Long polarization-maintaining fiber link (440 m) for magneto-optical trapping of francium atoms

K. Nakamura,[*1] S. Nagase,[*2] T. Nakashita,[*3] T. Hayamizu,[*4] T. Aoki,[*3] H. Nagahama,[*1] N. Ozawa,[*2] M. Sato,[*3,*4] K. Yamane,[*3] M. Fukase,[*2] D. Uehara,[*2] A. Takamine,[*4] and Y. Sakemi[*1]

We are currently developing an optical lattice francium (Fr) atom interferometer to determine the permanent electric dipole moment of an electron (eEDM). Fr is the heaviest alkali atom with an eEDM enhancement factor of approximately 799.[1)] The trapping of such Fr atoms in the optical lattice leads to an ultra-sensitive eEDM measurement system with a long interaction time between the isolated atoms and electric field. To load the atoms into the optical lattice, they must be cooled and trapped beforehand by techniques such as magneto-optical trapping (MOT). We developed a MOT system and connected it to a ^{210}Fr production beamline, which consists of a surface ionizer[2)] and neutralizer, installed in the E7 vertical course. In addition, we linked the MOT system to laser devices in the laser spectroscopy room (referred to as L) on the first basement floor of the RIBF building with 440 m-long polarization-maintaining (PM) fibers. In this paper, we report the performance of the PM fiber link.

The fiber link consists of a polyvinyl chloride (PVC)-coated 400 m flexible stainless steel tube cable (Nippon Steel Welding & Engineering, Picoflec) from L to the E7 entrance and another 40 m tube cable from the E7 entrance to the MOT system (Fig. 1(a)). Seven PM fibers are housed in each cable; among these, four are Fujikura PM63 (cutoff wavelength is 520–620 nm, mode field diameter is 4.5 ± 0.5 μm at 630 nm), two are PM85 (650–800 nm, 5.5 ± 0.5 μm at 850 nm), and one is PM98 (870–950 nm, 6.6 ± 0.5 μm at 980 nm). Both cables are connected using fiber connectors inside the optical rack installed at the E7 entrance. The typical transmission loss due to the connector was 0.25. The optical rack was also expected to serve as a hub base for optical transmission to other laboratories. The lights of the trapping lasers (wavelength of 718 nm for ^{210}Fr, 780 nm for ^{87}Rb, used for offline test) and repumping lasers (817 nm for ^{210}Fr, 795 nm for ^{87}Rb), which were frequency-stabilized within the natural linewidth of relevant transitions (several MHz) using a wavelength meter (HighFinesse, WS8-2), were transmitted to the MOT system via fibers (PM63). In general, frequency instability due to a fiber is low (~3 Hz for 6 km at 778 nm in Ref. 3)), and thus, negligible for our optical transmission.

In the case of a high-power CW laser beam transmitted along a long fiber, there are concerns related to the limit of transmitted power due to stimulated Brillouin scattering (SBS).[4)] To maximize the number of atoms to be captured, the trapping laser intensity (total of 6 axes of 3D MOT) should be several times (8 times in Ref. 5)) the saturation intensity of the cooling transition. The saturation intensity of ^{210}Fr (^{87}Rb) is ~2.9 (~1.6) mW/cm^2. When using our trapping laser (SolsTiS, CW, linewidth <50 kHz), the SBS threshold output power for the 400 m fiber (PM63) was 30 mW at 718 nm. This value is sufficient for our three-axis 3D MOT system (beam diameter of 1 cm) with opposing mirrors.

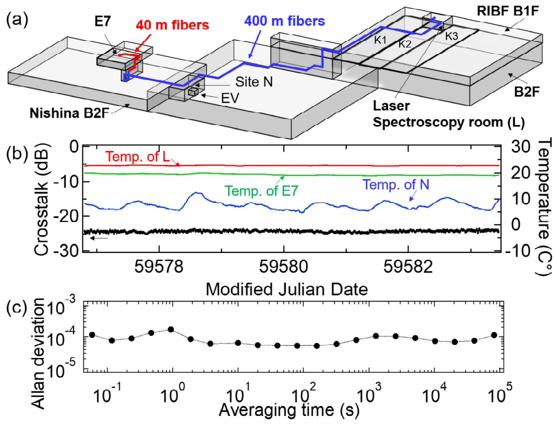

Fig. 1. (a) Overhead view showing the path of a fiber link. (b) Polarization crosstalk in the 400 m fiber and temperature measured at three sites. (c) Allan deviation of the crosstalk.

The stability of polarization of the 400 m PM fiber was investigated with a test laser (685 nm, 1 mW). The polarization crosstalk calculated from the optical power of the *p*- and *s*-polarized outputs split by the polarization beam splitter after launching from the 400 m PM fiber and the temperature measured at three sites (L, E7, and N) are shown in Fig. 2(b). Site N is near the elevator on the second basement floor of the Nishina Building (Fig. 1(a)). Figure 2(c) shows the Allan deviation calculated from the time series data of the polarization crosstalk. The PM fibers housed in the PVC-coated 400 m tube were robust against large diel temperature fluctuations along the fiber.

We achieved Rb MOT in July 2021 in an offline test. Online experiments are being conducted intermittently to achieve Fr MOT, and we are getting closer to achieving it.

*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

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