macQsimal—Towards Reliable Miniature Quantum Sensors

J. Haesler, S. Karlen, L. Balet, T. Overstolz, G. Bergonzi, F. Droz, S. Lecomte

As a project under the Quantum Technologies (QT) Flagship of the European Commission, macQsimal is at the forefront of European efforts to push the boundaries of quantum technologies. The project, coordinated by CSEM, develops advanced prototypes for enhanced applications in various fields such as communication, navigation, and medical imaging.

macQsimal [1] develops miniaturized advanced quantum-enabled sensors with outstanding expected sensitivity to measure physical observables in five key areas: magnetic fields, time, rotation, electro-magnetic radiation and gas concentration.

Five different types of miniaturized quantum sensor prototypes are under development: optically pumped magnetometers (OPM) for brain activity imaging, atomic clocks (MAC) for communication and space applications, nuclear magnetic resonance gyroscopes (NMRG) for autonomous cars driving, atomic GHz/THz sensors and imagers, and lastly, Rydberg-based gas sensors. The common core technology for these sensors is formed by atomic vapor cells realized as integrated microelectromechanical systems (MEMS).

Figure 1: MEMS atomic vapor cell fabricated at the wafer-level for: OPM (left), GHz/THz (middle), and MAC (right) applications.

Fabricating such MEMS atomic vapor cells at the wafer-level[2] allows for high-volume, high-reliability and low-cost deployment of miniaturized and integrated sensors, critical to wide-spread adoption. 6-inch wafers, with up to 744 cells per wafer, were already fabricated (Figure 1), and promising world-class low-drift performances have been measured [3], opening the path towards the first European commercial miniature atomic clock by our partner Orolia Spectratime in Neuchâtel. CSEM, thanks to more than 12 years of development towards reliable, well performing and cost effective MEMS atomic vapor cells, will thus be the provider of one of the core element of such a commercial clock.

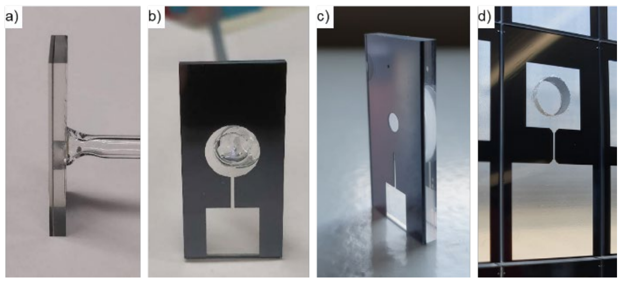

Figure 2: MEMS atomic vapor cell fabricated at the wafer-level for: a,b): gas sensing (with a stem attached by the University of Stuttgart), c): GHz sensing and imaging and d): THz imaging.

Wafers of customized dual-cavity cells (Figure 2) for GHz/THz applications were also successfully fabricated. Such cells show specific features like: i) compensation cavities, ii) filling stem for very low-pressure applications, iii) thin reflective inner walls for beam shaping and iv) very thin side walls for enhanced resolution.

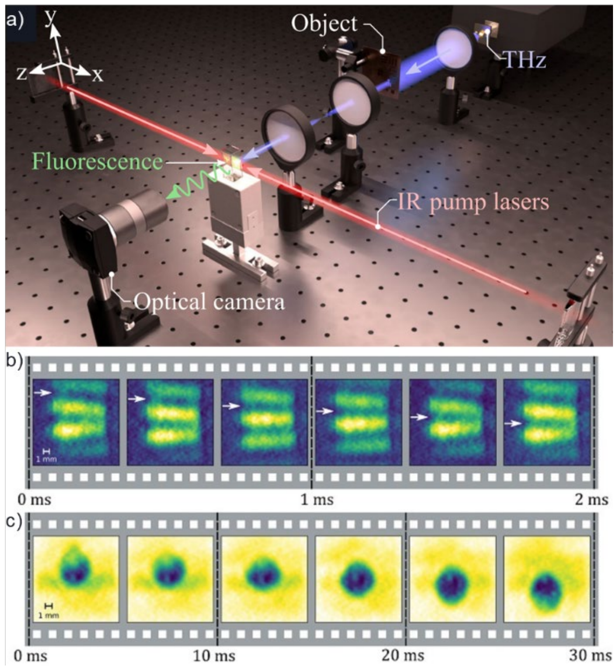

Figure 3: Fast 2D THz imaging demonstration by the University of Durham. a) lab setup, b) chopper wheel imaged at 3'000 frames per second, and c) falling water drop imaged at 500 frames per second.

THz imaging systems, one pillar of macQsimal, illustrates another big potential of such MEMS vapor cells. These systems have applications in security scanning, biomedical imaging, and non-destructive testing. This is due to the non-ionizing and penetrating nature of THz radiation. To circumvent the limitations of current THz imaging systems (low frame rate, low THz power and low THz detector sensitivity), colleagues at the University of Durham use an alkali vapor in a standard cubic glass cell that converts terahertz-frequency photons into easily detectable optical-frequency ones. They recently reported on a 2D THz imaging system (Figure 3) capable of fast and low noise full-field imaging[4], with frame rates two orders of magnitude higher than the current state of the art in THz imaging.

MEMS atomic vapor cell fabricated at CSEM will allow to further improve the THz imaging system performances by reducing interferences existing in the current cubic glass cell and thus improving the optical signal characteristics of the system.

macQsimal is funded by the European Union's Horizon 2020 research and innovation program under grant agreement No. 20393.

---

[1] www.macQsimal.eu

[2] CSEM patent n°US8906470 (B2)

[3] S. Karlen, J. Haesler, T. Overstolz, J. Gobet, L. Balet, F. Droz, S. Lecomte, "MEMS Cells for High Stability Miniature Atomic Clocks", CSEM Scientific and Technical Report (2020) 76.

[4] A. Downes, *et al.*, Phys. Rev. X, 10, 011027 (2020).