Space Technologies Studies 2018
Results

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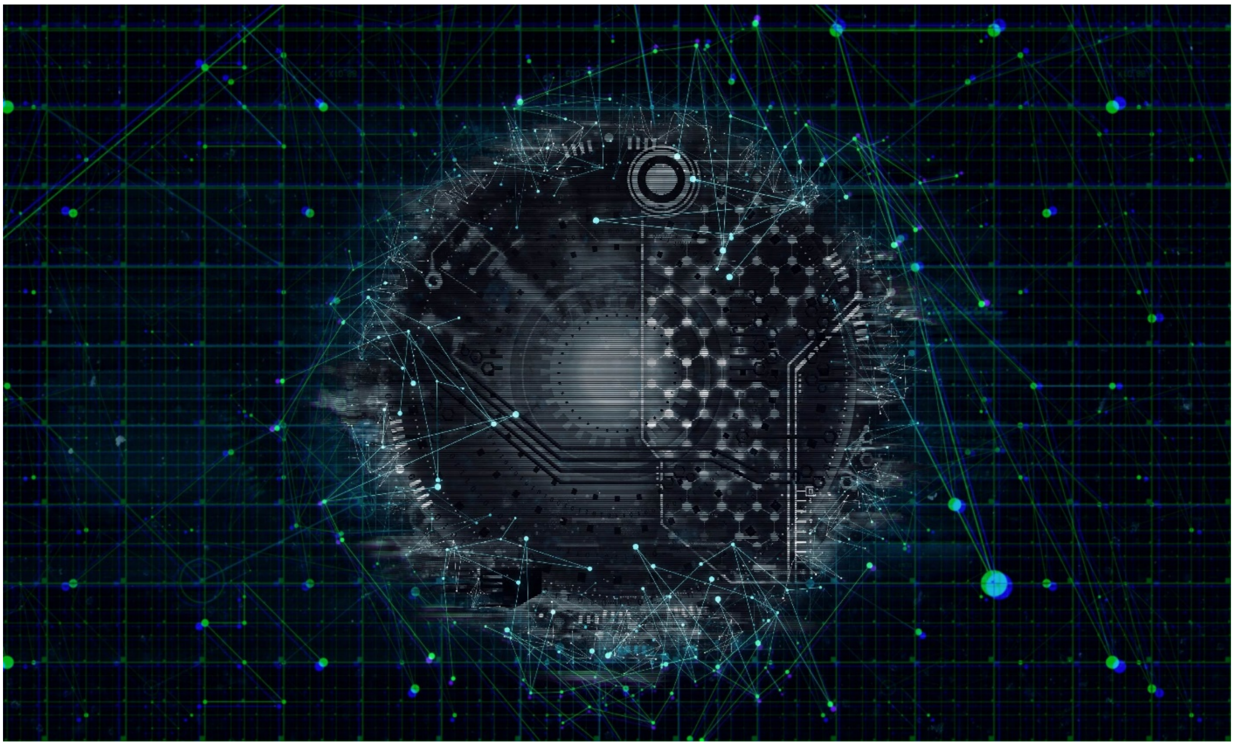
SwissTech Convention Center
Lausanne, Switzerland



Schweizerische Eidgenossenschaft
Confédération suisse
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Swiss Confederation

Federal Department of Economic Affairs,
Education and Research EAER
State Secretariat for Education,
Research and Innovation SERI
Swiss Space Office

swiss space center

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Dear reader,

you will find in this document the summary of the eleven projects funded under the call for proposals issued in 2018 by the Swiss Space Office of the State Secretariat for Education, Research and Innovation of the Swiss Confederation (SERI/SSO) to "Foster and promote Swiss scientific and technological competences related to space activities".

Following the four previous successful editions of the MdP Call for Proposals (Mesure de Positionnement), launched since 2010 to reinforce the technological and scientific capabilities of Swiss entities in the space sector, the SERI/SSO again initiated the MdP Call for Proposals in 2018. The goal of the "positioning measure", which is part of the National Complementary Activities for space, is to encourage the emergence of projects in space technology. Based on the same principles, it aims to develop niche sectors and to better position Swiss industrial and academic entities, particularly in the frame of ESA activities and other international programmes such as the EU Research Framework Programmes.

The SSO mandated the Swiss Space Center to implement the Call for Proposals 2018.

Objectives

The main objectives of this Call for Proposals are to foster and promote Swiss technological and scientific competences that have a clear potential for space products and services/applications. More particularly, this Call for Proposals aims:

- to foster the development of innovative ideas and new products related to the space sector;
- to promote the collaboration between Swiss industrial and academic partners to obtain a more stable and better structured Swiss space landscape;
- to better position Swiss industry with regard to future European and worldwide activities so as to be ready to submit competitive bids when the respective calls are published;
- to increase the technological maturity of ideas developed by academia and to promote competitive space products thanks to partnerships with industry.

<u>List of the projects:</u>

The content related to each project is the property and sole responsibility of the corresponding authors. For any questions, you are invited to contact them directly.

Diamond Mirror VECSELs for satellite power and data beaming

Manufacturing lasers to send optical power and data to Low Earth Orbit satellites

Competences:

LakeDiamond is a Swiss company manufacturing diamond-based optoelectronic devices. In particular, LakeDiamond specializes in designing and fabricating high-power, high quality lasers, building up on fruitful research performed at EPFL. LakeDiamond provides its own CVD diamond, grown in dedicated plasma reactors.

The Quack research group on Photonic Micro- and Nanosystems at EPFL provides expertise in the design, manufacturing and characterization of advanced photonic micro- and nanosystems. The research in engineering activities evolve around the central pillar of exploiting physics and mechanics at the micro- and nanoscale for advanced photonics and optics. Advanced micro- and nano- fabrication & -engineering are combined with system level integration approaches aiming to address emerging applications with high performance solutions (e.g. photonics for information and communication technologies), for highly miniaturized systems (e.g. diamond photonics for space or sensing), or for emerging concepts such as programmable photonics for physical implementation of neural networks (e.g. silicon photonic MEMS).

Summary:

The purpose of the project is to design and manufacture high-power, high quality VECSELs (Vertical External Cavity Surface Emitting Lasers). The specific use of these lasers envisaged is the transmission of power and data to flying vehicles and objects, such as drones, planes or satellites.

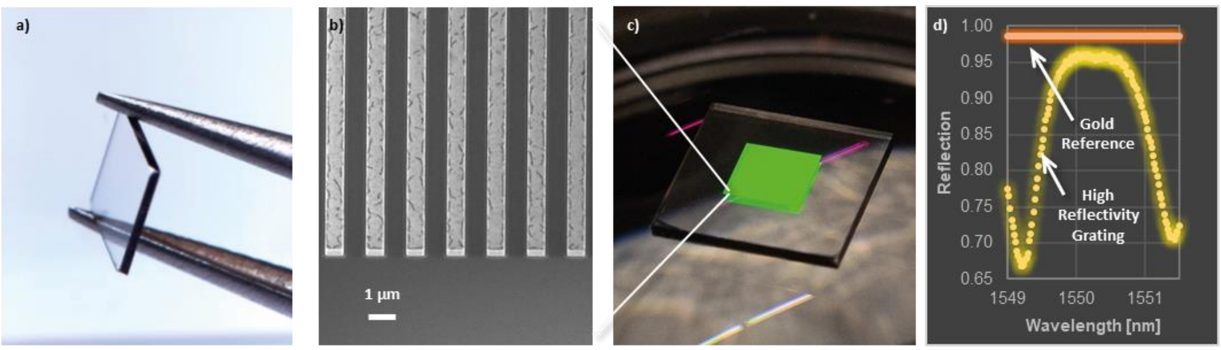

Figure 1: *a) High quality single crystal diamond manufactured by LakeDiamond, b), electron microscope recording, c) photograph, and d) measurement results of the high reflectivity grating in single crystal diamond.*

LakeDiamond
THE BRILLIANT SIDE OF TECHNOLOGY

EPFL

The beam quality factor suggests that using a telescope as beam expander, the diameter at a LEO satellite would be a few meters.

The key elements developed in the framework of this project are diamond mirrors designed and fabricated by the group of Prof. Niels Quack. As diamond is the best conductor of heat, with a very good transparency, these diamond mirrors also serve as heat dissipaters in the highly miniaturized VECSEL structure. LakeDiamond possess a world record for diamond VECSELs emitting at 1550nm, a wavelength combining good transmission in the atmosphere and optimal eye safety.

Results:

Monolithical diamond mirrors with reflectivities greater than 95% were designed and fabricated. These mirrors consisted in sub-wavelength gratings directly etched in diamond as shown in Figure 1.

In the framework of the project, a fully functional laser prototype was also implemented, emitting 6W in continuous wave, limited by pump power. A packaged version emitted 2W in continuous wave, also limited by pump power.

Patent Filing: *Gergely Huszka, Marcell Kiss, Niels Quack, "Optical Element with High Reflection at a First Wavelength and Low Reflection at a Different Second Wavelength", PCT/IB2019/055441, 2019.*

Scientific Publication: *Gergely Huszka, Nicolas Malpiece, Mehdi Naamoun, Alexandru Mereuta, Andreï Caliman, Grigore Suruceanu, Pascal Gallo and Niels Quack, "Single crystal diamond gain mirrors for high performance vertical external cavity surface emitting lasers", under review, 2020.*

Conclusion:

The study was very conclusive, as a packaged diamond VECSEL has been implemented, with laser power reaching 2W in continuous wave emission. The pump/emission characteristics suggest 10W can be reached for a single element.

As these lasers can easily be put in parallel, given their low footprint, 10 by 10 matrices can be implemented in a near future, with emission up to 1kW.

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IntegrAted eLectro-OptIc modulators in Space-based laser transmitters (ALOIS)

"A demonstration of electro-optic modulators that optimize size, weight and data rates of current space communication channels"

Competences and Background

The two partners of the ALOIS project are the Optical Nanomaterial Group (ETHZ-ONG) in the Institute for Quantum Electronics at ETH Zurich, and Thales Alenia Space in Zurich (TAS).

The ETHZ-ONG is part of the Department of Physics, located at the ETH Hönggerberg campus. The goal of the ETHZ-ONG is to understand the behaviour of metal-oxide materials at the nanoscale to develop compact devices for optoelectronics or imaging applications. The research focuses on strategies to enhance electro-optic and nonlinear optical signals in nanostructures as well as imaging techniques based on multiphoton processes for developing new types of microscopes to characterize materials.

TAS has demonstrated a high level of competence in several projects involving engineering, testing and production of optics and electronics, such as laser terminals for broadband inter-satellite communications, optical harnesses for satellites, laser altimeters for planetary research, radiation monitors and front-end electronics for various sensor (including CCD readout).

Summary

The ALOIS work was inspired by the activities of the ONG group in integrated lithium niobate electro-optic modulators. Together with the TAS team's expertise in inter-satellite communications, the goal of the MdP2018 was to study the feasibility of a new generation of electro-optic modulators in space.

The baseline concept is to fabricate electro-optic modulators on thin-film lithium niobate. Instead of Mach-Zehnder modulators, which represent the typical modulation configuration with a length of few millimetres, the MdP2018 explored the use of distributed Bragg reflectors (DBR) due to their smaller footprint (less than 0.5 mm lengths), thus significantly reducing the size and weight of current electro-optic modulators in space.

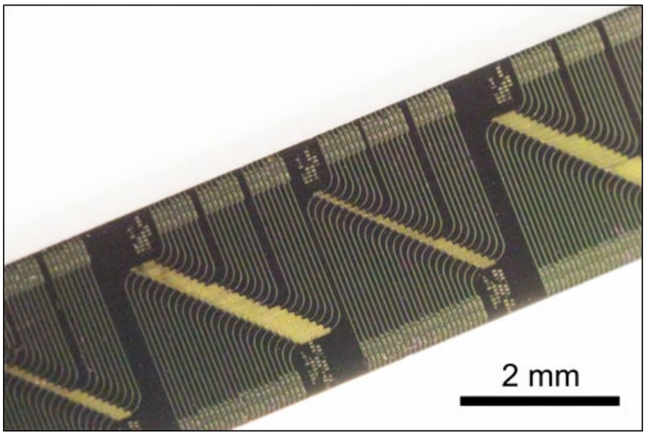

Figure 1. Photograph of a single chip with multiple electro-optic modulators fabricated during the ALOIS-MdP2018 project. Each set contains 24 Bragg modulators.

TAS identified the requirements for a successful space performance, for instance the SWIR spectral range for inter-satellite communications (in particular, the C-band), and the ETHZ-ONG team fabricated the devices (Figure 1).

The ALOIS study demonstrated the concept-proof of DBR electro-optic modulators in space. Figure 2 describes the device operating principle. The DBR introduced a well-defined resonance in the wavelength spectrum with 30 dB as extinction ratio (Figure 2a), which was later modulated with a radiofrequency (RF) electric signal due to the intrinsic electro-optic properties of lithium niobate. The RF modulation could reach 10 Gbit/s data rates with clear open eye diagrams (Figure 2b). The new concept of DBR electro-optic modulators allows to parallelize multiple communication channels with a minimal footprint while maintaining excellent data rates in space and competitive power consumptions.

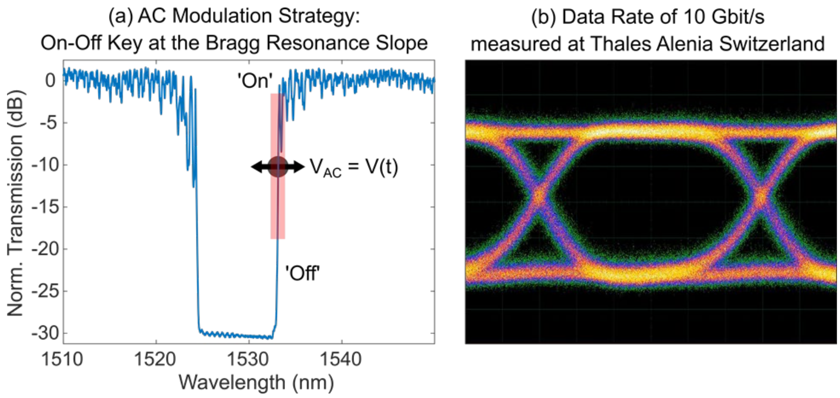

Figure 2. Modulation strategy for the distributed Bragg reflectors. (a) Measured Bragg resonance of a Bragg device fabricated at ETHZ-ONG. The voltage modulation (on-off transmission) should be applied to the steepest point of the Bragg resonance slope (highlighted red area). (b) Open eye diagram of the same ETHZ modulator measured at TAS at a data rate of ~10 Gbit/s. The signal-to-noise ratio (SNR) was ~13 (equivalent to ~22 dB).

Conclusion

The ALOIS team has demonstrated electro-optic modulators based on the DBR geometry. Although the ALOIS demonstration still has a low technology readiness level (TRL), its outcome opens the way towards commercialization of highly integrated electro-optic modulators with enhanced performance in space applications.

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ThalesAlenia Space — a Thales / Leonardo company

ETH zürich

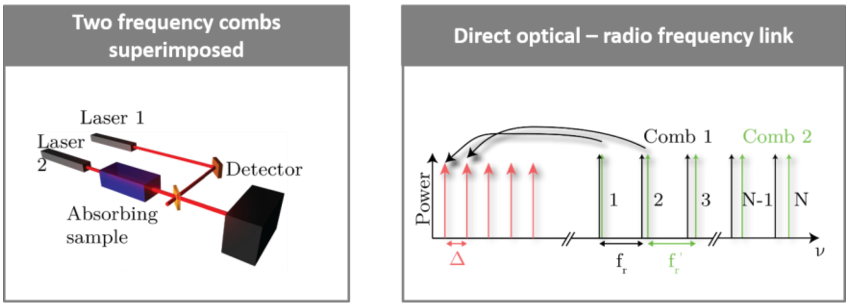
low-COnSumption Mid-Infrared dual-Comb Spectrometer (COSMICS)

Major improvements of mid-infrared dual comb-based spectrometry by frequency control and stabilization combined with advanced processing

Competences:

The two partners involved in the COSMICS project are IRsweep AG and the Laboratoire Temps-Fréquence (LTF) at the University of Neuchâtel as industrial and academic partners, respectively.

IRsweep is a company founded in 2014 that pioneered dual quantum cascade laser (QCL) comb spectroscopy, a powerful tool for broadband high-resolution and precision spectrometry in the mid-infrared (MIR) spectral region, based on compact semiconductor QCL comb laser sources. IRsweep's spectrometers are being increasingly used in stand-off detection, open-path detection and other applications, in the fields of, e.g., chemistry, biology, or combustion, due to its unique properties in measurement speed.
LTF is a leading research laboratory in Europe in the field of time and frequency metrology and laser stabilization. Among its vast field of expertise, it has a longstanding experience in the development, characterization and stabilization of various types of optical frequency combs and single-mode lasers, in particular for noise analysis and reduction in MIR QCLs.



Left: Scheme of principle of a dual-comb spectrometer. Right: frequency down-conversion of the optical spectrum to the RF domain via the multi-heterodyne signal (red).

Summary:

Dual-comb spectroscopy is a type of Fourier-transform spectroscopy that does not use any moving part and can perform measurements at a much higher speed and with a much higher spectral resolution than established technologies. It makes use of two independent frequency combs, each made of equally spaced laser lines, with a slightly detuned mode spacing that interfere on a photodiode, producing a multi-heterodyne beat-note signal in the radio-frequency (RF) domain, which is a down-conversion of the comb optical spectrum. The compactness, simplicity of operation and high degree of integration of QCL combs make them the most promising candidate for dual-comb spectrometers in the MIR spectral region that have a high potential for space-oriented applications. However, the current IRsweep's instrument is too large and power consuming for the space sector. The COSMICS project aimed

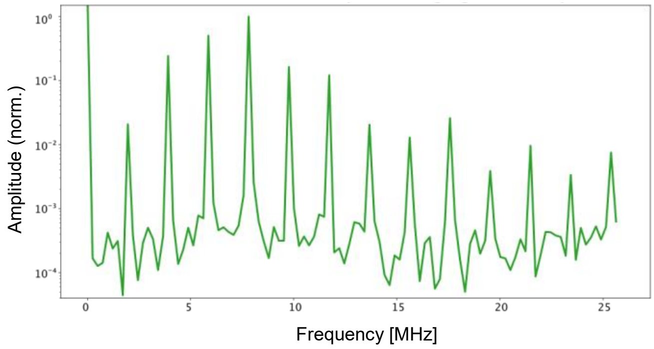
IRsweep

unine UNIVERSITÉ DE NEUCHÂTEL

at advancing the company's existing dual-QCL-comb technology towards a considerable reduction in the required operating power, a large fraction resulting from the computationally heavy data processing that requires the use of a graphics processing unit, and a simultaneous substantial improvement in the obtainable signal-to-noise ratio of the measurements. These challenges were successfully overcome by frequency control of the QCL comb spectrum and noise reduction of the multi-heterodyne RF beat-note signal, combined with a new processing approach based on coherent averaging.

Results:

While QCL comb sources had been operated in free-running mode so far in IRsweep's spectrometer, different approaches were investigated to achieve a mutual coherence between the two QCL combs. The most promising approach was implemented and a frequency stable harmonic multi-heterodyne comb in the RF domain was achieved based on a suitable noise cancellation electrical scheme, meaning that all modes of the RF comb correspond to exact multiples of the difference in mode spacing of the two QCL combs. Furthermore, a coherent-averaging algorithm was developed and applied in combination with the achieved stable harmonic multi-heterodyne RF comb to successfully demonstrate a reduction of the computational power required for data processing in the IRSweep's spectrometer by a factor of 12. A large improvement in the measurement signal-to-noise ratio by a factor of 20 resulting from the coherent-averaging process was also demonstrated.



Harmonics RF comb spectrum averaged over 500 μs and obtained by heterodyning two QCL combs, applying the frequency control scheme developed in the project.

Conclusion:

Thanks to a close and fruitful collaboration between the partners, the project has been highly successful and the outcomes fulfil all the initial objectives. The developed techniques and technologies will now be applied to IRsweep's spectrometers, improving their capabilities. It will reinforce the company position in the worldwide market and strengthen the European lead in QCL comb technology, advancing it to the next level by working on the integration of such sources into space and industry relevant sectors.

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BMG Flex

Fatigue investigations of BMG for space flexure applications

Competences:

Main Applicant (Academic):

Laboratory of Thermomechanical Metallurgy (LMTM)

Long standing expertise in recrystallization and grain growth, and thermomechanical testing + equipped with SLM machine

Industrial Partners:

Experience and competences in the development of compliant mechanisms, structural behavior and fatigue testing for space applications

Knowhow and competences in bulk metallic glasses like science, alloying, forming, testing and analysis

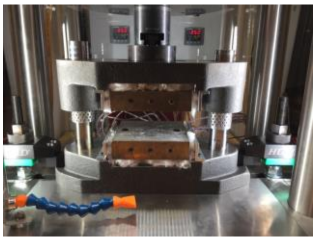
Summary:

Almatech developed and patented an innovative design of flexure (Almaflex) that is capable of large rotations up to 70° for infinite lifetime. As no lubricant nor wear occur, it is a clean and maintenance free component for lots of space applications like waveguide switch, scanning mechanism, laser terminal… It demonstrates a stable mechanical behaviour over lifetime and can even be actuated at resonant frequency to minimize power budget. As Almaflex relies on bending of blades, strains have to be maximized and thus metallic glasses have been identified as a potential improvement of the flexure performances in terms of angular rotation, lifetime and volume.

In order to assess the benefits of bulk metallic glasses for this application, fatigue behaviour had to be investigated. Two manufacturing processes have been selected: additive manufacturing (SLM) & Thermo-plastic forming (TPF). Additive manufacturing offers great capability of production of complex parts. However, challenges intrinsic to the process and metallic glasses required a comparison with the benchmark.
The main objectives of this project are:

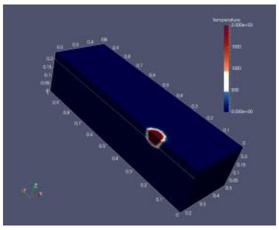
- Selection of best material candidates through:
    - Literature review (LMTM)
    - Material specification definition (Almatech)
    - Samples production optimization (LMTM & PX Group)
- Production of metallic glasses samples
    - Thermo-plastic forming (PX Group)
    - Additive manufacturing SLM (LMTM)
- Performance Test: fatigue tests at Almatech

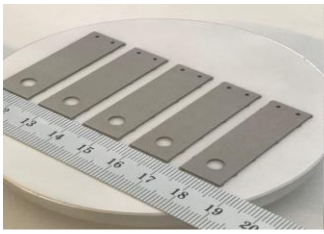
Samples have been produced by SLM and TPF for fatigue testing on a dedicated shaker designed by Almatech.



TPF samples are produced from bulk metallic ingots heated between their glass transition temperature and their crystallization temperature while pressed to the desired thickness. Optimisation of the process parameters has been performed within the project to provide amorphous samples.

SLM parameters optimisation has first been done using simulation to refine laser power, spot size, layer thickness, hatch distance… and then verified on SLM produced samples thanks to XRD to assess amorphous character of these samples





Conclusion:

Fatigue tests performed on the produced samples via TPF and SLM are below expectations at this stage. Nevertheless, it has to be noted that bulk metallic glasses are very sensitive materials to process. In that sense, improvement ways have been identified to improve fatigue behaviour: removing porosities, potential nano-crystals non detectable via XRD, presence of oxides and oxygen content in the powder, potential residual stresses and micro-cracks. At this stage, investigated manufacturing processes are not mature enough for the Almaflex application. However, there is still a potential improvement for the application in the future as it has to be noted that LMTM is the first European actor to have investigated fatigue in printed metallic glasses.

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LMTM LABORATORY OF THERMOMECHANICAL METALLURGY almatech PXGROUP

PrintHeaters

"Printed Heaters on CFRP and Aluminium Structures for Space Application"

Competences:

APCO Technologies SA is an independent Swiss company, specialised in the design and manufacture of high quality mechanical and electromechanical equipment for the Space, Defence and Energy industries.

CSEM mission is to develop and transfer micro technologies to the industrial sector in order to reinforce the sector's competitive advantage. Its specialities include printed electronics and sensors

AIT, the Austrian Institute of Technologies, notably develops ultrapure nano-inks for high performance printed electronics.

Summary:

The integration of surface printed electrical and thermal functions on the spacecraft and instruments structures by direct printing of heaters, thermocouples, power and grounding wires is an innovative solution and interesting opportunity, which could provide major benefits.

The objective of this technology development project performed by APCO Technologies, CSEM, and AIT is to develop direct printed heaters for installation on spacecraft structures made of CFRP and Aluminium sandwich panels.

Direct printed heaters allow:

- time and cost saving, mainly due to the automation of the installation process,
- mass saving,
- improved performance and reliability, due to the absence of adhesive between the substrate and the heater,

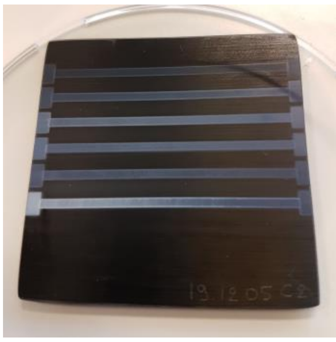
The driving requirements for the direct printed heaters are their thermal stability, and temperature resistance.

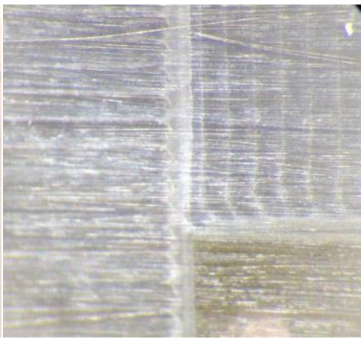
Results:

Insulating ink made of pure ceramic nanoparticles on a water base solution is deposited by Aerosol Jet printing on CFRP and Aluminium substrates.

Pulsed light from a xenon flash lamp is then used to sinter the ceramic nanoparticles.

The light flash, with a duration <1ms allows to locally reach a temperature of several hundreds of degrees, which allows the sintering of the ceramics particles without damaging the CFRP or Aluminium substrate.

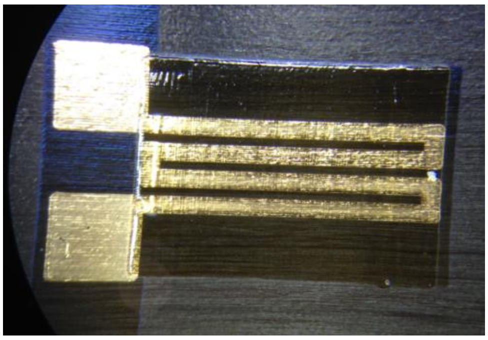


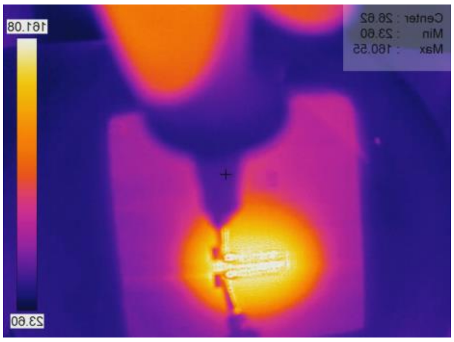


The same process is used to deposit the heating track in the insulating layer, but with metallic alloys which have a lower fusion temperature than ceramics.

An alternative solution with an insulating layer based on a high temperature epoxy has also been developed.

Functional heaters have been printed and tested.





Conclusion:

Promising results have been obtained. Ceramic insulating track needs to be optimised in order to improve its adhesion on the substrate.

Additional developments are needed to setup the printing process of a suitable metallic alloy that fulfils the thermal stability requirement.

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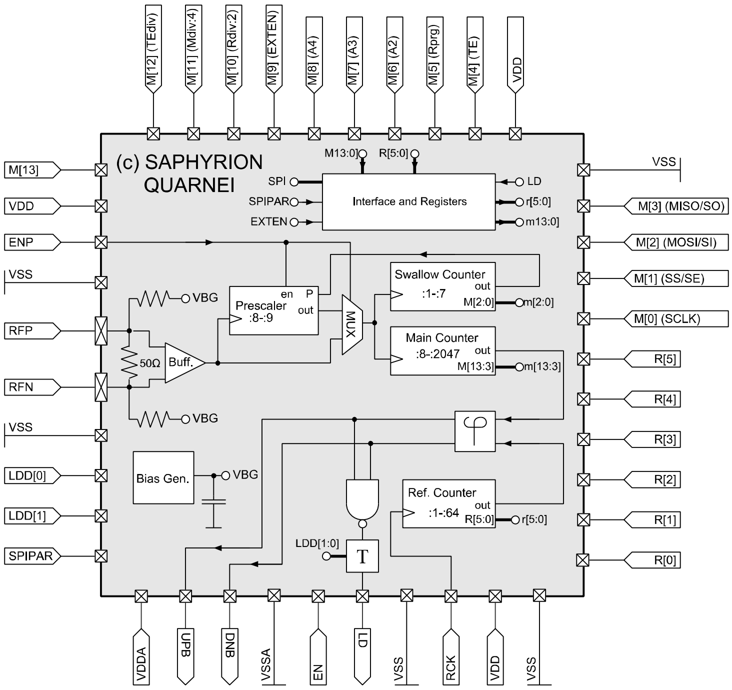
QUARNEI

Radiation Hardened Integer-N PLL Frequency Synthesizer

Competences:
The QUARNEI project is a collaboration between Saphyrion Sagl and SUPSI (Scuola Universitaria Professionale della Svizzera Italiana), Manno, Switzerland.
Saphyrion was in charge of designing, manufacturing and testing the PLL Frequency Synthesizer ASIC. SUPSI's contribution to the QUARNEI project was mainly the design and synthesis of the digital block part of the ASIC that includes a serial interface and a register array with Hamming error correction. In particular, the Institute of Systems and Applied Electronics (ISEA) has carried out the digital design and has provided the necessary facilities for testing the RF high frequency circuit parts of the device. The QUARNEI ASIC, called SY2301, was implemented using design techniques for radiation tolerance developed by Saphyrion for its space-borne ASIC products, which are flying already in several ESA Earth Observation missions.

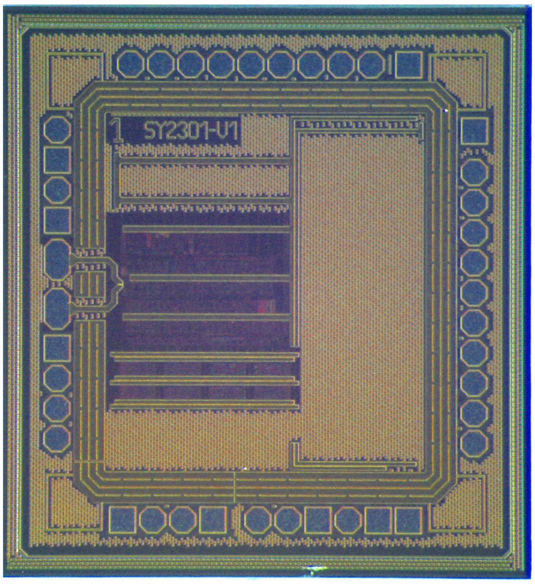
Summary:
The project consists in the realization of an integer-N PLL ASIC capable of frequency synthesis up to 15GHz, with the peculiarity to be a rad-hard device targeting 300kRad total dose and no SEL and SEU up to a LET of 85MeV. It includes all functional blocks needed to implement the digital section of a PLL frequency generator: a prescaler (64 to 16383), a main divider (8 to 2047) a reference divider (1 to 64) and a phase frequency comparator. The SY2301 ASIC supports two programming interface types, SPI and hard wired, which are selected via one of the device's pin. The input frequency ranges from 500MHz to 15GHz and supports a reference clock up to 200MHz. A typical frequency PLL synthesizer application would require the SY2301 ASIC, a VCO and an active loop filter made with an operational amplifier and a few passive components.
This architecture provides enough flexibility to cover many applications ranging from local oscillators in communications equipment to clock generation in microprocessor or DSP equipment.



Results:

The SY2301 ASIC has been designed and manufactured by means of a Multi Project Wafer run in IHP SG25 H3 SiGe process. The device was mounted chip-on-board on a dedicated test board for electrical characterization with bench-top instruments in a laboratory environment. The results have shown good performances in line with expectations:

- Frequency range 500M – 15GHz
- Input reference up to 200MHz
- Phase noise figure of merit: -210dBc/Hz
- Low power 40mA at 2.5V
- Serial SPI or parallel hard wire access
- Rad-hard design



Conclusions:

The QUARNEI ASIC is the result of an effective collaborative effort between Saphyrion and SUPSI, proving the good synergy between these two entities. The activity required just about one year of work and was successfully completed. The first prototype of the device demonstrated to behave correctly and with the expected performances. Thanks to the good results achieved, the project will be continued by Saphyrion with the characterization of the device under radiation. In case this prototype version will be confirmed to be the candidate one ready for production, Saphyrion will proceed with the industrialization of the SY2301 device. At the end of this still quite long and mainly self-financed process, the SY2301 product will be ready for commercialization and will be introduced in Saphyrion's product catalog of Space-qualified ASICs.

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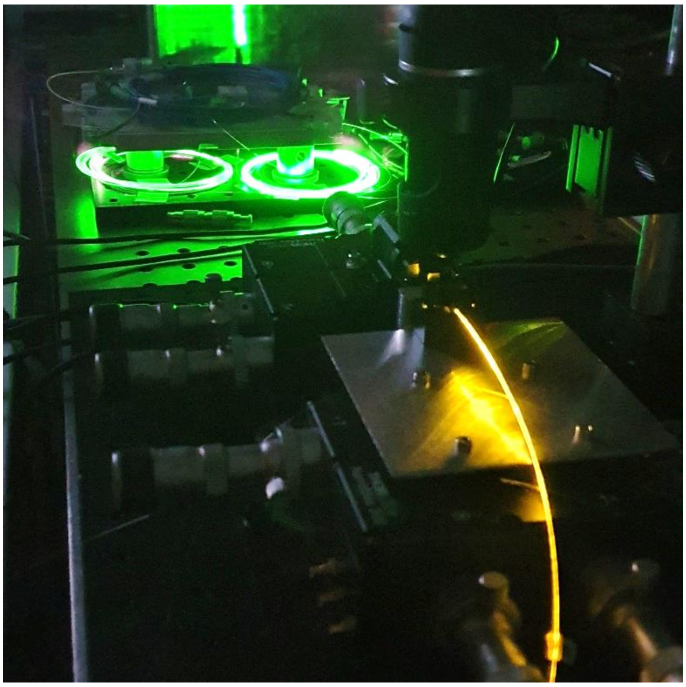
Spacewave

“Ultra-low-noise Femtosecond Oscillator for Space”



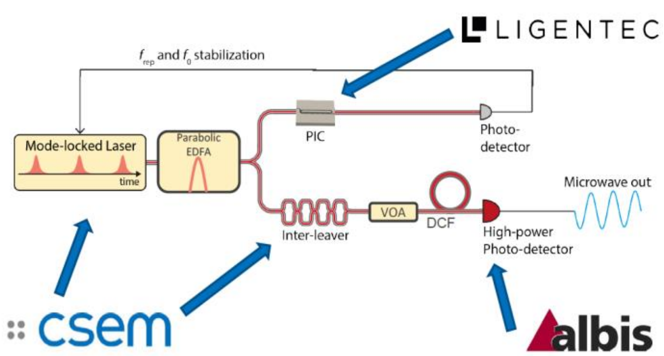
Competences:

CSEM: Laser and optical amplifier design, manufacturing and characterization
Simulations of non-linear photonics components
Laser stabilization and RF / microwave metrology

LIGENTEC: Manufacturing of low-loss SiN based integrated photonic components

Albis: Design and manufacturing of space compatible packaged high power highly linear photodiodes

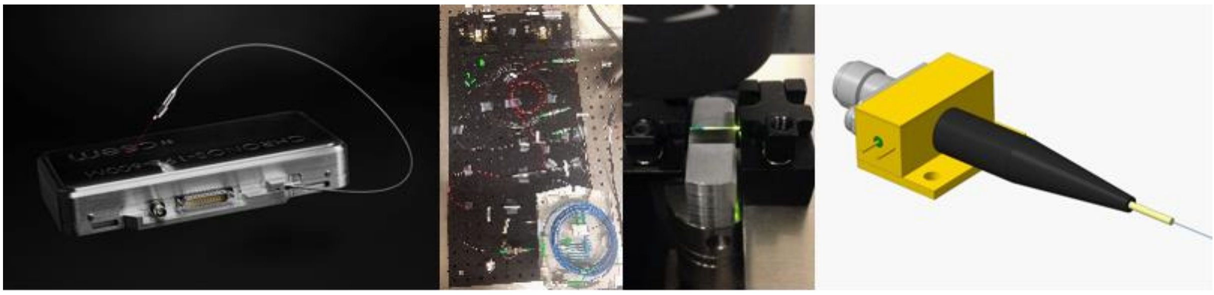
Summary:



An energy-efficient, ultra-low phase noise photonic oscillator based on mode-locked lasers was developed. This local oscillator (LO) suitable for current and future space applications **provides X-band microwave signals at 9.6 GHz as typically used for broadband telecommunication.** In addition, it **integrates an RF-to-optical link as required for optical clocks and navigation systems**. The design criteria **were best possible phase noise performance, while reducing power consumption and the physical size**. The Spacewave system reaches a **TRL 4 level**.

Results:

The Spacewave system was installed in the CSEM laboratory and is based on the photonic integrated circuit (PIC) from LIGENTEC and the packaged high-power photodiode from Albis. An on-chip **f-2f interferometer including supercontinuum and second harmonic generation** was demonstrated. The only external device of this interferometer is a packaged photodiode with related beam conditioning. This represents a **disruptive step for miniaturization of a frequency comb laser**. f_{CEO} and optical f_{rep} locks of the frequency comb were implemented and characterized. By using an optical reference, a lock **bandwidth of 100 kHz** was reached. The packaged high power Albis **photodiodes** have a 3dB bandwidth up to 22 GHz and **sustain up to 50 mA photocurrent**. This **allows to generate high carrier power without further RF amplification** and related noise generation. As the **microwave signal** is carried in an optical fiber it **can easily be distributed optically with low losses** and the electrical microwave signal can be directly converted where it is needed. The **phase noise of the system** was measured at a carrier frequency of **9.6 GHz**. The system reaches a **close to carrier phase noise of -135 dBc/Hz** at 1 kHz offset frequency and a **noise floor of -175 dBc/Hz.** While the TRL4 system was controlled by CSEM standard control electronics a final space product could achieve power consumption in the range of 10-20 W.



Conclusion:

The Spacewave system has reached TRL4. Next steps are the development of packaging for the PIC waveguides and further design iterations to decrease the power level for f_{CEO} detection. The Spacewave system requires further design steps to make it more compact especially regarding the non-space compatible and bulky electronic components (while CSEM has ready designs compatible with space environment). The packaged photodiodes are almost space qualified (from the ARTES Hopp project) and merit further characterization and design change to figure out the optimum working conditions for even lower phase noise.

Once the mentioned design steps have been implemented there are multitude of space and non-space applications:

- Telecom LO with optical signal distribution
- Phased array antenna for beam forming (telecom and Earth observation)
- RF-to-optical link for optical atomic clocks in future GNSS
- LO for ground-based radio telescopes and all typical applications for frequency combs
- LO for ultra-low phase noise synthesizer for radar and test & measurement

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Ultra-Laser

Ultra *Pure* ***Laser****s for Space Applications*

The ability to precisely control the color of light is at the heart of most applications of lasers, and many breakthroughs have been brought about by extremely precise laser technologies. The 2005 Nobel Prize in physics was awarded for precision laser control, and this has enabled extremely accurate and reliable optical atomic clocks, which will be key to long-range space navigation in the future as well as many other space missions. A key enabling technology for this and other space applications like precision long-range distance measurements and high capacity telecommunications are compact lasers with low frequency noise. It is challenging to find such lasers. The Ultra-Laser project's goal was to fix this by providing a platform capable of creating compact lasers with ultra-pure colors.

Competences:

MicroR Systems Sarl. – A startup company from EPFL focused on the development of optical microresonator technology for use in applications ranging from LIDAR to advanced telecommunications and optical filters. MicroR are specialists in compact ultra-pure lasers and optical frequency combs with experience in optical packaging. MicroR is passionate about precision applications using lasers.

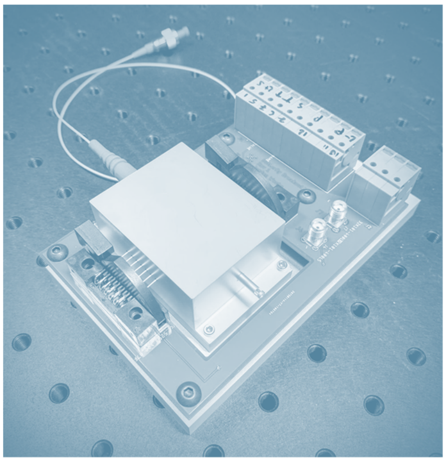
Laboratory of Photonics and Quantum Measurements at EPFL – World leader in optical frequency comb technology with a strong focus on applications and fabrication of silicon nitride based photonic chips.

Summary:

The Ultra-Laser project's aim was to create a compact, low noise laser for use in future space applications at the important wavelength of 1064nm, where it is challenging to find lasers with very pure colors (linewidths < 50 kHz). The team focused on developing a platform that could be heterogeneously integrated with photonic chip technology. The project combined a crystalline optical microresonator

MicroR systems

EPFL



with a silicon nitride photonic chip to create a narrow linewidth injection-locked laser. Such an injection-locked laser had never been demonstrated before the Ultra-Laser project.

Results:

The team was able to successfully demonstrate lasers with ultra-pure colors at both 1550nm as well as the challenging color of 1064nm. The system's frequency and phase noise properties where thoroughly characterized and the performances exceed that of most commercially available technologies. An important difference being that the Ultra-Laser technology integrates with other photonic chip systems to create compact laser-based optical systems.

Conclusion :

The combined team was able to take this technology from a low technology readiness level to an advanced prototype in only 15 months thanks to the MdP 2018 funding. An advanced laser prototype was demonstrated in a flexible platform capable of producing lasers with ultra-pure colors at a range of different wavelengths.

Contacts:

For any interest or more details in the technology, please contact Dr. John Jost at MicroR Systems. We would be happy to hear about your needs.

MicroR systems

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EPFL

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DeeCODE

Deep-learning models for Custom Object Detection from multi-sensor Earth observation imagery

The context of the **DeeCODE** project is the detection, segmentation and counting of objects in aerial images (satellite and drone) using machine learning. The project focuses on investigating and developing a system able (i) to operate with different sensors and resolutions (multi-sensor) and (ii) to improve the capability of learning from few labelled examples (low-shot learning). These enhancements will allow users to transfer knowledge from available datasets or from other already learnt classes to fulfill their custom needs.

Main achievements

The project has acted as a strong R&D component for positioning Picterra as the single player tool for object detection in Earth observation imagery, attracting customers and renowned international investors. Picterra's web platform moved from its beta version into a self-serve tool where paying customers are creating customized detectors with few annotations on a broad range of Earth observation imagery types. Moreover, the quality of the outputs provided by the platform has improved significantly over the course of the project. The project enabled to go towards user customizing their detectors while initially they would have accessed only a pre-built library of detectors. Finally, the prototyping and development of a model for object density estimation on Sentinel-2 images brought up a new set of high-temporal applications.

Results

The low-shot learning strategy has been adapted and implemented in the context of object segmentation and detection. This is a meta-learning approach which trains a machine learning model to learn a wide variety of heterogeneous tasks. The experiments showed that in the early phases of the training the model using the low-shot learning strategy started off in the better state, producing significantly higher scores and lower variability in the results, see Figure 1.

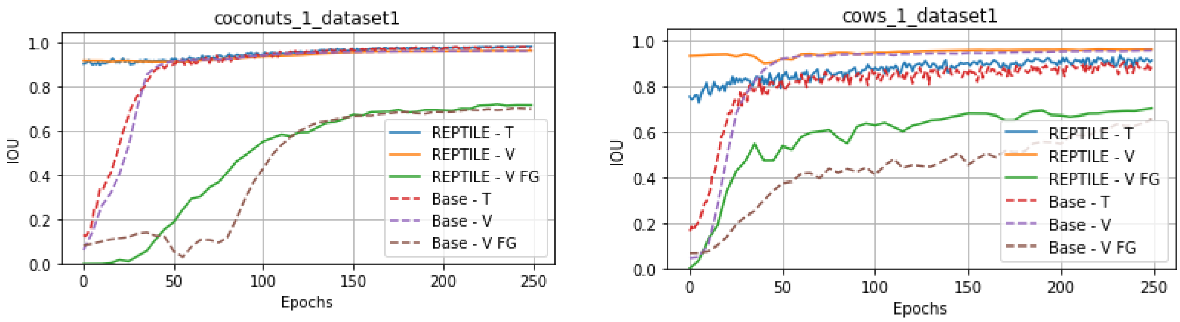


Figure 1. Performance of the custom detectors during fine tuning for two datasets. With low-shot learning-Reptile-strategy (green curve) the model converges faster than without (dashed brown curve).

A demonstration project was performed to detect Slurry tanks around farms over the whole country of Denmark. This low-shot learning project only required 56 training examples of slurry tanks to then apply the detector over 34'000 farms of Denmark, on imagery at 25 cm of resolution. This represented more than 1 TB of data processed.

Figure 2. Slurry tanks detection over the whole country of Denmark (pink disks representing the farms).

The prototyping and development of a model for predicting the object density on Sentinel-2 images enabled to handle extreme resolution differences: from centimeters drone imagery to Sentinel 10m. This model detects and predicts the number of objects within Sentinel-2 pixels. The demonstration has been done with the detection of coconut trees on drone images over Zanzibar to then train the density estimation model. The results of the prediction of object density on Sentinel-2 imagery is shown in Figure 3. The mean square error is around 0.3 for validation areas. This opens up applications where counting estimation at parcel level can be done from Sentinel-2 imagery and at a high temporal frequency.

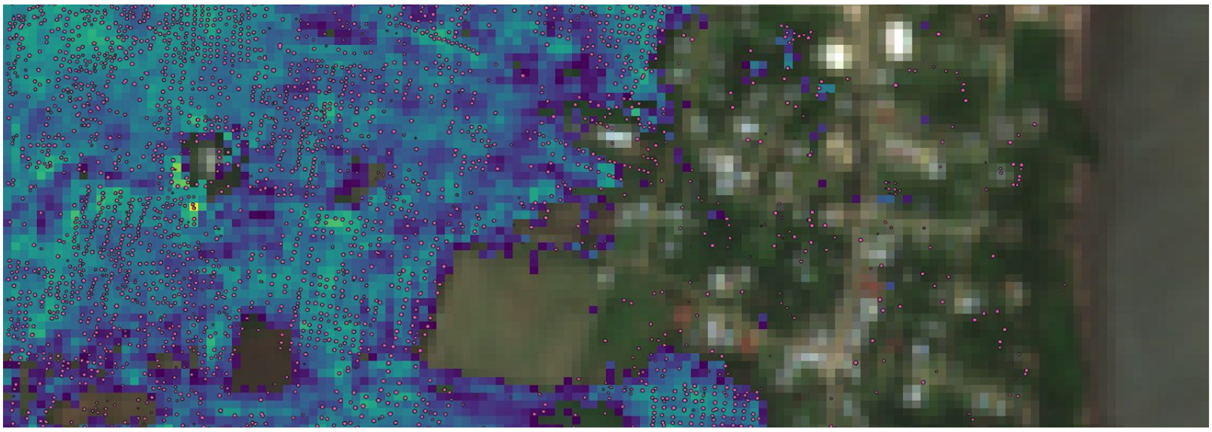


Figure 3. Sentinel-2 density estimation of coconut trees. Densities lower than 0.5 are set transparent, low densities are dark blue and highest densities yellow. The ground truth (coconut) detections are overlayed as pink circles.

Conclusion

The **DeeCODE** project paved the way towards fast and interactive training of custom detectors as well as handling extreme resolution differences. Finally, a deeper expertise and the developments of the low-shot learning and multi-resolution modules for Earth observation provided the academic and innovative advantages to both Picterra and the IDA team.

Picterra is a Swiss startup company founded in 2016 which aims at democratizing the use of EO imagery through machine learning giving everyone the opportunity to analyze and draw insights from satellite and aerial imagery, all in just a few clicks. Contact at contact@picterra.ch or frank.demorsier@picterra.ch

The **HEIG-VD/HES-SO** Data Science team is part of the Institute for Information and Communication Technologies (IICT). This team pursues research in the domain of Machine Learning techniques applied to diverse sources of data and has extensive experience in interdisciplinary projects.

Hes·so University of Applied Sciences Western Switzerland

Picterra

SSBio

*"SSBio (**Standard for Space Bioreactors)** is a study to produce cost efficient small biological instruments that are flight carrier and platform independent and interoperable for future experiments in micro-gravity and for industrial use"*

Competences:
The study has been carried out in partnership by one Academic and one industrial partner having complementary competences and expertise in the concerned field:

- <u>Academic partner:</u> **Lucerne University of Applied Science and Arts** (HSLU)
  The Institute of Medical Engineering (IME) at HSLU maintains the "Space Biology Group" that was founded in 1977. The "Space Biology Group" is a leading research unit specialized in conducting bio-medical and biotechnological research in the context of space medicine, regenerative medicine and mechanobiology.

- <u>Industrial partner:</u> **ORACAN Sàrl**
  ORACAN is a privately held start-up created in May 2018 located in the EPLF Innovation Park in Lausanne. ORACAN develops innovative bioreactors for terrestrial applications based on Space technologies. Our strength is to be able to work on Terrestrial and Space markets. We are able to spin-in Space technologies becoming innovative technologies for terrestrial applications and to spin-out terrestrial technologies to decrease drastically and standardise Space bioreactor technologies and applications.

Summary:
The motivation behind the Standard Bioreactor for Space (SSBio) was born from current limitations and needs when life-science experiments need to be carried out in space or under microgravity conditions. Today, whenever a space experiment that applies any kind of bioreactor technology had been selected for a space flight, the related hardware has to be built from scratch by an industrial partner. Instead reusing already existing bioreactor technologies and making them more efficient, more stable and more robust, the hardware development started anew. Therefore, nowadays numerous bioreactor systems exist that apply slightly different technical solutions to solve the same issues.

Therefore, the objective of the study is to propose a set of design guidelines for the development of an experimental bioreactor to be used under microgravity conditions and in space. This study will be a standardization effort to optimize the extremely high costs related to the development and testing of custom instrumentation for space biology.

During project it appeared that the terrestrial biotech and pharma industry were very interested in performing micro-gravity tests for bioprocesses or for stem cells cultures.
The capability of the SSBio, to be tested in parallel on 1g conditions (terrestrial conditions) or in microgravity conditions to compare the results opens a huge potential for Biotech and pharma R&D to develop and test new molecules for drug development.

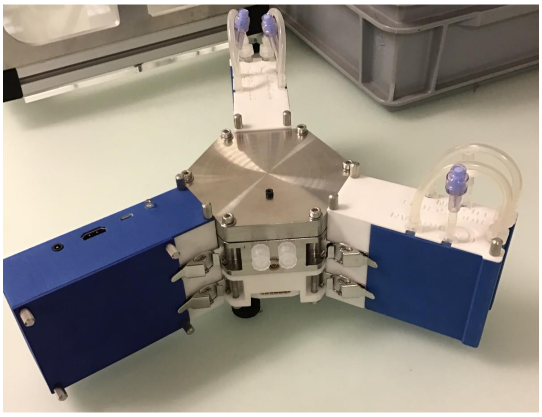
Lucerne University of Applied Sciences and Arts
HOCHSCHULE LUZERN

ORACAN

Proposed solution

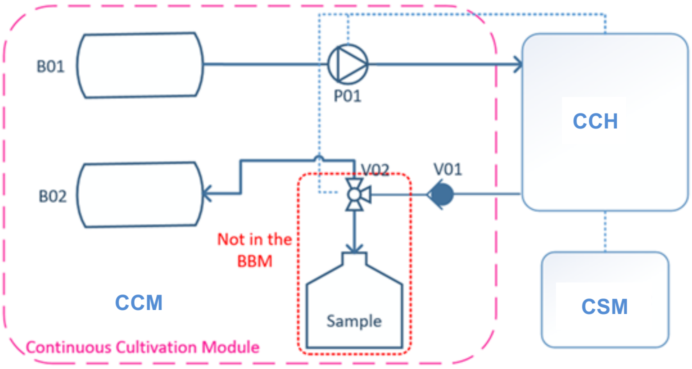
The SSBio developed proposes the following benefits:

- Cost efficient and compact
- Deployable on a variety of microgravity platforms, either on ground, parabolic flights, sounding rockets or on the ISS facilities
- Interchangeably.
- Modular design (plug and play) to provide maximum versatility
- Standardized interfaces



Features

- **CCH** : Cultivation CHamber
- **CSM**: Control and power Supply Module
- **CCM**: Continuous Cultivation Module
  - **B01**: Feed tank (Vol. 25 ml)
  - **B02**: Waste tank (Vol. 25 ml)
  - **P01**: Micro-Pump (Fmax 3ml/min)
  - **V01** : Duckbill valve
  - **V02** : 3 way valve for sampling



Conclusion:

The SSBio prototype was tested successfully in the lab for functionality and usability on microgravity platforms as well as on ground in a regular laboratory environment. These tests allowed for the identification of new requirements and changes that are necessary to advance the TRL of the bioreactor. Taken together, our tests have shown that the design of the bioreactor is aiming into the right direction and that the design is well suited for use on microgravity platforms as well as in regular laboratories. Industrial partners have already announced interest in the technology, thus encouraging us in our aspiration to render our product market ready.

For the way forward, the following actions are planned: Validation biology benchmark; ESR definition, pre-design of new modules (i.e pH, cell counting, control of gas exchanges, temperature control, mixing).

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MEGA

“Micro-fabricated Electron Gun for Atomic Clocks”

Competences:

CSEM: The Swiss Center for Electronics and Microtechnology – CSEM – is an applied Research and Development center involved in the design and development of micro- and miniaturized systems for the industry. CSEM’s staff comprises about 437 people, working at technological innovation in a number of new products and applications: medical, space, automotive, aeronautics, among others. The MEGA project has been carried out by the “Micro&Nano Systems division” using its state-of-the-art clean room located in the Neuchatel CSEM building, in a 700 m² area class ISO5/ISO7, equipped for processing of 150mm diameter wafers.

Orolia/Spectratime: SpT is a world leader in the generation and synchronization of precise time and frequency signals. SpT designs, manufactures and markets atomic clocks and network timing and synchronization solutions used in wireline and wireless telecom networks, as well as in space and defense systems. SpT has worldwide leadership positions in both timing and synchronization and is the number one worldwide provider of Space-qualified Passive Hydrogen maser clocks, Rubidium Atomic Frequency Standard and High-performance synchronization modules & solutions.

Summary:

Purpose of the project is to develop a micro-fabricated “cold cathode” electron gun to be integrated in the next generation “Hg trapped-ion” atomic clocks for space applications. Spectratime has started the development of such clock with support from ESA and the “electron gun” today used for the ion generation is a standard hot-cathode filament emitter. This solution has several drawbacks: high operating temperature (>1500°C), high power consumption, noise generation and lack of redundancy. In contrast, a “cold cathode” electron gun operates at room temperature with very low power consumption, small size and therefore possibility for redundancy.

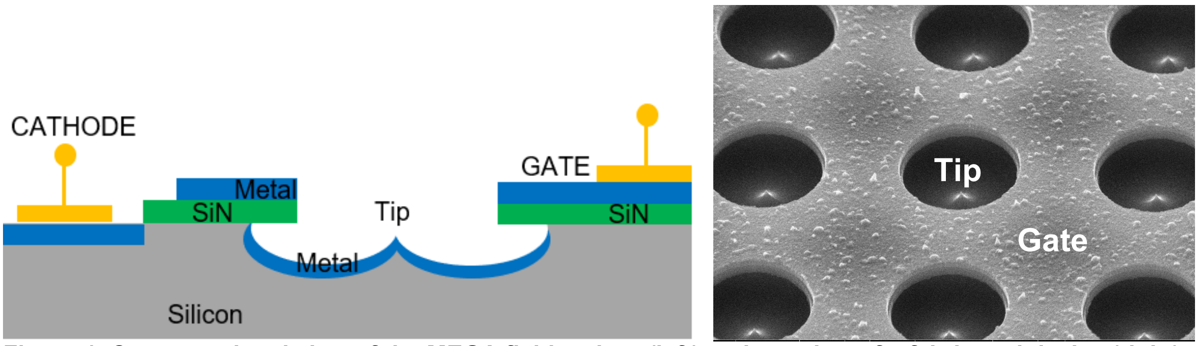

Figure 1. Cross sectional view of the MEGA field emitter (left) and top view of a fabricated device (right).

The MEGA electron gun is done by a “Field Emitter Array” i.e. an array of sharp tips which emits electrons at room temperature when immersed in the very high electric field generated by an extraction (gate) electrode (figure 1). The sharp tips array and the gate electrode are integrated in a monolithic silicon chip, using a technology developed at CSEM. The tips and gate are coated by a metallic film to enhance the

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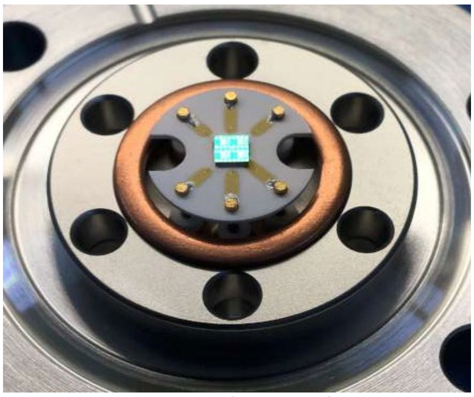
emission and increase the device lifetime. The electron gun has been assembled in a UHV vacuum setup (figure 2) at Spectratime and characterized in terms of I-V emission properties, where V is the voltage between gate and cathode (tips).



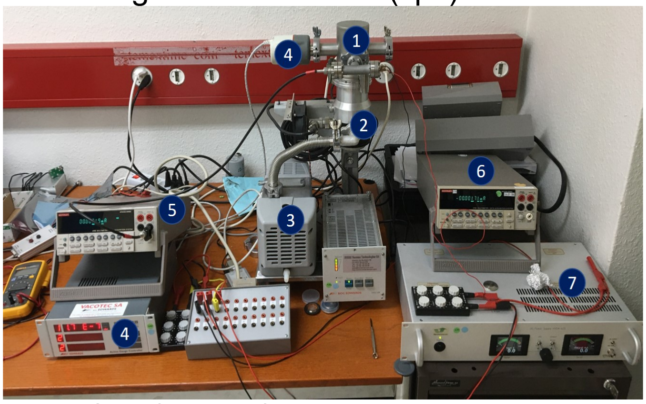
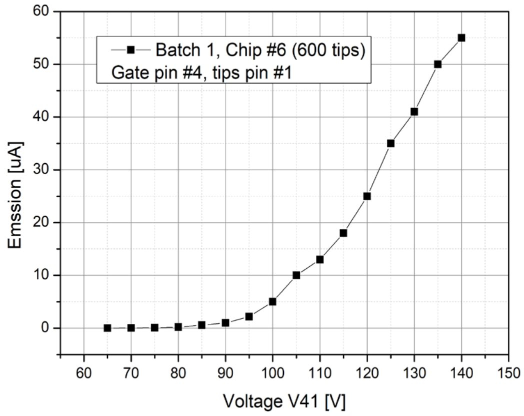


Figure 2. Pictures of the MEGA chip mounted in a CF16 flange (left) and in the vacuum test setup (right).

Results:

The vacuum is set at 10^{-7} mbar and the emission current measured with a Faraday cup, as a function of V. The results of the first tested samples are shown in figure 3:



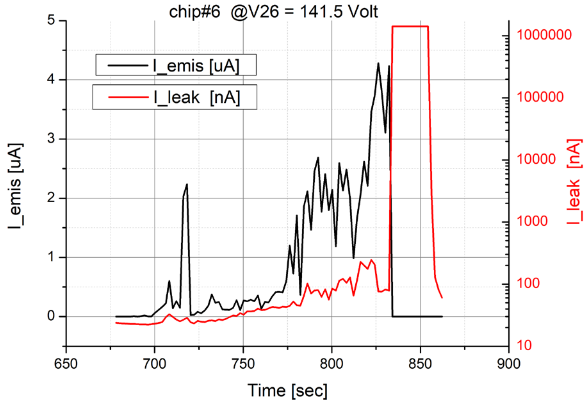


Figure 3. V-I curve of the emitted current from a MEGA sample (left) and preliminary emission time evaluation (right). The maximum measured current has been 55µA @140V.

Conclusion :

The feasibility of electron emission in vacuum with the MEGA electron gun, at the required current level >10µA, has been demonstrated. The project will continue to characterize the emission lifetime as a function of operating conditions in a realistic space environment, with to reach the technology readiness level TRL4.

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