Experimental set-up for loading Sr atoms into a hollow-core fibre for continuous operation of optical clocks

Sławomir Bilicki[1], Marcin Bober[1], Maciej Chomski[2], Piotr Morzyński[1], Marcin Witkowski[1], and Michał Zawada[1]

[1]Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Grudziadzka 5, PL-87-100 Torun, Poland

[2]Central Office of Measures, Time and Length Department, New Technologies of Time and Length Laboratory, ul. Elektoralna 2, 00-139 Warszawa

Email: slawko@fizyka.umk.pl

Optical clocks (OC) are based on the highly precise interrogation of an optical transition, where instabilities and inaccuracies in the 10^{-18} range can now be reached[1]. Most OC realizations include an oven at over 500 K and strong dynamic magnetic fields. Spatially separation between the production region and the measurement region would be a great improvement. In the present generation of OC a laser locked to an ultra-stable optical cavity preserves the frequency stability while a new sample of ultracold atoms is prepared and loaded into the atomic standard. At the same time, the linewidth provided even by the best reference lasers is much broader than the atomic clock transition. One of the proposed solution is the system with continuous superradiant lasing of an ensemble of atoms on the clock transition[2], producing light directly at the clock frequency. Our way to continuously load ultra-cold atoms to the reservoir is the development of a fibre-based delivery system for atoms based on laser guiding through a hollow-core crystal fibre.

In our project we develop an experimental setup to trap ^{88}Sr atoms in magneto-optical trap and transfer them spatially with assist of optical dipole potential inside a hollow-core fibre. Strontium atoms have a level structure with narrow intercombination lines, which allow for second-stage laser cooling to temperatures in the range of a few µK. This lower temperature promises to reduce the required trap depth inside the fibre, which is a great advantage. We focus on the delivery of atoms from a preparation area that consists double stage cooling by $^1S_0$-$^1P_1$ and $^1S_0$-$^3P_1$ transitions into the measurement area on the other side of the fibre. Assuming a transport velocity of order 1 m/s and loss rates well below 1 s^{-1}, which can be achieved in free-space optical traps, atom guiding over a distance of many meters is feasible. The dominant source for heating in the fibre has been identified as a modulated potential caused by back reflections from the fibre end[3]. The associated heating rate of 300 µK/s can be compensated by continuous laser cooling. We want to experimentally determine the optimal cooling and loading strategy for Sr. During guiding we aim to increase atom lifetime to the range of 1 s by reducing the residual heating by employing targeted cooling schemes, and a moving optical lattice to control the atoms' forward velocity. We will extend length of the fibre to 5 meters. We will use a Kagome fibre (63 µm core diameter) of low birefringence and small excitation of cladding modes.

[1] The OC18 collaboration, Guidelines for developing optical clocks with 10^{-18} fractional frequency uncertainty

[2] M. A. Norcia and J. K. Thompson, Cold-strontium laser in the superradiant crossover regime, Phys. Rev. X 6, 011025 (2016)

[3]S. Okaba et al., Lamb-Dicke spectroscopy of atoms in a hollow-core photonic crystal fibre, Nature Commun. 5, 4096 (2014)