Trapped Ion based Optical Atomic Clock: A Possible Way of Redefining SI Second

Subhasis Panja [†]

CSIR-National Physical Laboratory, Dr. K S Krishnan Marg, New Delhi 110012, India
Academy of Scientific & Innovative Research, Ghaziabad 201002, India

Synopsis We report progress at CSIR-NPL towards a single-ion $^{171}Yb^{+}$ optical clock based on the 435 nm electric-quadrupole transition. The ion is trapped in an rf Paul trap under ultra-high vacuum and laser cooled at 369.5 nm with 935 nm and 760 nm repump lasers. The clock laser is narrowed by locking to an ultra-low-expansion Fabry–Pérot cavity (finesse 50000, FSR 1.5 GHz). Optical clocks may enable a redefinition of the SI second.

The present definition of time or frequency is based on a microwave transition of laser-cooled caesium atoms. The variance of the measurement, the "Allan deviation", is inversely proportional to the resonance frequency, so an optical frequency standard with a resonance frequency of a few hundred THz can be two to three orders of magnitude more accurate than a microwave frequency standard [1]. It is expected that the SI unit of time will be redefined with an optical clock, based either on the atomic transition of ultra-cold atoms confined in optical lattices or on a single ion trapped in a radio-frequency ion trap and laser cooled [2,3].

At CSIR-NPL we are working towards building an optical atomic clock based on the quadrupole transition of a single ytterbium ion, stored in a Paul trap inside an ultra-high vacuum. The ion confined within the rf trap will be cooled to micro-Kelvin temperature using laser cooling to restrict its motion to the Lamb–Dicke regime. The strong transition at 369.5 nm will be used for laser cooling. However, in this case the excited state decays to two different metastable states, so two repump lasers at 935 nm and 760 nm will be used to deplete the long-lived metastable states and achieve closed-loop laser cooling. Hence three lasers at different frequencies are needed for laser cooling alone (Fig. 1). For clock operation we need to measure the transition at 435 nm, which has a natural linewidth of a few Hz. However, light from a typical extended-cavity diode laser has a linewidth of a few tens of kHz, and it is not possible to measure such a narrow spectrum with a laser of kHz bandwidth. For line narrowing, the laser will be locked to a highly stabilised Fabry–Pérot cavity. The cavity, of finesse 50000 and free spectral range 1.5 GHz, will be made of ultra-low-expansion material which has a zero expansion coefficient at room temperature. The present article describes activities and progress towards developing the optical atomic clock at CSIR-NPL.

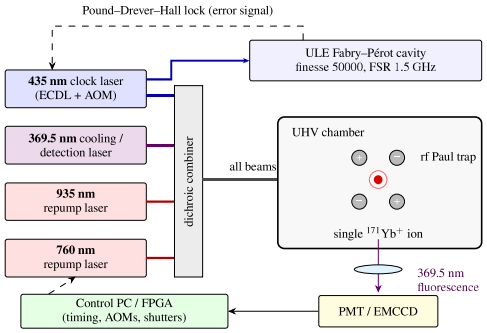

Figure 1. Schematic of the experimental setup for a single-ion $^{171}Yb^{+}$ optical clock. The 369.5 nm cooling, 935 nm and 760 nm repump beams and the 435 nm clock beam are overlapped on a single ion in an rf Paul trap in UHV. The clock laser is pre-stabilised to an ULE cavity; 369.5 nm fluorescence is detected with a PMT or EMCCD.

References

[1] Sharma L, Rathore H, Utreja S, Neelam, Roy A, De S and Panja S 2020 *MAPAN–J. Metrol. Soc. India* **35** 531
[2] Aeppli A, Kim K, Warfield W, Safronova M S and Ye J 2024 *Phys. Rev. Lett.* **133** 023401
[3] BACON Collaboration 2026 *Phys. Rev. Lett.* **137** 033201

[†]E-mail: panjas.nplindia@csir.res.in