Workshop on

"Laser Diodes for Space Applications"

Palaiseau (France), 23-24 November 2015

Location: Auditorium. III-V Lab, Thales Research and Technology, Campus Polytechnique 1, Avenue Augustin Fresnel, F-91767 Palaiseau Cedex, France.

Book of Abstracts

Organized by the BRITESPACE consortium:

In collaboration with:

The FP7-Space Project BRITESPACE in collaboration with ESA is pleased to announce the international Workshop on “Laser Diodes for Space Applications”, devoted to promote the contact between developers and manufacturers of laser diodes with developers and users of space systems.

The aim is to promote the interaction between communities of laser diodes manufacturers and space systems developers and users in both research and industry environments. In particular, this workshop will focus on the needs of appropriate laser diodes sources and configurations required by specific space applications.

Scope:

- Design, development and manufacturing of pulsed and CW laser diodes and semiconductor amplifiers: Broad Area Laser Diodes, DFB, DBR, VCSEL, VECSEL, Diodes Arrays, Bars and Stacks, Master Oscillator Power Amplifier (MOPA), Photonic Crystals.
- Space applications of laser diodes: Free Space Communications, Pump Modules, Intra Satellite Communications, Microwave Photonics, Navigation Sensors, Clocks, Planetary Exploration and Monitoring: LIDAR, Spectrometers.
- Reliability of laser diodes in space environment: Thermal, Vacuum/Contamination, Radiation, Vibration. Space qualification, performance testing and characterization of laser diodes.

Technical Committee

Ignacio Esquivias, Universidad Politécnica de Madrid, Spain.
Michel Krakowski, III-V Lab, France.
Martin Traub, Fraunhofer-Institut für Lasertechnik, Germany.
Juan Barbero, Alter Technology Group, Spain.
John G. Rarity, University of Bristol, United Kingdom.
Gerhard Ehret, Deutsches Zentrum für Luft- und Raumfahrt, Germany.
Mustapha Zahir, European Space Agency, ESTEC, The Netherlands.

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Information: www.britespace.eu/workshop-2015

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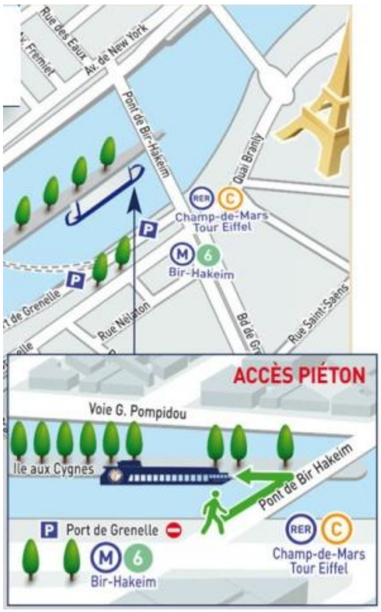
Pratical Information

Workshop Dinner

Capitaine Fracasse Cruise

Meeting at 20:30 – Middle of Bir Hakeim bridge – L'île aux Cygnes – 75015 Paris

(GPS coordinates: 48.855233, 2.287314)

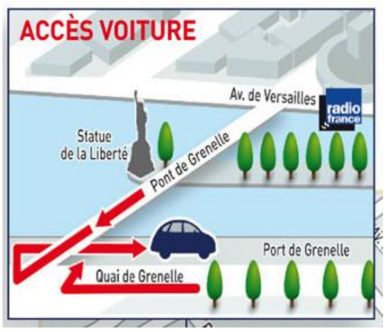


The best way from Palaiseau:

Take the RER B to Denfert Rochereau Station

Then take the metro M6 to Bir Hakeim station

Walk to the Bir-Hakeim bridge located in front of metro station to the left in the 15th arrondissement, then go to the middle of the bridge and down the stairs that will take you to l'Île aux Cygnes



By car:

You have the option of dropping off those accompanying you in the middle of Bir Hakeim Bridge and then park in the parking lot of Port Autonome located at the Grenelle dock (small descent in the beginning of Grenelle bridge, on the side of the 15th Arrondissement). Free parking but limited access.

Wifi Internet Access during the workshop

A Wifi code will be given to each participant.

Workshop Program

Monday November 23		
Time	**Duration**	**Topic**
14:00	10 min	Welcome to III-V lab
14:10	10 min	Welcome to the workshop (Ignacio Esquivias, UPM)
14:20	**90 min**	**Session 1: (Chairman: Ignacio Esquivias, UPM)**
	30 min	*Failure physics of laser diodes. Historical issues and recent updates.* (Massimo Vanzi, University of Cagliari)
	30 min	*Sudden degradation of AlGaAs-based high-power diode lasers: Analysis of bulk and facet failures.* (Jens Tomm, Max-Born Institute)
	30 min	*Space qualification strategy for laser diodes* (Olivier Gilard, CNES)
15:50	**30 min**	***Coffee break***
16:20	**100 min**	**Session 2: (Chairman: Michel Krakowski, III-V Lab)**
	30 min	*High-brightness multi-section semiconductor laser for space-borne lidar measurements of atmospheric carbon dioxide.* (Ignacio Esquivias, UPM)
	30 min	*8 Years in Space: Laser Diode Pump Modules in the Laser Communication Terminal* (Hanno Scheife, TESAT Spacecom)
	20 min	*Low-noise pump sources for laser communication terminals* (Karl Häusler, FBH)
	20 min	*A unified multiple stress reliability model for 1.55 µm DFB laser diode module for space validation.* (Alain Bensoussan, IRT Saint Exupery/Thales)
18:00		***End of first day***

20:30 Workshop dinner

Tuesday November 24		
Time	**Duration**	**Topic**
09:30	**70 min**	**Session 3: (Chairman: Martin Traub, Fraunhofer ILT)**
	30 min	*Semiconductor laser development for space applications at III-V lab* (Frédéric van Dijk, III-V Lab)
	20 min	*Passive coherent combining of two high-brightness tapered laser diodes in a Michelson external cavity* (Guillaume Schimmel, Institut d'Optique)
	20 min	*A versatile technology platform for micro-integration of diode-laser based, space compatible modules* (Ahmad Bawamia, FBH)
10:40	**30 min**	***Coffee break***
11:10	**90 min**	**Session 4: (Chairman: Frédéric van Dijk, III-V Lab)**
	30 min	*Beam Shaping of High Power Laser Diodes for Space Applications.* (Martin Traub, Fraunhofer ILT)
	30 min	*Evolution and perspectives of QCW high power laser diodes for space applications* (Andreas Kohl, Quantel)
	30 min	*Space qualified solutions with high-power diode lasers.* (Martin Wölz, Jenoptik)
12:40	**60 min**	***Lunch break***
13:40	**90 min**	**Session 5: (Chairman: Juan Barbero, ATN)**
	30 min	*Laser diode reliability testing for Space applications* (Lip Sun How, Adveotec)
	30 min	*Testing and evaluation of laser diodes for space applications at ESTEC.* (Jorge Piris, ESA)
	30 min	*Testing of laser diodes for space applications at ALTER* (Juan Barbero, ATN)
15:10	**30 min**	***Coffee break***
15:40	**60 min**	**Session 6: (Chairman: Gerhard Ehret, DLR)**
	20 min	*Discrete Mode Laser Diodes emitting at λ~689 and 780 nm for Optical clocks applications.* (Richard Phelan, Eblana)
	20 min	*Dual-frequency VECSEL for atomic clocks using coherent population trapping* (Paul Dumont, Institut d'Optique)
	20 min	*Optoelectronic modules and sub-systems for laser-based satellite communications* (Efstratios Kehayas, Gooch & Housego)
16:40	**10 min**	**Concluding Remarks (Ignacio Esquivias, UPM)**
16:50	**60 min**	**III-V Lab tour**
17:50		***Workshop Ends***

Session 1

Talk 1.1

Failure physics of laser diodes. Historical issues and recent updates.

Massimo Vanzi

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Mostly based on devices developed for telecom application, the history of laser diode failure mechanisms is first resumed. Defect propagation (DLD, REDR), Electrostatic Discharge, Catastrophic Optical Damage of facets will be illustrated since their first documentation. A particular emphasis will be given to the link between mechanisms and modes that is between root causes and observable effects.

A second part will be dedicated to the increasing relevance of second-harmonic excitation in several types of devices, despite their single-mode operation design. Moreover, some recent results on migration of radiation-induced defects on commercial VCSELS and DFB will be reported and interpreted.

Talk 1.2

Sudden degradation of AlGaAs-based high-power diode lasers: Analysis of bulk and facet failures

Jens W. Tomm, Martin Hempel, Thomas Elsässer*

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Sudden degradation in high power diode lasers may be caused by catastrophic optical damage (COD). This effect represents a generic degradation mechanism that also takes place in any light-guiding material providing that absorbing defects are generated or pre-existing impurities are accumulated. Technological measures may delay COD towards increasing optical power levels, but cannot eliminate it completely. Therefore it is of principal interest to learn more about the details, in particular the kinetics of this process. We discuss two sets of experiments where COD in the interior and at facets is artificially excited and investigated.

Internal COD is analyzed using a set of single-spatial mode lasers emitting at 980-nm. These devices are operated either in continuous wave long-term operation or ultra-high power short term operation (stress-test). We find that both tests eventually activate the same degradation mechanism, namely internal COD. In the case of ultra-high power operation, we find that the mechanism that initializes COD is a lateral widening of the optical mode, resulting in increased absorption outside the waveguide. Defects formed during long-term aging may eventually lead to a similar situation. Stress testing allows for activation of several degradation mechanisms in a device one after the other and for distinguishing between mechanisms induced by aging and other ones.

Facet-related COD is provoked with a single microsecond pulses in broad-area devices. Transient surface morphology and thermal kinetics at the facets are monitored. Time-resolved micro-reflectance spectroscopy with a streak-camera (time resolution ~20 ns and spatial resolution ~2 µm) allows for observing the creation sequence of up to 4 distinct degradation seed points at a device facet within < 300 ns. The full shaping of the damage seeds at the surface takes less than 30-40 ns. Their nonplanar face is formed by local melting of the semiconductor surface and subsequent bending of the facet coating. This represents the main mechanism behind observed reflectivity reductions, while reflectivity enhancements point to localized heating. Subsequently the surface temperature decreases within the pulse which originally initiated the damage process.

Stress-tests as applied here to two types of devices could pave the way towards more economic reliability testing, e.g., when comparing different technology variants in development.

Talk 1.3

Space qualification strategy for laser diodes

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Today laser diodes are considered as strategic devices for a number of current and future space applications. In the telecommunication domain they have been already used as emission sources in optical inter-satellite links, in inter-equipment high speed data links and they will be at the center of future opto-microwave repeaters. Laser diodes are also key elements of a number of sensing systems such as fiber optic gyroscopes, LIDAR, optical atomic clocks, optical magnetometers, FBG-based temperature sensors, etc.

Among all the requested laser diodes very few are space qualified and most of the time COTS devices have to be used. Radiations, microgravity, vacuum, thermal cycles, mechanical shocks and vibrations: the environmental constraints that may affect the reliability of laser modules during their lifetime in space are numerous. The purpose of the qualification process is to verify that the devices selected for flight can actually withstand these harsh space environment constraints with an acceptable impact on their performance and their reliability.

The qualification process to apply on laser diode is usually based on the ESA ESCC (European Space Components Coordination) policy. A first extensive evaluation phase aiming to detect possible failure modes is followed by a qualification testing phase whose objective is to obtain an authorization for use in space. However it is also noteworthy to mention that the qualification is actually the final outcome of a set of component engineering tasks that have to be correctly performed first (i.e. component selection, procurement, characterization, evaluation, screening, etc.). Generic recommendations to secure all these tasks will be presented.

Session 2

Talk 2.1

High-brightness multi-section semiconductor laser for space-borne lidar measurements of atmospheric carbon dioxide

Ignacio Esquivias[1,], Mariafernanda Vilera[1], Antonio Pérez-Serrano[1], José Manuel G. Tijero[1], Mickael Faugeron[2], Frédéric van Dijk[2], Michel Krakowski[2], Gerd Kochem[3], Martin Traub[3], Juan Barbero[4], Pawel Adamiec[4], Xiao Ai[5], John Rarity[5], Mathieu Quatrevalet[6] and Gerhard Ehret[6]*

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The availability of suitable laser sources is one of the main challenges in future space missions for accurate measurement of atmospheric CO_2. In the framework of European Project BRITESPACE, we propose an all-semiconductor laser source for an Integrated Path Differential Absorption (IPDA) lidar system for column-averaged measurements of atmospheric CO_2 in future satellite missions. Semiconductor lasers are superior to other types of lasers in terms of reliability, compactness and efficiency, but they cannot provide the high peak power required by the application. In consequence, the complete system architecture has to be adapted to the particular emission properties of these devices. The proposed transmitter design is based on two InGaAsP/InP monolithic Master Oscillator Power Amplifiers (MOPAs), providing the ON and OFF wavelengths close to the selected absorption line around 1.57 µm. Each MOPA consists of a frequency stabilized Distributed Feedback (DFB) master oscillator, a modulator section, and a tapered amplifier. Initial experimental results on the fabricated MOPAs indicate that the use of a bended structure to avoid undesired feedback provides good spectral properties together with high output power and good beam quality. The modulator section is required by the Random Modulated Continuous Wave (RM-CW) approach that has been selected as the best adapted to semiconductor laser. The fabricated lasers provide single mode emission with maximum powers of around 600 mW, and more than 20 dB extinction ratio when internally modulating the laser at a bit rate of 25 Mb/s as required by the application. The laser module includes the beam forming optics and the thermoelectric coolers. The DFB emission is tuned and stabilized by an offset locking technique referenced to a CO_2 gas cell.

Talk 2.2

Eight Years in Space: Laser Diode Pump Modules in the Laser Communication Terminal

Hanno Scheife[1], Frank Heine[1], Eberhard Möss[1], Karl Häusler[2], Martin Traub[3] and Rolf Meyer[4]*

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Tesat-Spacecom's Laser Communication Terminals (LCT) operate successfully on five LEO and GEO satellites. The first launch dates back to 2007 (NFIRE), the most recent was in June 2015 (SENTINEL-2). Optical data transmission is achieved via an optical data link at 1064 nm wavelength. The laser sources are space-qualified diode-pumped Nd:YAG single-frequency lasers.

The talk will highlight the actual operation scenario as part of the European Data Relay System (more than 100 successful LEO-GEO optical links over 40,000 km distance) and the underlying space-application-specific laser technology with focus on laser diode pump modules.

Talk 2.3

Low-noise pump sources for laser communication terminals

K. Häusler, R. Staske, M. Erbe, M. Ekterai, A. Knigge and G. Tränkle*

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Laser communication terminals utilized in free space communication systems require semiconductor lasers as pump source of solid state lasers. Laser diode benches with an emission wavelength stabilized at 808 nm are used as pumps of Nd:YAG ring lasers which are applied as transmitter and local oscillator in heterodyne optical communication terminals. Active stabilization of the Nd:YAG emission requires pump sources with stable wavelength and low relative intensity noise (RIN $< 0.5\%$) in the sub MHz range. Multimode operation and optical feedback in the laser diode significantly contribute to noise originating from mode competition, feedback-induced dynamic instability and thermal effects. We compare laser chips with external Volume Bragg Gratins to chips with integrated DBR gratings aimed at minimizing the low frequency RIN below the specified limit. Results of electro-optic characterization, noise measurements and burn-in data indicate the suitability of the devices as potential candidates for pump sources in laser terminals.

Talk 2.4

A unified multiple stress reliability model for 1.55 µm DFB laser diode module for space validation

A. Bensoussan [a, b], E. Suhir [c], P. Henderson [d], M. Zahir [e]*

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The establishment of European suppliers for DFB Laser Modules at 1.55 µm is considered to be essential in the context of future European space programs, where availability, cost and schedule are of primary concerns. Also, in order to minimize the risk, associated with such a development, the supplier will be requested to use components which have already been evaluated and/or validated and/or qualified for space applications. The Arrhenius model is an empirical equation able to model temperature acceleration failure modes and failure mechanisms. The Eyring model is a general representation of Arrhenius equation which take into account additional stresses than temperature. The present paper suggests to take advantage of these existing theories and derives a unified multiple stress reliability model for electronic devices in order to quantify and predict their reliability figures when operating under multiple stress in harsh environment as for Aerospace, Space, Nuclear, Submarine, Transport or Ground. Application to DFB laser diode module technologies is analyzed and discussed based on evaluation test program under implementation.

Full paper to be published in Microelectronics Reliability Volume 55, Issues 9–10, August–September 2015, Pages 1729–1735, Proceedings of the 26th European Symposium on Reliability of Electron Devices, Failure Physics and Analysis. SI:Proceedings of ESREF 2015.

Session 3

Talk 3.1

Semiconductor laser development for space applications at III-V lab

Frédéric van Dijk, Mickaël Faugeron, Michel Krakowski, Alexandre Larrue and Mohand Achouche*

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Photonics is getting an increasing interest for space applications not only for observations, for which it was initially used, but also for telecommunications, free-space optical transmissions, sensing, distance measurement… For all these applications use of semiconductor devices for light generation, amplification and detection are advantageous because they are compact, energy efficient and of low sensitivity to radiations. The talk we present recent development of different type of semiconductor devices developed at III-V Lab that could be of interest for space applications.

Talk 3.2

Passive coherent combining of two high-brightness tapered laser diodes in a Michelson external cavity

G. Schimmel[1], I. Doyen[1], S. Janicot[1], M. Hanna[1], J. Decker[2], P. Crump[2], G. Erbert[2], P.Georges[1] and G. Lucas-Leclin[1]*

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High-brightness direct diode laser systems are becoming prominent in the laser industry, thanks to their high wall-plug efficiency. As the brightness of single emitters is physically limited, multiple laser diodes need to be combined in order to scale up their performance. Among the different combining techniques, coherent beam combining (CBC) specifically results in a single high-power laser beam with excellent spectral and spatial properties [1,2]. But it can only be achieved in an arrangement that forces the required phase relation between the emitters. We propose a new CBC architecture for the passive phase-locking of a diode laser array that is designed to ensure a stable high-power operation and a high electrical-to-optical efficiency. It uses a common laser external cavity on the back side of the emitters for phase locking, while coherent beam superposition of the phase-locked beams is realized on the front side [3]. As a consequence, a strong optical feedback is achieved on the back facet to maintain the phase-locked operation at high currents, and losses are minimized on the useful output on the front side.

For this experiment, we used two tapered laser devices emitting around $\lambda = 976$ nm [4]. The lasers were mounted p-side up on C-Mount to allow access to both facets. They contain a 2 mm long ridge section, and a 4 mm long tapered section (6° taper angle). The two sections are separately driven by currents I_R and I_T, respectively. After external stabilization, the extracted optical power reaches 4 W at $I_R = 400$ mA and $I_T = 6$ A, corresponding to an electrical-to-optical (E-O) efficiency of 26%. The beam is diffraction-limited along the fast axis; along the slow axis the beam quality factor is $M^2_{4\sigma} \approx 2.5$ at $I_T = 6$ A. The external cavity is based on a Michelson interferometer on the rear-side: the two laser beams are combined on a 50/50 beam splitter (BS), and a diffraction grating at Littrow incidence on one arm closes the external cavity [3]. Since both lasers share the same external cavity, they undergo minimum losses if the two laser beams are in phase at the BS – resulting in constructive interference in the direction of the diffraction grating, and destructive interference on the other BS arm. This external cavity forces phase-locked operation of the two tapered lasers. On their front facet, a 50/50 BS is used as a combiner to perform coherent superposition of the beams.

The maximum combined optical power is 6.5 W at $I_T = 6$ A and $I_R = 400$ mA, corresponding to a combining efficiency $\eta' = 82\%$; the E-O efficiency $\eta_{E\text{-}O}$ is thus $\geq 21\%$. We observe that the external cavity on the rear side acts as a lateral mode filter: the beam quality is improved to $M^2_{4\sigma} \leq 1.3$ when the two emitters are phase-locked. And since the combining stage on the front facets operates as a second spatial filter rejecting high-order lateral modes, the beam quality of the combined beam is further enhanced to $M^2_{4\sigma} \leq 1.2$. Finally with an actual spatial filtering stage on the output beam, we are able to select only the central diffraction-limited lobe of each beam. The measured combining efficiency increases to 92%, corresponding to a combined power of 5.9 W in the filtered beam and a spatial brightness above 500 MW/cm^2/sr.

The short-term stability of the phase-locking is guaranteed by the common cavity, as the lasing frequency passively self-adapts to maintain a zero-phase difference between the two beams on the rear BS. The long-term stability of the CBC cavity is ensured with a semi-active feedback loop implemented on the ridge-section currents of both devices that maintains the combined power at its maximum.

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Talk 3.3

A versatile technology platform for micro-integration of diode-laser based, space compatible modules

Ahmad Bawamia[1], Mandy Krüger[1], Christian Kürbis[1], Wojciech Lewoczko-Adamczyk[1], Christoph Pyrlik[1], Andreas Wicht[1], Achim Peters[1,2] and Günther Tränkle[1]

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We present a new technology platform for compact, robust and energy-efficient semiconductor laser modules that are suitable for field operation and for a deployment in space. Applications include coherent optical communication and coherent manipulation of atoms and molecules, as in optical atomic clocks and matter-wave interferometers.

We report on the integration of two arbitrary laser chips, micro-optics, DC and RF electronics including fiber-coupling into a single-mode, polarization maintaining fiber on a structured AIN substrate within a footprint of 80 x 30 mm². The AlN substrate is encapsulated into a hermetically sealed housing with custom-made feedthroughs for all DC, RF and optical signals.

We present a MOPA module based on this technology that is suitable for laser cooling and atom interferometry with Rb atoms. It consists of a distributed feedback laser (DFB) emitting at 780 nm as master oscillator, and a ridge-waveguide semiconductor amplifier. Moreover, we show that our technology platform is capable of housing very compact and robust spectroscopy modules or frequency-doubled lasers.

Furthermore, we present an ultra-narrow-linewidth semiconductor laser module consisting of a DFB diode at 780 nm optically self-locked to a mode of an external Fabry-Pérot resonator. The unique combination of a DFB diode and external Fabry-Pérot resonator enables a reduction of frequency noise of at least a factor 1000 for all Fourier frequencies above 1 kHz as compared to a standard grating-based extended-cavity laser. The corresponding intrinsic linewidth is of the order of a few Hz.

Session 4

Talk 4.1

Beam Shaping of High Power Laser Diodes for Space Applications

Martin Traub[1], Gerd Kochem[1], Jens Loehring[1], Dieter Hoffmann[1] and Hanno Scheife[2]*

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High power diode lasers are well-established pump sources for solid-state lasers due to their narrow emission spectrum, high efficiency, high reliability and compact setup. Not only terrestrial applications but also space applications benefit from the diode lasers' properties. Depending on the laser to be pumped, different beam shaping concepts like beam transformation and homogenization are necessary to adapt the intensity distribution of the diode lasers to the geometry of the active material.

In this talk, we will introduce different concepts of diode laser beam shaping, and examples of pump module designs will be presented, i.e. designs developed for the Tesat-Spacecom Laser Communication Terminal (LCT), the BepiColombo mission and the MERLIN mission. Furthermore, aspects like material choice as well as mounting and alignment procedures will be covered.

Talk 4.2

Evolution and perspectives of QCW high power laser diodes for space applications

Andreas Kohl

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QCW high power diode laser stacks for pumping of space qualified solid state lasers have made tremendous progress over the last 15 years. Today's lifetime data show that the devices outperform the requirements of space missions. Extensive testing in the frame of different ESA programs has shown that the packaging of the diodes is compatible with the different aspects of space requirement such as proton radiation, operation under vacuum or sustaining harsh environment.

The technology of the components has taken advantage of developments in other fields of applications such as pump diodes for telecom and fiber lasers, defense lasers and pump arrays for high energy class lasers (HECDPSSL).

This talk discusses the evolution of QCW diode stacks over the years and the technology drivers from other fields of applications which helped making them a reliably component well suited for space missions.

Talk 4.3

Space qualified solutions with high-power diode lasers

Ekkehard Werner, Svent-Simon Beyertt, Uli Röllig, Martin Wölz, Valentin Loyo*

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In 2018 within the ExoMars mission a rover is planned to search for organic molecules on mars surface. JENOPTIK developed, tested and delivered a space qualified diode laser module for use as a solid state laser pump source in the analytic unit.

The laser specifications are 808 nm, pulsed operation at 200 µs with 2% duty cycle, 160 W peak power out of a 600 µm fiber and electrically redundant operation. Jenoptik's effort was directed at chosing materials and technologies for operation under space conditions. A lightweight Si/Al alloy was qualified for the first time to make a laser housing. The optics were made from sapphire and space grade glass. The glue technology for mounting the optical elements and the soldering of the window were optimized for robustness and herme-ticity. In total 30 modules were produced, 15 non-flight modules for demanding qualification tests and 15 flight modules to undergo acceptance tests. The qualification included vibration tests (static load and sine vibration 20..25g, random vibration 6 dB / oct, pyroshock 1500 g), thermal vacuum (8 cycles -55 .. 65°C), radiation (proton beam 10 MeV, Co60 20krad) and lifetime test (38 Mshots).

http://exploration.esa.int/mars/48088-mission-overview/

http://www.mps.mpg.de/310479/MOMA/

Session 5

Talk 5.1

Laser diode reliability testing for Space applications

Lip Sun How

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Reliability for Space applications has to face the big challenge to match quantitatively and qualitatively device and mission specifications especially when the device has been qualified for terrestrial purposes. This is especially true for laser diodes that are frequently COTS samples and of various types in terms of materials and assembly.

If mission needs and requirements are quite clearly defined with conditions that vary according to application, it is up to the reliability and also laser diode experts to understand the problematic and devise a set of tests that can simulate the real application on the specific laser diode that is intended to fly.

The European Space Agency through its ESCC 23201 has issued a helpful guideline document for the evaluation programme of laser diode modules. It is not exhaustive and cannot fully reply to the wide range of laser technologies existing in the market. Reliability test optimisation is therefore needed with the implementation of well-dimensioned measurement and test scheme on the specific component, taking into account the budget constraints. On the one hand, the optimum exploitation and understanding of standard optical measurements is essential along with the tailoring of special measurements that can track latent defects. On the other hand, accelerated tests for a specific Space application are designed with respect to the Space mission requirements. Through the illustration of a few cases, performing reliability tests on laser diodes for Space becomes finally a matter of experts understanding fully the response of the specific laser diode to the applied test and measurement stimuli.

Talk 5.2

Testing and evaluation of laser diodes for space applications at ESTEC

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Laser diodes have become almost ubiquitous in ESA's missions, ranging from high power laser diode arrays to pump powerful solid state lasers for in-orbit LIDAR systems, to low power-high stability single emitters for atomic clock applications. Ranging systems for rendez-vouz and docking, Laser Induced Breakdown Spectroscopy to test remotely the composition of rocks, wavelength references for spectrometer calibration and free-space laser telecommunications are just some other examples of the extensive range of application.

Nevertheless, and due to the low number and lengthy development of space missions, the space sector remains a niche market for laser diode producers. The volume of sales does not justify in many cases the immense efforts for product adaptation and qualification for the particular environmental requirements of an isolated space mission, with the associated recurrent cost for construction and dismantling of production/test facilities; this does not guarantee continuity and knowledge building for future missions. In addition, the same device may not available for future missions after all the qualification efforts, due to the fast product cycle required for commercial competitiveness.

In order to support ESA projects and the European industry, a laser diode test facility has been put in operation at the European Space Research and Technology Centre, ESTEC, within the Optics and Optoelectronics Laboratories. The mission of the laboratory and its personnel is to perform assessments and provide advice in emergency situations, design and conduct proof-of-concept experiments and, most importantly, guarantee continuous knowledge building for future missions.

In this presentation, an overview of the current laser diode test facilities will be presented, followed by some examples of past and current test campaigns involving high and low power laser diodes.

Talk 5.3

Testing of laser diodes for space applications at ALTER

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This presentation will include test setup developments performed at ALTER and some results during the testing of laser diodes for space applications focusing on test methodology. The necessity of a proper thermal control and all the related issues, such as the thermal design of the packaging, including the location of the temperature sensors near the laser diode and the actual manufacturing of the package with an optimized thermal resistance will be considered. The thermal resistance of each sample should be measured for every sample as this has a direct impact of the characteristics of each laser and on the reliability. A real example of the problems related to thermal management due to a pour manufacturing of the package will be presented. Regarding test methodology the emphasis will be focused on getting the maximum information from the samples under test by considering monitoring during test as the baseline for getting a deeper knowledge of the behavior of the laser. ALTER setups used for monitoring electro-optical characteristics of the lasers during radiation and thermal vacuum tests will be presented.

Session 6

Talk 6.1

Discrete Mode Laser Diodes emitting at λ~689 and 780nm for Optical clocks applications

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Compact monolithic single-mode red emitting diode lasers are still not readily available for many wavelengths. Strontium lattice clock are one of the most widely investigated optical clocks worldwide and the transitions wavelengths required are in the red and blue wavelength spectral region. The current state of the art technology uses external cavity laser diodes (ECDL) and frequency doubling crystals in order to hit the desired wavelength with external amplifiers used to meet the power requirements. Compact rugged monolithic narrow linewidth laser sources operating in the red and blue wavelengths are a key technology that could be used to replace all these costly, energy inefficient and vibration sensitive components. Here, we present results on Discrete Mode (DM) diode lasers emitting near the Strontium second stage cooling wavelength of 689 nm. Work on laser diodes at 780nm for Rb clock will also be presented.

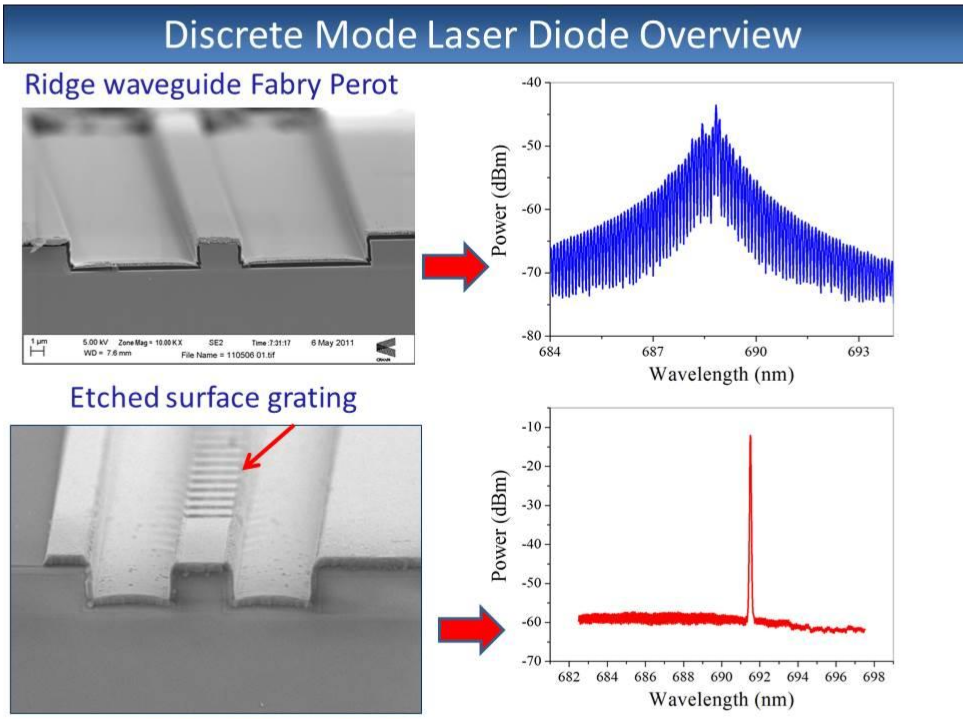

Fig. 1 Electron micrograph of Fabry Perot laser cavity (top left) and Discrete Mode Laser, fabricated by etching a surface grating into the laser ridge (bottom left) along with spectral characteristics of typical visible laser with and without etched filters (top and bottom right respectively)

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Talk 6.2

Dual-frequency VECSEL for atomic clocks using coherent population trapping

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Atomic frequency references provide high-precision stable signals, which are crucial in the most demanding applications as high bitrate communication networks, high-end inertial navigation, or satellite positioning. In this context, coherent population trapping (CPT) is an interesting technique for the development of compact atomic references [1]. It is based on the coupling of the two hyperfine ground states of an alkali atom, through excitation to a common atomic level, by two phase-coherent laser fields. In the case of Cs atomic clocks, it needs two laser fields at 852 or 894 nm with a frequency split of 9.2 GHz. One way to obtain those laser fields with low intensity- and frequency-noise is to use the dual-frequency and dual-polarization emission of an optically-pumped vertical external-cavity semiconductor laser (OP-VECSEL). This emission is induced by intracavity birefringent components which induce a controllable phase anisotropy within the laser cavity and force emission on two cross-polarized longitudinal modes.

The semiconductor active structure consists in $GaAs/Al_{22\%}Ga_{78\%}As$ quantum wells on top of a high-reflectivity Bragg mirror. It is pumped with a high-power laser diode emitting up to 1 W at 670 nm. The 10 mm long cavity includes a birefringent–YVO_4 plate which induces a 50 µm separation modes inside the semiconductor structure, an electro-optic crystal (MgO:SLT) to tune continuously the frequency difference, and a Fabry-Perot etalon made of a 100 µm YVO_4 plate. The birefringence of this etalon forces the frequency difference between the modes at 9 GHz. The whole laser cavity is mounted in a compact and thermally-stabilized casing ($90 \times 90 \times 50$ mm^3).

The dual-frequency laser emission is stabilized using two separated servo-loops. First the wavelength of the ordinary polarized mode is locked onto the Cs D2 line using a saturated absorption set-up with feedback to a piezo-transducer glued on the output coupler. Then the frequency difference between the cross-polarized lines is locked on a local oscillator using electronic feedback to the intracavity electro-optic crystal. The detailed characterization of the noise properties of the laser emission is done with both servo-loops operating. The relative intensity noise (RIN) is flat from 100 Hz to 100 kHz at a level of -110 dB/Hz, limited by the pump RIN transfer to the laser. The frequency noise is limited by mechanical resonances below 1.5 kHz and by thermal fluctuations induced by the pump source above. The residual phase noise of the beatnote signal is reduced to a level below -90 dBrad^2/Hz on the frequency range 100 Hz – 10 MHz [2].

The performance of this laser source is already adequate for a CPT atomic clock. The noise performance of the laser result theoretically in a clock stability of 1.6×10^{-12} at 1 second (Allan standard-deviation), limited by the laser RIN. This limit can be overcome using power stabilization loop and/or intensity normalization of the CPT signal [3]. We now aim at targeting a clock stability of 3×10^{-13} at 1 second, in order to tackle the actual performance vs size trade-off of CPT atomic clocks.

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Talk 6.3

Optoelectronic modules and sub-systems for laser-based satellite communications

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We present progress on the design, development and qualification of optoelectronic modules and sub-systems for use in space applications. We focus on high-power laser sources and optical fiber amplifiers that are key enabling elements of next-generation high-capacity laser communication terminals.

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