Progress on a Surface-Electrode Ion Trap for Optical Frequency Metrology

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***Abstract*—We present our latest results obtained with a surface-electrode ion trap designed for optical frequency metrology. A prototype trap, based on a simple geometry realized on a printed-circuit board, has been successfully used to trap single Yb$^+$ ions. Our long-term goal is the realization of a compact single-ion optical clock.**

***Keywords*—ion optical clock; surface-electrode trap; time and frequency metrology**

I. INTRODUCTION

We report on the ongoing realization of a compact optical ^{171}Yb$^+$ clock on a chip. Ion frequency standards are well suited for compact optical clocks. In particular, several compact optical clock projects are based on Yb$^+$ ion [1]. The targeted fractional frequency stability is $10^{-14}\tau^{-1/2}$ for a total volume of less than 500 L, including vacuum cell, optics and electronics. Such a compact clock would be part of the growing European optical clocks network that already triggers new applications in a large variety of domains, ranging from relativistic geodesy to fundamental science [2, 3].

II. METHODS

Four lasers are needed for ionization (398 nm and 370 nm), cooling (370 nm) and repumping (935 nm and 638 nm) of ^{171}Yb$^+$, see Fig. 1. We use a single commercial wavelength meter from HighFinesse for frequency stabilization of the four lasers. The wavelength meter accuracy of 60 MHz and frequency drift of 20 MHz/day [4] require daily calibrations using built-in neon lamp.

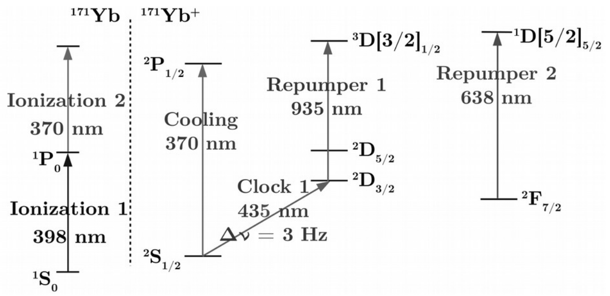

Fig. 1. Relevant atomic levels of ^{171}Yb and ^{171}Yb$^+$.

The laser at 435.5 nm which will excite the quadrupole clock transition of ^{171}Yb$^+$ is obtained by second harmonic generation from a 871 nm laser diode in a PPLN waveguide. We have characterized the phase noise induced by the second harmonic generation modules with a Mach-Zehnder interferometer and observed a relative phase noise as low as -40 dBrad^2/Hz at 1 Hz, which makes them compatible with the best up-to-date optical clocks and ultra-stable cavities [5]. The 871 nm laser is currently stabilized on an optical frequency comb referenced to an ultra-stable optical Fabry-Perot cavity [6], but this will be replaced in the future by a compact reference cavity at 871 nm based on a 25 mm long Fabry-Perot resonator embedded in a compact setup [7].

The ion trapping potential is generated by a surface-electrode linear Paul trap. It follows the "five wires" design and microfabrication techniques that have been primarily developed and used by the quantum information community [8]. Its operation at an RF frequency of 5.8 MHz and a voltage of 190 V leads to a 300 meV deep linear Paul trap with harmonic trapping frequencies of 360 kHz radially and 100 kHz axially. The ion-chip distance of 500 µm has been chosen to limit anomalous heating.

The current chip is 30×60 mm^2 large and has a mini-SD connector in order to allow fast plug-and-play replacements [9], see Fig. 2. This prototype trap is based on a PCB board, but the next version will take advantage of standard cleanroom microfabrication techniques.

The experiment control essentially relies on low noise compact home-built digital electronics.

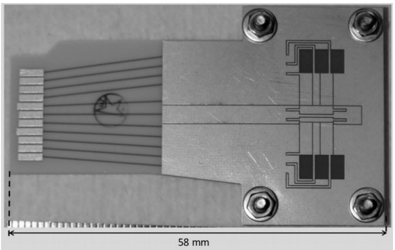

Fig. 2. Photograph of the trapping chip. It is driven at 5.8 MHz and 190 V to generate a linear Paul trap with 300 meV depth. The trapping electrodes are located on the right-hand side, while the micro-SD format on the left-hand side is used for electrical connection.

III. RESULTS AND DISCUSSION

We recently demonstrated trapping of Yb^+ ions in the prototype trap (see Fig. 3). Using $^{176}Yb^+$ isotope, trapping times of up to 1500 s have been measured. However, with a residual background pressure of a few 10^{-9} mbars, the average ion lifetime is limited to 220 s (see Fig. 4). A new version of the chip based on standard cleanroom microfabrication processes, associated with an improved pumping scheme for the vacuum chamber, should lead to at least a factor ten improvement on the residual pressure and strikingly improve the ion lifetime.

We will present the first characterization of our trap, including ion temperature, lifetime and heating rate measurements.

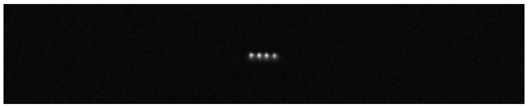

Fig. 3 Fluorescence image of a linear crystal of four $^{176}Yb^+$ ions in our prototype trap. The spacing between the ions is about 16 µm.

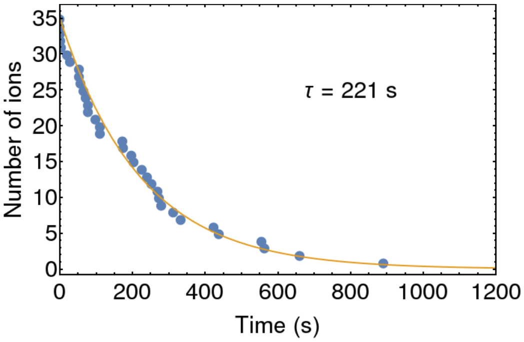

Fig. 4. Single trapped ions lifetime (blue dots) and exponential decay fit (yellow curve).

IV. CONCLUSIONS

We have developed and tested a prototype surface-electrode trap for optical frequency metrology. The first characterizations of the trap are promising for the targeted clock operation, and the clock laser is being set up. Current efforts are dedicated to improvements of ion lifetime and heating rate, in preparation for interrogation of the clock transition.

V. REFERENCES

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