

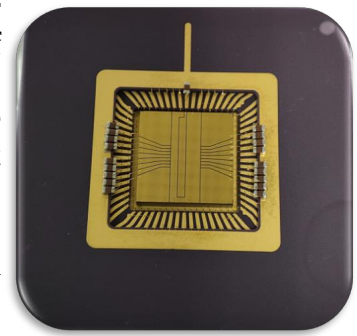
Clock laser influence on single ion optical clocks frequency stability

The project

This thesis subject is part of a compact and transportable optical clock project based on the a surface-electrodes (SE) Yb^+ ion trap developed in the Time and Frequency Department (TF Dpt) of the FEMTO-ST institute in Besançon.

The research carried out at the TF Dpt belongs to the field of frequency metrology, and aims more particularly at the development and the characterization of ultra-stable oscillators, sensors and atomic clocks. The PhD student will integrate the OHMS (Ondes, Horloges, Métrologies et Systèmes) team, an internationally recognized player in the TF field.

Atomic clocks have sustained a constant experimental progress for about fifty years. Today's most efficient clocks are based on the use of frequency-stabilized lasers locked to an optical transition between two energy levels of trapped, ultra-cold atoms. These devices have benefited both from technological advances related to the development of lasers, and from advances in atomic physics and quantum engineering granting an advanced control of the energy states of atoms. "Quantum logic", "composite pulses", "quantum non-demolition" and "squeezing" methods use quantum properties to further improve performance.



Micro-fabricated Surface Electrode trap

We are currently developing a compact optical clock based on trapped Ytterbium (Yb^+) ions. The objective of this project is to develop an atomic clock of reduced volume (about a hundred liters, compared to the tens of cubic meters occupied today by laboratory experiments) and with performances ten times better than current compact atomic clocks. This ambitious project involves the realization of a surface Paul trap, allowing to trap a single ion 500 μm away from micro-fabricated electrodes carrying radio-frequency (RF) voltages of about 250 V. This trap is inserted in an ultra-high vacuum chamber maintained under ultra-high vacuum ($\ll 10^{-9}$ mbar) that also contains the atom source (Ytterbium), and enables optical access for cooling, spectroscopy and fluorescence detection.

We demonstrated single-ion trapping and laser cooling in June 2018 with a prototype chip, a first in Besançon. A more sophisticated chip has been microfabricated in 2019 at the MIMENTO platform, using DRIE on a SOI wafer, and is currently being integrated in the vacuum chamber.

The thesis will focus on the development of the local oscillator of the optical clock and the implementation of the spectroscopy and laser lock sequences on the trapped ion.

A laser bench for frequency pre-stabilization will be developed. The quadrupole transition at 435.5 nm is achieved by second harmonic generation in a nonlinear crystal, from an infrared (IR) beam at 871 nm generated by an extended cavity laser diode. This IR laser will be pre-stabilized to an optical frequency comb, which will transfer the fractional frequency stability of an ultra-stable laser at 1542 nm locked to a Fabry-Perot cavity. An optical bench for the characterization of this fractional frequency stability transfer must be set up. The use of such a device will enable a test of the influence of the stability of the local oscillator on the performance of the clock by swapping the reference laser at 1542 nm.

In parallel to this experimental work, a simulation and programming work will be carried out to set up the experimental sequences of spectroscopy and servo control of the clock laser. The ARTIQ environment, already setup to drive the experiment, will be used for this. On the basis of simulations, the experimental parameters of Rabi, Ramsey or composite sequences (hyper-Ramsey, generalized Ramsey or auto-balanced) will be determined in order to be tested on the experiment.

The candidate

We are looking for candidates with a training in atomic and/or quantum physics, optics, or general physics. Experimental and/or instrumental training will be a great addition, as well as knowledge in analog and/or digital electronics. We also expect that the candidate will be a team-player, able to organize his/her own planning and work, and open to critical discussions about the project.

This thesis will allow the candidate to acquire an exceptional know-how and experimental methodology, in a high level scientific environment. The context of frequency metrology requires to master and control the noise sources of the experimental setup as well as possible, a skill that is extremely useful in many other research fields. The candidate will also develop an expertise in the field of trapped ions, which is still relatively unrepresented in France but very fertile at the European level.