PhD thesis proposal

Inertial sensing based on strain coupling in rare-earth-doped crystals

Keywords: quantum sensor, accelerometry, strain coupling, optomechanics, light-matter interaction

The realization of a **broadband, high-sensitivity accelerometer** operating at cryogenic temperatures is a major challenge in many cutting-edge experimental physics domains, from quantum technologies (including near-field microscopy, quantum memories, quantum signal converters, etc.) to seismology and gravitational wave detection. To realize such a sensor, it is interesting to turn to **hybrid optomechanics**, a field of research based on the coupling between quantum and mechanical degrees of freedom in a single physical system.

In this context, **rare-earth ion-doped crystals**, well known for their exceptionally narrow optical transitions at low temperatures (3K), and increasingly used in quantum technologies, have recently emerged as a promising hybrid optomechanical system. In these materials, the optomechanical coupling is based on the sensitivity of the rare-earth ions' energy levels to the mechanical stress of the host matrix via the crystal field surrounding the ion.

We have recently demonstrated that this coupling can be exploited to provide a **continuous optical measurement of the mechanical vibrations of a cryostat** using a doped crystal, with an already very promising sensitivity and bandwidth [1,2]. This measurement is based on the continuous interrogation of the optical transition with a monochromatic laser.

However, there is still significant work required to advance the development of an **ultra-sensitive, unidirectional and calibrated accelerometer**. At the fundamental level, the very nature of the optomechanical coupling needs to be better understood. Indeed, the role of the atomic population and coherence lifetimes on the sensing bandwidth and sensitivity is still to be elucidated. Besides, the anisotropic sensitivity of the ions' optical lines to mechanical strain could be an interesting way to provide directionality. On the technical level, controlled vibrations will be used to validate the method and estimate the device's performance in terms of sensitivity, bandwidth and directionality. Finally, in a more device-oriented perspective, the extension of the accelerometer's functionality at various operational conditions, (e.g. higher temperatures, up to 10K), will be key to define the potential applications for this innovative accelerometer.

[1] A. Louchet-Chauvet et al. *Piezospectroscopic measurement of high-frequency vibrations in a pulse-tube cryostat*, Review of Scientific Instruments, 90, 034901 (2019).
[2] A. Louchet-Chauvet, et al. *Limits to the sensitivity of a rare-earth-enabled cryogenic vibration sensor*, AVS Quantum Science, 4, 024401 (2022).

Techniques/methods in use: Spectral hole burning, stable lasers, closed-cycle cryostats

Applicant skills: background knowledge in one or several of the following fields: quantum mechanics, optics, light-matter interaction, laser physics and/or condensed matter physics. A taste for experimental physics and teamwork is expected, as well as a good level of English. Basic programming skills are appreciated (e.g. Matlab).

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Possibility for a Doctoral thesis: Yes (EDPIF)