. 19, 203-205, 2007.
- N. Michel, M. Calligaro, M. Krakowski, W. Kaiser, S. Deubert, A. Forchel, J.P. Reithmaier, B. Boulant, T. Fillardet, "High-power (14W CW), narrow far-field (3° FWHM) 920nm quantum-dots tapered laser mini-bar," Conf. on Lasers & Electro-Optics (CLEO), Baltimore, MD, 6th-11th May 2007.
- W. Kaiser, J.P. Reithmaier, A. Forchel, H. Odriozola, I. Esquivias: "Theoretical and experimental investigations on temperature induced wavelength shift of tapered laser diodes based on InGaAs/GaAs Q-dots," Appl. Phys. Lett., Vol 91, 051126, 2007.
- W. Kaiser, S. Deubert, J.P. Reithmaier, A. Forchel "Single mode tapered quantum dot laser diodes with monolithically integrated feedback gratings," Electron. Lett., Vol. 43, 926-927, 2007.

Lasers in Medicine & Optical Wireless Networks

- A. Johansson, J. Svensson, S. Andersson-Engels, N. Bendsoe, K. Svanberg, E. Alexandratou, M. Kyriazi, D. Yova, S. Gräfe, T. Trebst, "Fluorescence and absorption assessment of a lipid mTHPC formulation following topical application in a skin tumour model," J. Biomed. Opt., Vol. 12, 034026, 2007.
- D. Gorpas, M. Kyriazi, K. Politopoulos, D. Yova, "Development of a computer vision binocular system for non-contact small animal model skin cancer tumour imaging," Euro. Conf. on Biomedical Optics – Diffuse Optical Imaging, Munich, 17th-21st June 2007.
- E. Alexandratou, M. Kyriazi, T. Trebst, S. Gräfe, D. Yova, "Photodynamic therapy of non melanoma skin cancer murine model by topical application of a novel m-THPC liposomal formulation," Euro. Conf. on Biomedical Optics – Therapeutic Laser Applications, Munich, 17th-21st June 2007.
- C.H. Kwok, F.K. Lau, R.V. Penty, I.H. White, "Receiver sensitivity improvement of optical wireless channels with delayed-diversified pulse-position modulation," Conf. on Lasers & Electro-Optics (CLEO), Baltimore, MD, 6th-11th May 2007.
- C.H. Kwok, R.V. Penty, I.H. White, "Temporal-domain diversity reception with improved link reliability for optical wireless access networks," Euro. Conf. on Optical Communication (ECOC), Berlin, 16th-20th Sept. 2007.

External Cavities Lasers & Frequency Doubling

- M. Chi, O.B. Jensen, J.P. Huignard, P.M. Petersen, "Two-wave mixing in a broad-area semiconductor amplifier," Opt. Express, Vol. 14, 12373-12379, 2006.
- O.B. Jensen, J. Holm, B. Sumpf, G. Erbert, P.E. Andersen, P.M. Petersen, "Generation of >300mW diffraction-limited light at 405nm by SHG of an external cavity tapered diode laser," Proc. SPIE, Vol. 6455, 03, 2007.
- V. Reboud, N. Dubreuil, P. Fournet, G. Pauliat, G. Roosen, D. Rytz, "Single-mode output power enhancement of an extended cavity BA laser diode by an intracavity photorefractive crystal," Appl. Phys. B, Vol. 87, 233-237, 2007.
- D. Paboeuf, G. Lucas-Leclin, P. Georges, B. Sumpf, G. Erbert, C. Varona, P. Loiseau, G. Aka, B. Ferrand, "450nm blue laser emission of an intracavity-doubled Nd:ASL crystal pumped by an extended-cavity tapered laser diode," Conf. on Lasers & Electro-Optics (CLEO Europe), Munich, 18th-22nd June 2007.

Diode Laser Physics, Degradation & Reliability

- J.W. Tomm, T.Q. Tien, M. Ziegler, F. Weik, B. Sumpf, M. Zorn, U. Zeimer, G. Erbert, "Degradation behaviour and thermal properties of red (650nm) high-power diode single emitters and laser bars," Proc. SPIE, Vol. 6456, 06, 2007.
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- M. Ziegler, T.Q. Tien, S. Schwirzke-Schaaf, J.W. Tomm, B. Sumpf, G. Erbert, M. Oudart, J. Nagle, "Gradual degradation of red-emitting high-power diode laser bars," Appl. Phys. Lett., Vol. 90, 171113, 2007.
- M. Bou Sanayeh, P. Brick, W. Schmid, B. Mayer, M. Müller, M. Reufer, K. Streubel J.W. Tomm, G. Bacher, "Temperature-power dependence of COD in AlGaInP laser diodes," Appl. Phys. Lett., Vol. 91, 041115, 2007.
- S. Bull, J.W. Tomm, E.C. Larkins, "Identification of degradation mechanisms in high-power laser bars using by-emitter degradation studies," 12th Int. Conf. on Defects – Recognition, Imaging & Physics in Semiconductors (DRIP), Berlin, 9th-13th Sept. 2007.
- J. Nagle, M. Oudart, "Defect impact and defect signatures in high power laser diodes," *(invited)* 12th Int. Conf. on Defects – Recognition, Imaging & Physics in Semiconductors (DRIP), Berlin, 9th-13th Sept. 2007.

Laser Design, Modelling & Optimisation

- P.J. Bream, R. MacKenzie, J.J. Lim, S. Bull, A.V. Andrianov, A.J. Kent, S. Sujecki, E.C. Larkins, "Nonequilibrium gain and nonlinear optical response of QWs," *(invited)* Nonlinear Dynamics in Semiconductor Lasers, Berlin, 19th-21st Nov. 2007.
- L. Borruel, H. Odriozola, J.M.G. Tijero, I. Esquivias, S. Sujecki, E.C. Larkins, "Design strategies to increase the brightness of gain-guided tapered lasers," Int. Workshop on Physics & Applications of Semiconductor Lasers (PHASE), Metz, 28th-30th Mar. 2007.
- J.M.G. Tijero, H. Odriozola, L. Borruel, I. Esquivias, S. Sujecki, E.C. Larkins, "Enhanced brightness of tapered laser diodes based on an asymmetric epitaxial design," IEEE Photon. Technol. Lett., Vol. 19, 1640-1642, 2007.
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- H. Odriozola, J.M.G. Tijero, L. Borruel, I. Esquivias, H. Wenzel, F. Dittmar, K. Paschke, B. Sumpf, G. Erbert, S. Sujecki, E.C. Larkins, "High power 980nm tapered lasers with separate contacts," Conf. on Lasers & Electro-Optics (CLEO Europe), Munich, 18th-22nd June 2007.
- R. Mackenzie, J.J. Lim, A.J. Kent, S. Sujecki, E.C. Larkins, "Detailed heat modelling in high power and high speed quantum well laser diodes," Int. Conf. on Phonon Scattering in Condensed Matter, Paris, 15th-20th July, 2007.
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- R. MacKenzie, J.J. Lim, S. Bull, S. Sujecki, E.C. Larkins, "The impact of thermal boundary resistance in optoelectronic devices," Numerical Simulation of Optoelectronic Devices (NUSOD) Conf., Newark, DE, 24th-27th Sept. 2007.

PROJECT e-NEWSLETTERS

Don’t miss the next WWW.BRIGHTER.EU e-Newsletters!

In Edition 3 in March ’08, look out for the following:

- Partner profiles – *Keopsys, Max Born Institute, OSRAM, University of Würzburg*
- “Laser display applications” – *University of Cambridge, OSRAM*
- “Raman amplification” – *Keopsys*
- “Role of spontaneous emission in high-brightness lasers” – *University of Nottingham*
- “Overgrowth free high power single mode lasers” – *University of Würzburg*

And, don’t miss the following in Edition 4 in September ’08:

- Partner profiles – *Ferdinand Braun Institute, LCFIO, Risø, University of Madrid*
- “Behaviour and performance of external cavity lasers” – *University of Nottingham, Risø, LCFIO, Thales Research and Technology*
- “Interstitial photodynamic therapy” – *Biolitec*
- “Mirror heating in high power lasers” – *University of Madrid, Max Born Institute*
- “High-Brightness lasers with multi-contacts” – *Ferdinand Braun Institute*

e-Newsletter Back Issues

If you missed Edition 1, or would like to see our 3 e-Newsletters from the earlier WWW.BRIGHT.EU project, please visit out website at http://www.ist-brighter.eu where PDF copies of all published e-Newsletters can be downloaded.

Some highlights of previous e-Newsletters!

Applications Articles

- High-brightness laser diodes – An enabling technology for the 21st century
- Prospects for cladding-pumped erbium-doped fibre amplifiers
- Medical applications of laser diodes and optical technology
- Review on short range optical wireless communication systems
- Technology and applications of frequency-doubled laser diodes

……*and more*

Technical Papers

- Spectroscopic analysis of external stresses in semiconductor devices
- Operating principles and performance limits of tapered lasers
- Pressure and temperature tuning of laser diodes
- Design of high-power high-brightness lasers
- By-emitter degradation analysis of high-power laser bars

……*and more*

CALENDAR OF EVENTS

The calendar below lists some important events in 2008 at which the Consortium will be represented.

JANUARY 2008

19th – 24th January
SPIE Photonics West
San Jose, CA, U.S.A

FEBRUARY 2008

24th – 28th February
Optical Fiber Communication Conference (OFC)
San Diego, CA, U.S.A

MARCH 2008

17th – 19th March
Semiconductor and Integrated Optoelectronics Conference (SIOE)
Cardiff, Wales, U.K.

24th – 28th March
Materials Research Society (MRS) – Spring Meeting
San Francisco, CA, U.S.A

APRIL 2008

7th – 11th April
SPIE Photonics Europe
Strasbourg, France

MAY 2008

4th – 9th
Conference on Lasers and Electro-Optics (CLEO)
San Jose, CA, U.S.A

26th – 30th
European Materials Research Society (EMRS) – Spring Meeting
Strasbourg, France

AUGUST / SEPTEMBER 2008

31st August – 5th September
Numerical Simulation of Optoelectronic Devices Conference (NUSOD)
Nottingham, U.K.

SEPTEMBER 2008

14th – 18th September
IEEE International Semiconductor Laser Conference (ISLC)
Sorrento, Italy

21st – 25th September
European Conference on Optical Communication (ECOC)
Brussels, Belgium

Workshop Announcement

"Toxicology, Safety and Environmental Issues in III-V Epitaxial Growth"

Wednesday 13th February 2008

Thales Research and Technology
Palaiseau, Paris, France

This half-day workshop is primarily targeted towards scientists and technicians working in III-V epitaxy in industrial and research facilities.

The workshop will introduce BRIGHTER and its applications and then cover topics including: an introduction to toxicology for researchers, respiratory exposure to gases and particulates, toxicology of some compounds, biometrology at work and MBE maintenance.

More details will be available in the near future at http://www.ist-brighter.eu.

8th International Conference on **Numerical Simulation of Optoelectronic Devices**

31st August – 5th September 2008

University of Nottingham, U.K.

Conference Chairs: Joachim Piprek, NUSOD Institute and Eric Larkins, University of Nottingham

The University of Nottingham, the NUSOD Institute and the WWW.BRIGHTER.EU Consortium are pleased to announce that the next international Numerical Simulation of Optoelectronic Devices (NUSOD) conference will be held at the University of Nottingham, U.K, from 31st August to 5th September 2008. More details can be found on the NUSOD 2008 website, http://www.nusod.org/conf08.

NUSOD Institute