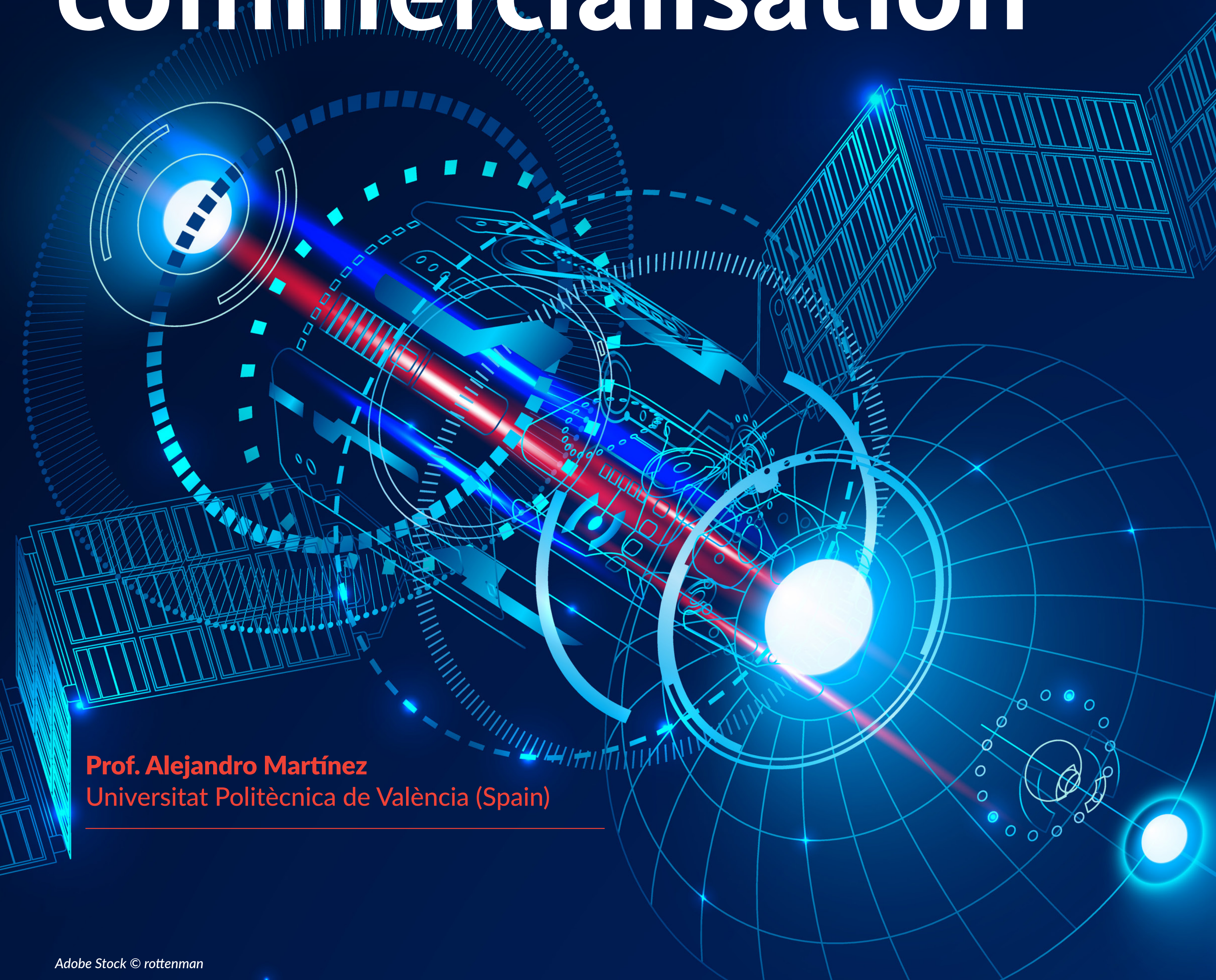
Silicon-photonics microwave oscillators closer to commercialisation



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Microwave sources displaying high spectral purity are required in a myriad of applications spanning radar, wireless networks, radioastronomy and satellite communications. Typically, low-noise microwave oscillators are made by applying frequency multiplication to a low-frequency electronic source. This requires a cascade of frequency-doubling stages, which adds noise and reduces the signal power.

Recently, techniques to produce microwave tones using photonics have been proposed. The resulting device is termed optoelectronic oscillator (OEO), and it possesses several advantages with respect to its electronic counterparts: immunity to electromagnetic interference, low weight, compactness, long-distance transport using optical fibres, and extremely-low noise.

First realisations of OEOs included long paths of optical fibre as a feedback mechanism to achieve oscillation. This resulted in bulky, heavy devices, not appropriate in applications requiring compactness and low weight. An interesting alternative to generate microwave tones optically in a compact system is via mechanical waves coexisting and interacting with optical waves in semiconductor cavities. This approach would allow for extreme miniaturisation of the OEO since the wavelength of mechanical waves in solids is about five orders of magnitude smaller than in their electromagnetic counterparts.

In the PHENOMEN project (funded by H2020 under the FET-Open programme), researchers of the Nanophotonics Technology Center (NTC) in the Universitat Politècnica de València (UPV, Spain) designed and demonstrated that an **optomechanical cavity** (Figure 1) with a foot-print of the order of several μm^2 could perform as an ultra-compact OEO. The cavity, which was built on a silicon chip using standard nanofabrication tools, supported confined optical and mechanical modes that could strongly interact because they coexist in a nanoscale volume. When the device is properly operated using an external telecom-wavelength laser, mechanical vibrations inside the cavity are amplified, even reaching a state of self-sustained oscillations (or phonon lasing, which is the analogue of a laser but for mechanical waves instead of light). Then, the laser is modulated by a series of ultra-narrow microwave tones, corresponding to multiples of the mechanical frequency, so the device behaves as an OEO. In the demonstrated device, the mechanical frequency was 4 GHz, and the measured phase noise, the metric determining the purity of the signal, was below -100 dBc at 100 kHz, which compares well with traditional, bulkier solutions (Mercadé *et al.*, 2020).

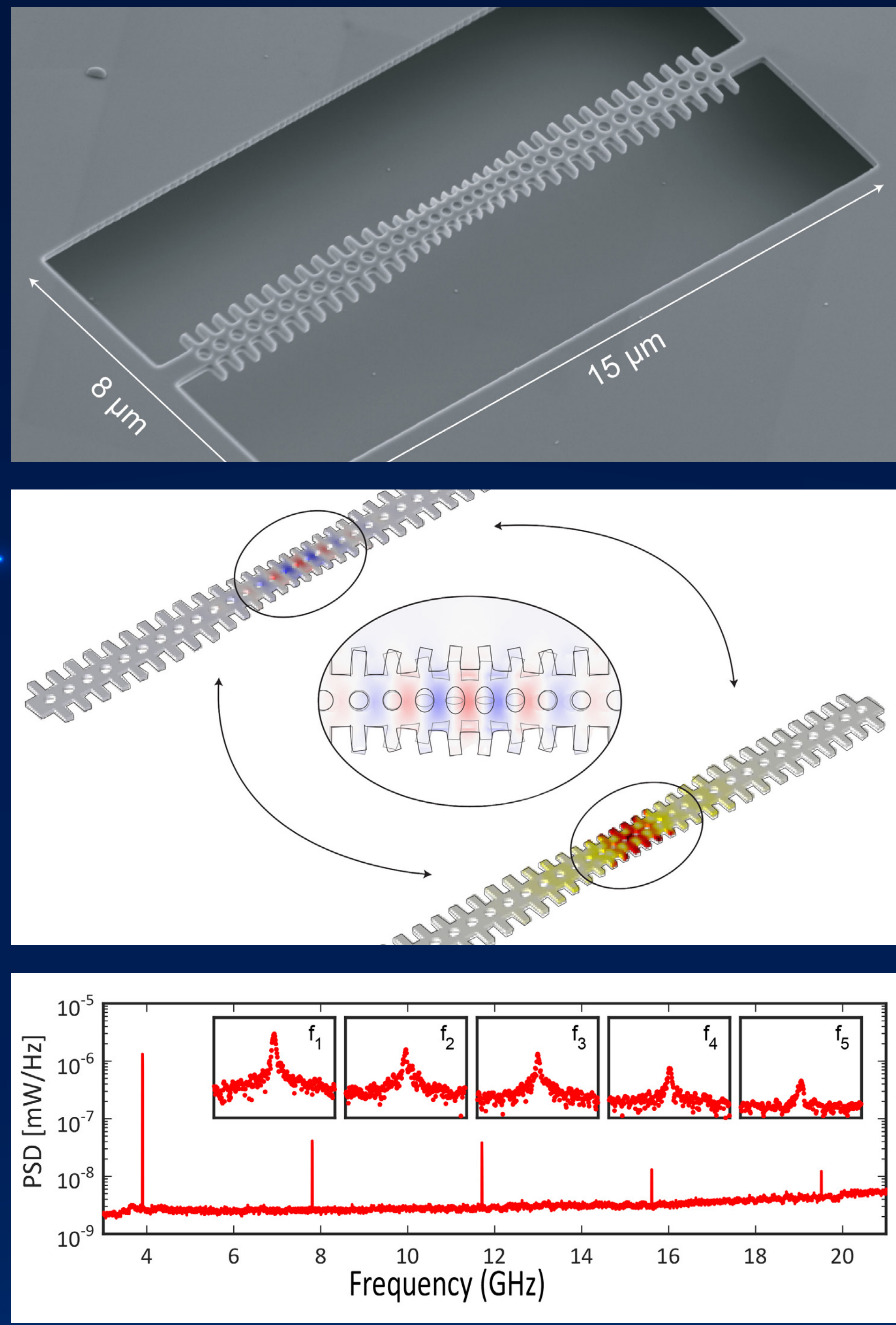

Figure 1: *(a)* Scanning electron microscopy image of the silicon optomechanical crystal cavity. *(b)* Optical (top) and mechanical (bottom) field profiles of the optomechanical system. The inset figure shows the optical field profile on top of the displacement maximum and minimum boundaries result of the mechanical mode displacement. *(c)* Generated RF spectrum after photodetection of the OMO signal, showing a set of microwave tones at integer multiples of the mechanical resonance.

Figure 2: DAS Photonics clean-room to test devices for SATCOM applications.

Indeed, this OMO has three key advantages:

i. it is fabricated in **standard silicon technology**, meaning that it can be potentially manufactured in large volumes at low cost as well as that it can be easily interconnected with electronics;

ii. it can be **easily connected to optical fibres**; and

iii. it is **extremely compact and low-weight**, which makes it very suitable for space and satellite applications.

The SIOMO project aims to turn a silicon-photonics-integrated OMO, developed at the NTC (partner UPV), into a genuine economic innovation by addressing its technological transfer to the space sector via collaboration with the Spanish SME DAS Photonics. DAS Photonics is an experienced Spanish company providing high-end solutions based on its proprietary photonics technology for the most demanding applications worldwide.

To achieve this ambitious goal, SIOMO planned to test the developed OMO using parameters established for operation in satellite communications (SATCOM) environments. To this end, DAS's engineers assessed its practical applicability on a real space application test bed (see Figure 2), like in the context of the previous OPTIMA project, where DAS Photonics demonstrated some of the most important benefits of a photonic payload in SATCOM systems. Measurements of the phase noise as well as the frequency conversion efficiency of the OMO were carried out. Results confirmed the potential of the new technology in SATCOM applications. In particular, using harmonics of the generated microwave tone the highly-relevant X-band (between 8 and 12 GHz) is attainable. Therefore, the characterisation in a realistic environment confirmed the potential of the technology.

Noticeably, the SIOMO device acting simultaneously as a photonic local oscillator and a frequency mixer shows features that make it interesting in fields beyond SATCOM networks. For instance, it can be used to down- and up-convert data modulated using orthogonal frequency domain multiplexing (Mercadé *et al.*, 2021). This feature highlights its potential as a building block in photonics-driven wireless access networks (like 5G), where the frequency conversion process to adapt data streams to the right frequency channel is a key process.

Yet some improvements are still necessary. The OMO needs to be packaged and connectorised using polarisation-maintaining fibre and its interface with fibre improved to get better power efficiency. All these steps will be followed in the future.

Overall, SIOMO has demonstrated how a technology (silicon OM cavity) developed in the framework of a fundamental-research project has the potential to be used in a real application (SATCOM systems). SIOMO has also made it possible to benchmark this technology against competing devices in the market, leading to the elaboration of an industrialisation roadmap towards exploitation and commercialisation. NTC and DAS Photonics will continue to work together to bring this technology out of the lab so that local oscillators in SATCOM systems can in the future be made of silicon-technology OMOs.

References

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Mercadé, L., Morant, M., Griol, A., Llorente, R. and Martínez, A.(2021) 'Photonic frequency conversion of OFDM microwave signals in a wavelength-scale optomechanical cavity', *Laser & Photonics Reviews*, 15, 2100175. doi: 10.1002/lpor.202100175.

SIOMO video:

https://www.youtube.com/watch?v=y89sWlpJhfw&t=79s

Websites:

NTC
https://ntc.webs.upv.es

DAS Photonics
https://www.dasphotonics.com

SIOMO project
https://www.siomo-project.eu

PROJECT NAME

SIlicon Optomechanical optoelectronic Microwave Oscillator SIOMO

PROJECT SUMMARY

SIOMO aims at turning a silicon-photonics optomechanical microwave oscillator (OMO) into a genuine economic innovation by addressing its technological transfer to the space sector via the SME company DAS Photonics. To this end, the OMO has been tested in a SATCOM test bed, showing its suitability to be used as a photonics-based local oscillator operating in the X-band in satellites and aircrafts.

PROJECT LEAD PROFILE

Prof. Alejandro Martínez is leading the Plasmonics and Optomechanics group at the Nanophotonics Technology Center in Universitat Politècnica de València (Spain). His research interests include cavity optomechanics, plasmonics, nanoantennas and metamaterials and its integration into silicon photonics chips. He has co-authored over 100 papers in international peer-reviewed journals and holds eight patents. He has also supervised eight PhD theses and more than 30 masters' theses.

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