

Sputtering of yttrium on the ^{225}Ac source for the magneto-optical trap of ^{221}Fr

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The violation of the charge conjugation and parity (CP) symmetry is a fundamental condition for understanding the origin of the matter-dominated universe. Currently, the CP violation from the standard model of elementary particles is insufficient to explain the observed matter-antimatter asymmetry.¹⁾ The permanent electric dipole moment (EDM) of elementary particles shows the CP violation. If a finite value of EDM is discovered, a new limitation will be set to build the new theory of physics beyond the standard model. Francium (Fr), the heaviest alkali element, enhances the EDM of the electron by a factor of 799.²⁾ Our group is developing a trapping system for measuring the EDM of Fr atoms.

For the precise measurement of the EDM, sufficient supply and trapping of Fr atoms are important. Since Fr has no stable isotopes, they have to be produced artificially. In this study, ^{221}Fr produced through the α -decay from actinium-225 (^{225}Ac , $T_{1/2} = 9.9$ d) was adopted. Compared to nuclear fusion reactions, the Fr source from the ^{225}Ac generator does not need to be produced using the accelerator, and the experiment can be operated in a compact system for a longer time.

The magneto-optical trap is an experimental apparatus to trap atoms. In our previous work, a source of electrically neutral ^{221}Fr atoms was introduced.³⁾ ^{225}Ac was electrodeposited on a platinum foil and a thin yttrium foil was formed over the source by the argon sputtering deposition. Fr atoms generated from this source were stopped inside the yttrium foil and released by heating the ^{225}Ac source. However, the high heating temperature of 1300 K was required to release the Fr atoms, and the outgas from the source increased the pressure of the chamber up to $\sim 10^{-4}$ Pa. The over-deposited yttrium could increase the temperature required to release the atoms. The thick yttrium foil may decrease the number of the released ^{221}Fr atoms. Therefore, we planned to search for the best thickness of the yttrium foil by optimizing the sputtering process.

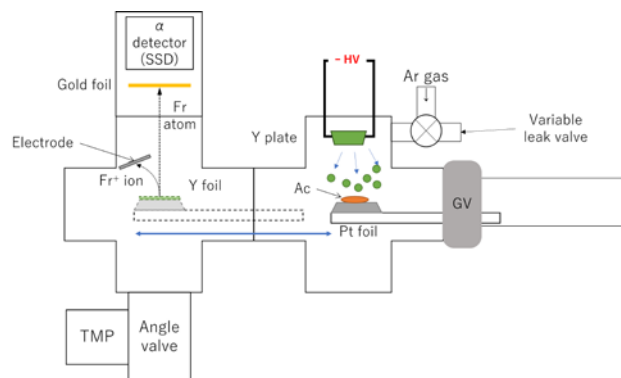


Fig. 1. Schematic of the yttrium sputtering chamber.

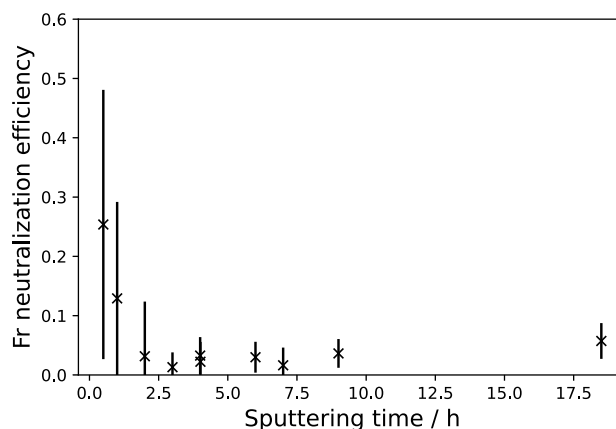


Fig. 2. Neutralization efficiency of ^{221}Fr atoms as a function of sputtering time.

Figure 1 is a schematic of the vacuum chamber for the sputtering. The ^{225}Ac of 0.86 MBq was electrodeposited on a platinum foil before forming a yttrium foil. This ^{225}Ac source can be moved inside the chamber by a linear motion feedthrough. The source was moved under the yttrium plate to create the yttrium foil and the chamber was filled with approximately 4 Pa of argon gas. Argon ions sputter on the surface of the yttrium plate when a negative high voltage (-700 V) is applied. The sputtered yttrium atoms accumulate on the source and form the thin foil. The thickness of the yttrium foil is assumed to be proportional to the sputtering time. For measuring the Fr atoms, argon gas was pumped out and the source was moved under the solid-state detector (SSD). The Fr atoms released from the source were collected by the gold catcher foil in front of the SSD, and α particles emitted from them

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were counted. When negative voltage was applied to the electrode, only neutralized Fr atoms were detected. The total number of released Fr atoms and the fraction of neutral atoms were measured after every certain time of yttrium sputtering. The ^{225}Ac source was heated to approximately 1000 K for 60 s on each measurement to release Fr atoms.

Figure 2 shows the fraction of the neutral Fr atoms from the ^{225}Ac source (neutralization efficiency). For the sputtering time of 0.5 hours, few atoms are stopped by the yttrium foil, which results in the large error in neutralization efficiency. For the sputtering time of 1.0–18.5 hours, the neutralization efficiency showed no significant change around 10%. This low efficiency indicates that the neutralization effect by the yttrium foil is not observed in this experiment.

Figure 3 shows the relative number of Fr atoms released without heating the source. These atoms were not stopped inside the yttrium foil and treated as background when measuring the neutralization efficiency. In the first experiment (the same experiment as that shown in Fig. 2), the neutralization efficiency was measured on each point, and the background Fr atoms increased after the first measurement point. This can be attributed to a thermal diffusion of ^{225}Ac inside the foil; however, the detailed reason is yet to be elucidated. In the second experiment, a new ^{225}Ac source of 0.98 MBq was installed. The source was not heated during the 6 hours of yttrium sputtering to observe the effect of heating on the formation of the yttrium foil, and only background measurements were conducted. The background Fr atoms decreased faster than the previous experiment. After the sputtering, the efficiency of the neutralization was measured with the same heating condition as the first experiment. The efficiency was improved to $73 \pm 6\%$.

These results confirmed that the neutralization efficiency and the capacity of stopping Fr atoms were affected by heating the source. Therefore, the measurement of the neutralization efficiency should be conducted only after forming a sufficient amount of yttrium to stop the ^{221}Fr atoms. The best conditions of sputtering to increase the number of neutral atoms were not confirmed, and therefore, the improved experiment has to be considered to optimize the sputtering conditions. The development of the system for the magneto-optical trap is in progress to improve the trapping efficiency for the next experiment.

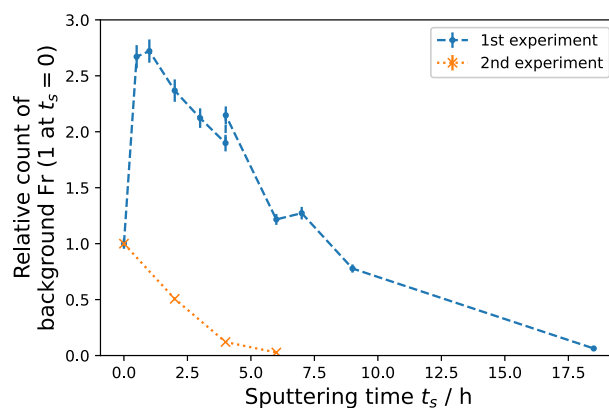


Fig. 3. Relative number of background Fr atoms. In the first experiment, the Ac source was heated at every point to measure the neutralization efficiency. In the second experiment, the source was not heated and only the background was measured.

References

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