

Development of laser system for magneto-optical trapping of francium atoms

K. Nakamura,^{*1} S. Nagase,^{*2} T. Nakashita,^{*3,*4} T. Aoki,^{*3} H. Nagahama,^{*1} and Y. Sakemi^{*1}

Francium (Fr), the heaviest alkali metal, is a promising candidate for probing the permanent electric dipole moment (EDM).^{1,2} Our goal is to perform ultra-precise EDM measurements using cold Fr atoms trapped in an optical lattice. To achieve this, Fr atoms must first be pre-cooled and trapped using a magneto-optical trap (MOT).

This report presents the laser system for the Fr MOT developed at RIKEN. As shown in Fig. 1, the experimental setup spans several locations in the Nishina and RIBF buildings. The laser sources are located in the laser room (K2L), while the ²¹⁰Fr and ²²¹Fr MOT apparatuses were located in the target room E7 and the hot laboratory (HL), respectively.

The laser beams are transmitted from K2L via a 400 m fiber optic cable to the optical relay rack, which distributes them to E7 (40 m) and HL (55 m). The relay rack acts as a central hub, allowing directional switching via optical fiber connectors.

The laser system is shown in Fig. 2. A Ti:sapphire laser is used as the Fr trapping laser (wavelength 718 nm). An external cavity diode laser (ECDL) with an interference filter is used as the Fr repumping laser (817 nm). Additionally, a Littrow-type ECDL (780 nm) and a distributed feedback (DFB) laser (795 nm) provide trapping and repumping beams for the ⁸⁷Rb MOT, which serves as a test system.

A wavelength meter (HighFinesse WS8-2) with an 8-channel fiber switch measures and stabilizes up to seven laser beams simultaneously using a proportional-integral-derivative (PID) controller. The system is calibrated every 10 minutes using a frequency-stabilized ECDL locked to the ⁸⁷Rb D2 transition (780 nm) by modulation transfer spectroscopy.

The Fr trapping and repumping beams were combined into a common path using the dichroic mirror DM1, while the Rb beam was combined via DM2. These combined beams, called MOT beams, were then orthogonally combined at the polarizing beam splitter (PBS1). The Fr and Rb MOT beams can be switched by rotating the half-wave plate (H1). The MOT beam is split into three paths by PBS and H and then directed into three polarization-maintaining (PM) fibers. A quarter-wave plate (Q) converts the polarization to circular before entering the MOT apparatus. The MOT beams are introduced along three axes and reflected by mirrors on each diagonal, forming

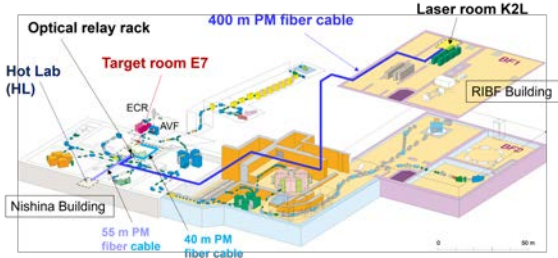


Fig. 1. Whole light path of PM fiber cable for MOT experiment.

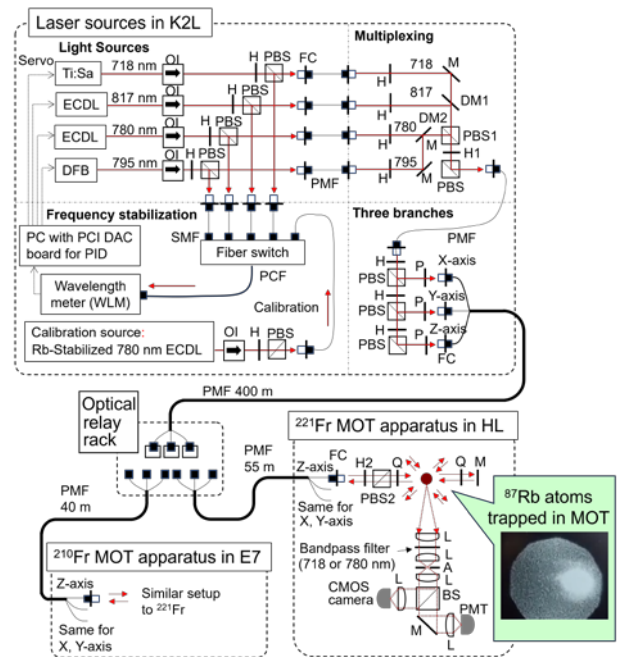


Fig. 2. Schematic diagram of laser system developed at RIKEN. Inset shows fluorescence image of ⁸⁷Rb MOT by CMOS camera in HL.

a three-dimensional MOT.

The optical transmittance of the 400-m fiber is 0.68 at 718 nm and 0.79 at 780 nm at low input. Stimulated Brillouin scattering limited the maximum optical power transmitted through the fiber at high input. When the 400-m PM fiber was connected to the 40-m PM fiber for light delivery to the MOT apparatus at E7, the typical transmission power was 14 mW at 718 nm.

We have successfully demonstrated MOT with stable ⁸⁷Rb atoms in E7 and HL. Optimization efforts are underway to achieve MOT with Fr atoms, paving the way for future precision EDM measurements.

References

- 1) Y. Sakemi *et al.*, CNS Ann. Rep. **2020**, 15 (2022).
- 2) V. Spevak *et al.*, Phys. Rev. C **56**, 1357 (1997).

^{*1} Center for Nuclear Study, University of Tokyo

^{*2} Department of Physics, University of Tokyo

^{*3} Graduate School of Arts and Sciences, University of Tokyo

^{*4} RIKEN Nishina Center