BRITESPACE

High Brightness Semiconductor Laser Sources for Space Applications in Earth Observation

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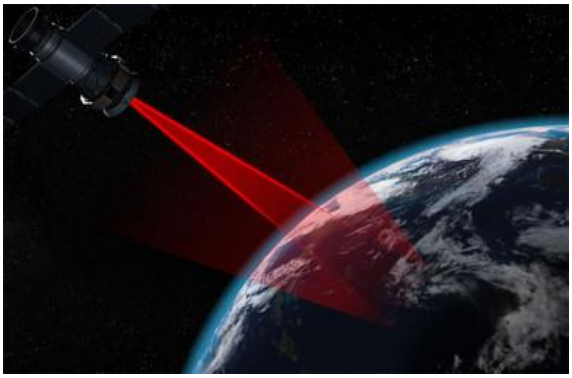
Grant Agreement Number 313200 funded by the EC FP7-Space

SECOND YEAR PUBLISHABLE REPORT

Description of project context and objectives.

BRITESPACE project has been conceived for the design, realization and validation of a semiconductor laser transmitter to be used for the detection of carbon dioxide in future Earth Observation space missions. The proposed system consists of an Integrated Path Differential Absorption (IPDA) lidar based on a fully integrated semiconductor Master Oscillator Power Amplifier (MOPA). The project aims to demonstrate that high brightness semiconductor lasers can be used as optical sources in space applications which require simultaneously high power, beam quality and spectral purity.



Artistic vision of BRITESPACE space-borne LIDAR mission.

An IPDA lidar basically works on the use of two different wavelengths for the measurement of CO_2 concentration: one wavelength is strongly absorbed (λ_{OFF}) and the other is lightly absorbed by the gas (λ_{ON}). In BRITESPACE the laser light is Randomly Modulated in Continuous Wave (RM-CW) in order to allow the determination of the height and differential absorption of the air column under measurement.

The main objectives of BRITESPACE Project can be summarized as follows:

- Definition of the requirements of the semiconductor laser source for future space-borne IPDA lidar mission.
- Definition, simulation and development of the complete RM-CW lidar system
- Design, fabrication and testing of the MOPA laser chip.
- Design, fabrication and testing of a space compatible Laser Module including the MOPA laser chips.
- Implementation of a Frequency Stabilization Unit and control electronics in the Laser Transmitter
- Laser Transmitter Performance Verification
- Integration of the Laser Transmitter into the complete PRM IPDA lidar system
- Test of the complete system on the ground in comparison with a pulsed IPDA lidar system

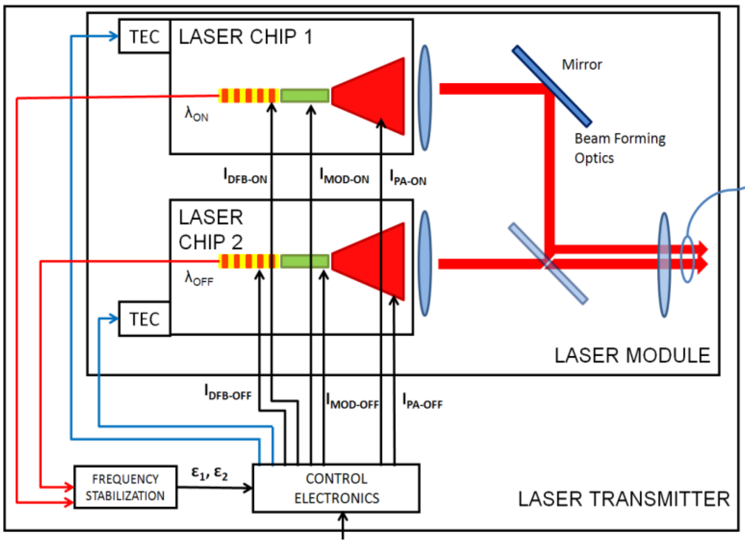
BRITESPACE Consortium:

Universidad Politécnica de Madrid (UPM), Spain	www.upm.es
III-V Lab, France	www.3-5lab.fr
Fraunhofer Institute for Laser Technology (ILT), Germany	www.ilt.fraunhofer.de
Alter Technologies (ATN), Spain	www.altertechnology.com
Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany	www.dlr.de
University of Bristol (UBRIS), United Kingdom	www.bris.ac.uk

Main results achieved during first and second year

BRITESPACE Laser Transmitter architecture

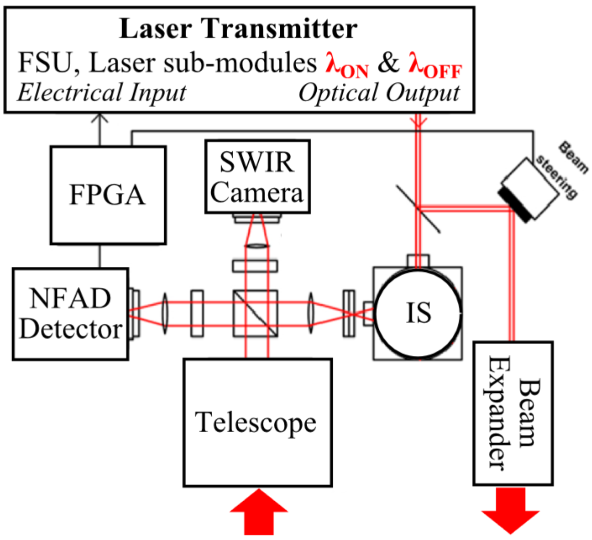
The architecture of BRITESPACE Laser Transmitter has been defined according to the performance requirements imposed by the implementation of the final IPDA lidar. The most challenging tasks are high power output, good beam quality and high frequency stabilization. The core solution addressing these issues is the use of two fully integrated semiconductor Master Oscillator Power Amplifiers (MOPAs), with a novel three-section structure, consisting of a Distributed Feedback (DFB) laser, a modulator and a tapered amplifier section. Each MOPA works at one of the two emission wavelengths required for CO_2 detection. Long term frequency stability, low frequency noise and tunability is assured by a Frequency Stabilisation Unit (FSU) with offset frequency, locking scheme and opto-electronic feedback referred to a CO_2 reference cell. The output beam profile is optimized by the geometrical design of the MOPAs, and the two output beams are collimated, combined and sent to output with the use of a specific beam forming optics layout.



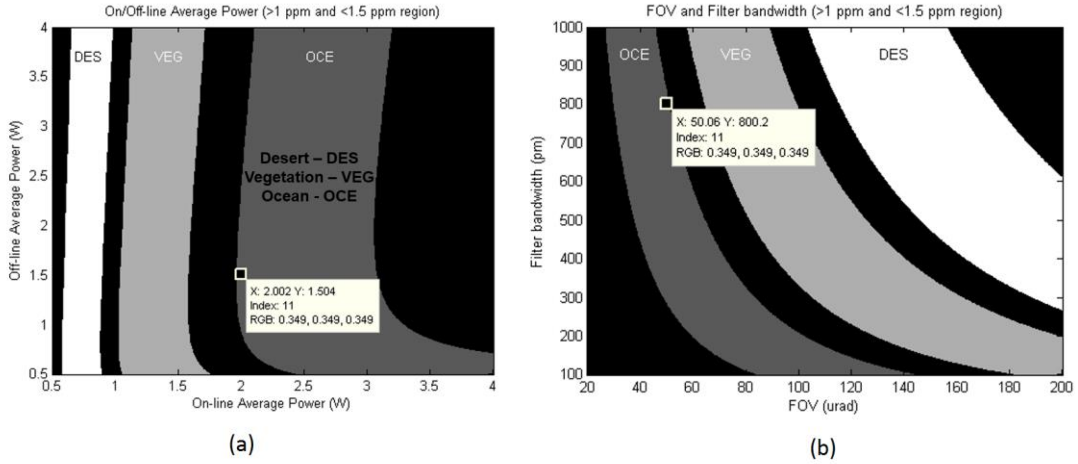
BRITESPACE IPDA lidar system.

The Laser Transmitter is integrated into the complete BRITESPACE IPDA lidar prototype designed by UBRIS. The output beam from the transmitter is split in two branches: one portion of the beam is sent to the beam expander and then to the atmosphere and the other is used as reference for the calculation of gas concentration, by comparison with the received signal. The reflected light from Earth ground is collected with a telescope and alignment issues are addressed with the use of a short wave infrared (SWIR) camera.

A very high sensitivity detector based on InGaAs negative feedback avalanche diodes (NFAD) is used for single photon counting of the received signal. Narrow band optical filter limits the unwanted contribution of reflected light from ground. The modulation sequence and the decorrelation process required by the RM-CW format are implemented with a Field Programmable Gate Array (FPGA).

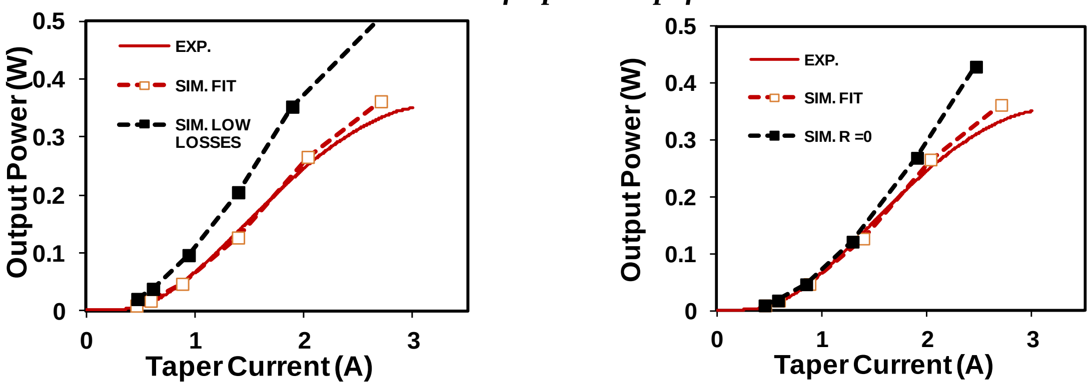


Simulations of Random Modulation Continuous Wave (RM-CW) lidar



A new approach has been applied by UBRIS to simulate the performance of the proposed RM-CW lidar system. The results indicate that for the proposed system architecture, major noise contributor is the ambient light shot noise and the detector dark count in the RM-CW scheme. From this, to use a narrow band-pass filter at the receiver and a single photon detector is needed. The trade-off between two selected parameters for typical application parameters are shown in the figure: the highlighted areas indicate the range of acceptable retrieval precisions (0.5-1.5ppm) for three types of ground surfaces. The labelled data points represent optimised configurations and are selected as the baseline.

Simulation of tapered amplifiers



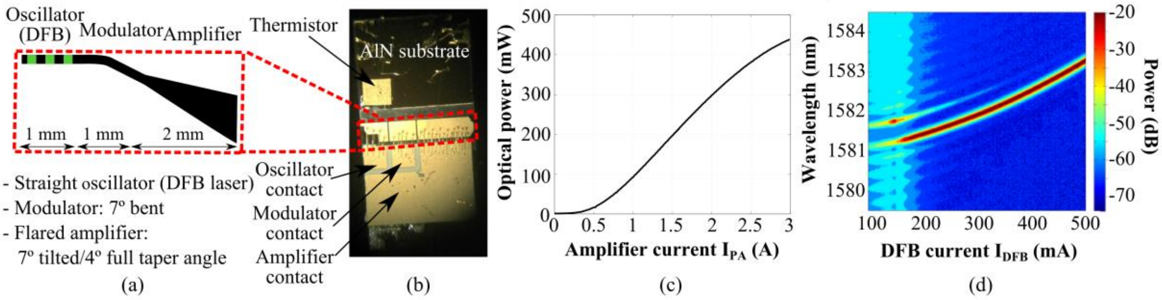
A Quasi-3D simulation tool for tapered lasers was adapted by UPM to tapered Semiconductor Amplifiers in order to optimize the geometry of the devices. The results indicate better beam properties in large area devices at expenses of higher driving currents. The figure shows a comparison of the experimental and simulated output power of a MOPA as a function of the taper current. Left: effect of the scattering losses in the fitting. Right: Effect of the contact resistance in the fitting. The best fitting (open squares) was achieved with high scattering losses and contact resistances. This work has been recently published [Tijero et al. Opt. Quant. Electron., DOI 10.1007/s11082-014-0108-8, 2015].

Definition of spectral performances

The selection of the appropriate CO_2 absorption line and the definition of the requirements on spectral performances of the BRTIESPACE laser transmitter was performed by DLR (see attached table)

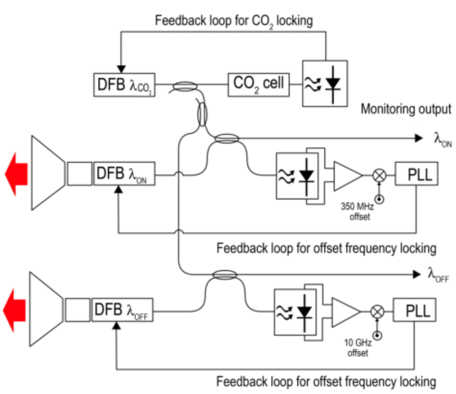
Nominal sounding frequencies	○ *on-line channel* ν_{on} *190.704710 THz.* ○ *off-line channel* ν_{off} *190.694980 THz.*	
On-line channel tunability		*+/- 350 MHz.*
On-line and off-line frequency stability (over 10s)	*maximum*	*desirable*
○ *on-line channel*	*0.1 MHz*	*0.02 MHz*
○ *off-line channel*	*100 MHz*	*20 MHz*
Spectral linewidth		*≤ 60 MHz*
Linewidth knowledge		*+/- 5 MHz*
Effective Spectral Purity		*≥ 99.9%*

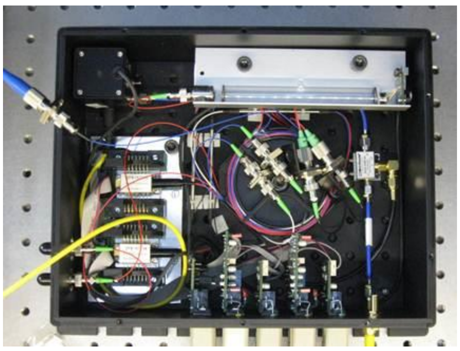
MOPA Devices



III-V Lab has fabricated a 3-section monolithic MOPA on InP (Fig. (a) and (b)). The 1st section is the oscillator (DFB laser), the 2nd section is a modulation section (MOD) and the 3rd section is a flared power amplifier (PA). Best results were obtained with a bent modulator section in order to reduce the facet reflections at the end of the amplifier. We observed that this architecture is more stable than the straight one, where all the sections are aligned. We observe stable emission around 1583 nm with a side mode suppression ratio better than 45 dB. Fig. (c) shows the optical power as a function of the amplifier current I_{PA} (I_{DFB} = 0.4, I_{MOD} = 300 mA). The maximum optical power is 420 mW at 18ºC (I_{PA} = 3 A); by decreasing the temperature to 12 and 6°C, we have obtained a maximum output power of 510 and 600 mW respectively. Fig. (d) shows the optical spectra dependence on I_{DFB} for I_{MOD} = 300 mA and I_{PA} = 3 A. The laser exhibits multimode operation close to the threshold (DFB laser without phase-shift) and single-mode operation without any mode hopping from 300 to 500 mA.

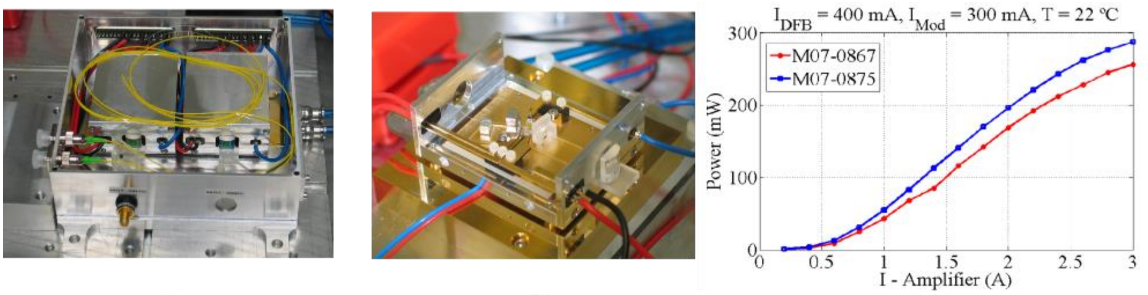
Development of Frequency Stabilization Unit





The first design of the Frequency Stabilization Unit (FSU) employs an offset frequency locking scheme referenced to a CO_2 gas cell for frequency stabilization of the two MOPAs inside the BRITESPACE laser transmitter. A first prototype, based on two commercially available lasers is being characterized at ATN.

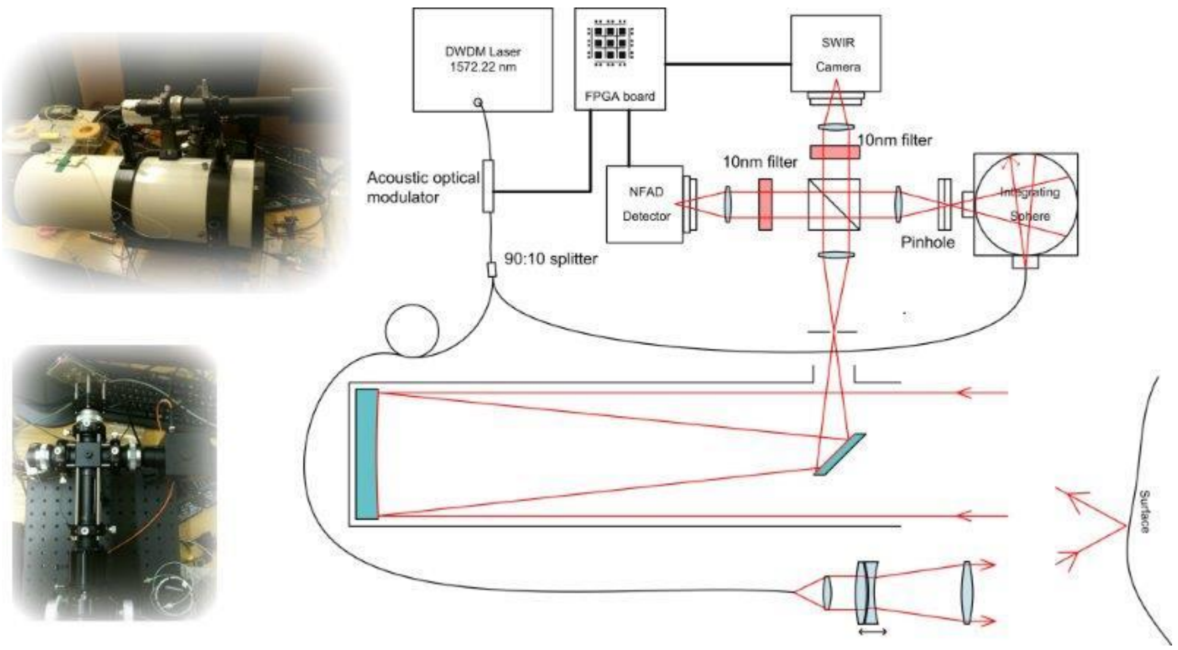
Laser Module



(a) (b) (c)

The BRITESPACE laser module (a) by ILT consists of two sub modules, each of them housing one laser chip (b). The sub-modules provide electrical access and temperature control elements to each MOPA. Beam forming optics and photodiodes are placed in the laser module, where the beams are collimated and combined and sent to the output. Fig. (c) shows the output power from the laser module while varying the amplifier current.

Development of the receiver



Two prototype systems have been successfully built in year one, (a) a laser ranging system using pulsed visible laser which demonstrates the validity of the proposed modulation scheme. (b) a fibre based IR DIAL simulator that proves the random modulation scheme is capable of achieving ppm resolution under the expected space-borne operating conditions. The finalised system (shown in the Figure) has been completed in year two. It is a standalone Lidar with a low power laser, good for 200 meter range. When integrated to the BRITESPACE MOPA, DIAL functionality can be achieved with 2 km range to demonstrate the concept.

Workshop on "Laser Sources for LIDAR Applications"

The first BRITESPACE workshop was held in Deutsches Zentrum für Luft- und Raumfahrt (DLR) Oberpfaffenhofen, Institut für Physik der Atmosphäre, Weßling, Germany, 25-26 November 2014. It was devoted to promote the contact between developers and manufacturers of laser sources with developers and users of LIDAR sytems. The number of participants on site was 40, coming from 10 different EU countries. 16 participants came from industry. The number of institutions/companies with representation at the workshop was 29, and the number of talks given was 18, with 11 invited. It was also available the remote assistance and participation. The number of remote assistants was 32, with participants from 8 countries worldwide. More details at www.britespace.eu/workshop

Expected final results and their potential impacts and use

The main expected final result is the demonstration of semiconductor lasers as convenient optical sources in such an important space application as remote sensing of atmospheric CO_2, which simultaneously requires high power and beam quality, and excellent spectral properties. Other relevant results are the demonstration of different key technologies for active sensing (detectors, system, transmitters). These results have potential impacts at different levels:

- At technological level, this would pave the way for the direct use of semiconductor lasers in other space applications, improving the capacity of European companies and research centres to lead future innovations in this field.
- At scientific level, the high degree of innovation of the project would provide new advances in the design and applications of Photonic devices and systems.
- At social level, the advances in technologies enabling a faster, cheaper and more reliable monitoring of the greenhouse gases distribution in the atmosphere should help in the struggle against global warming.