Thesis title : Development of a stabilized laser on a Fabry-Pérot cavity for metrology and fundamental physics
Host Laboratory : FEMTO-ST
Speciality : Optics and photonics
Keywords : Time&frequency metrology ; laser physics ; optics : electronics ; Fabry-Pérot cavity ; dark matter ; instrumentation

Job description

Ultra-stable lasers have a central role in numerous scientific experiments for high precision measurements, atomic spectroscopy, diffusion of time & frequency signals by optical fiber, detection of gravitational waves and dark matter research. The performances are currently reaching frequency relative stabilies of an order of magnitude of 0^{-16} at 1 seconde of integration, however, it is still insufficient for many applications. To overcome the current limits, the proposed thesis consists in realizing a laser which will be stabilized on a cryogenic Fabry-Pérot cavity.

A Fabry-Pérot cavity consists of two mirrors aligned precisely facing each other. If we manage to limit the fluctuations in the length of the cavity, it becomes a length standard, and therefore a frequency reference. This length stability is then transferred to a laser locked on a resonant frequency of the cavity. The difficulty in designing an ultra-stable cavity therefore lies in stabilizing the length of the cavity. In order to limit this length noise, the cavity mirrors are stuck to an ultra-rigid spacer. The contribution of thermal noise to length noise is also minimized by cooling the cavity to cryogenic temperatures.

During this thesis, the heart of the device will be a Fabry-Pérot cavity in mono-crystalline silicon, already realized and available. The cavity is cooled to 17 K to make the thermal expansion of the spacer negligible. The cryostat, the vacuum chamber and the heat shields to block the radiation coming from the outside are already manufactured and operational [1].

However, there are effects which degrade the frequency stability of the laser, such as vibrations which must remain below -110 dB$(m/s^2)^2$/Hz at 1 Hz, laser power fluctuations which will be controlled better than ≈ 100 pW [2] or the residual amplitude modulation which degrades the quality of the laser servo loop on the cavity [3]. The first objective of this thesis will be to minimize them in order to reach the relative frequency stability of 3×10^{-17}.

In parallel, one of the objectives of this thesis will be to set up the instrumentation for a dark matter detection test with this silicon cavity. Some dark matter models predict that these particles possess an energy of less than 1 eV.c^{-2} and fall within the domain of « ultralight scalar fields ». In this case, dark matter can be treated as a classical field, which causes variations in the frequency of clocks due to the oscillation of the fundamental constants of physics. In the same way, with a laser locked on an optical cavity, we can detect the presence of dark matter with the variation of the frequency of the laser, because of a change in the length of the cavity due to the oscillation of certain constants (mass of the electron, fine structure constant) and therefore the Bohr radius [4].

In summary, during this thesis, the candidate will have the opportunity to :
— develop a local ultra-stable frequency reference, reducing parasitic effects (vibration, residual amplitude modulation, laser power fluctuations).
— perform frequency comparisons with other frequency references in Europe, by doing frequency beat notes, via the European Fiber Metrological Network (REFIMEVE).

— participate in the development of a second cryogenic cavity cooled to a few hundred millikelvins, in order to improve the frequency stability by about an order of magnitude in the future.
— set up a dark matter detection experiment with a silicon cavity, in order to put new constraints on dark matter models in the 10^{-9} eV.c^{-2} range.

Bibliography

[1] A. Didier, Développement de cavités Fabry-Perot ultra-stables pour références de fréquence optique de nouvelle génération, thèse, 2016

[2] D. Świerad *et al.*, *Sci Rep* **6**, 33973, 2016

[3] J. Gillot *et al.*, Optics Express, Opt. Express **30,** 20, 2022

[4] E. Savalle *et al.*, Phys. Rev. Lett. **126**, 051301, 2021, arxiv:2006.07055

Applicant profile

The candidate will join the OHMS team of the Time-Frequency department of FEMTO-ST. The candidate must have a major interest in high-precision measurements, present skills in optics, electronics and instrumentation. Knowledge of mechanical design and fundamental physics is a real asset. The candidate will evolve within a team made up of researchers, engineers and technicians, and will have the support of the electronic, mechanical and IT services of the FEMTO-ST Institute and the OSCILLATOR-IMP infrastructure of excellence, dedicated to time & frequency metrology. The candidate will present its work at international conferences and will aim to have its work published in international journals.

Preferred selection criteria :
- Skills in optics, electronics and instrumentation
- Professional and academic background

Personal characteristics:
- autonomous at work
- likes to discuss and present their results with a team

Financement : ANR

If interested, application must be do as soon as possible
Starting : no earlier than December 1, 2022
Gross salary : 1975 €

Thesis Supervisor

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Applicants are invited to submit their application to the PhD supervisors at the mail addresses provided above.
Application must contain the following documents :
- CV with a cover letter
- Master’s transcripts
- At least 1 reference letter