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TWO-DIMENSIONAL BEAM PROFILE MONITOR FOR ALPHA EMITTER

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Abstract

We developed two-dimensional beam profile monitors for alpha-emitters along with other larger number of ions the experiment to measure the permanent electric dipole moment of the electron using francium (Fr) atoms at CYRIC in Tohoku university. Fr is produced by the fusion reaction between the oxygen beam from the cyclotron accelerator and the gold target, and a far larger number of other ions such as Na^+ or K^+ are also emitted from the target. It is difficult to measure the beam profile of Fr^+ since it is hidden by these ions. To measure the Fr^+ beam profile in this condition, we installed two beam profile monitors consisted of the micro-channel plate and phosphor screen. If we stop the beam after the injection to the monitor in sufficient time, we can only observe the fluorescence of the alpha particle emitted by Fr atoms on the surface of the plates. By using this monitoring system, we can optimize only the Fr^+ beam transportation and removed most of other ions by Wien filter.

INTRODUCTION

Search of the permanent electric dipole moment (EDM) using various kinds of atom and molecules has been carried out in recent years. The infinite value of electron EDM would imply of a new physics beyond the standard model of particle physics [1].

We are preparing the precise measurement of the EDM using a Fr in CYRIC. Fr is one of a suitable atom to search the electron EDM. It is the heaviest alkaline metal so that it has a large enhancement factor of EDM and can be applied laser cooling technique [2].

Fr is produced by nuclear fusion reaction between an oxygen beam (^{18}O) provided from CYRIC and gold target (Fig. 1). The intensity of the Fr production is limited such as 10^6 /s due to the intensity of the oxygen beam [3].

Fr is ionized by surface ionization on the gold target, and transport 12 m length to the measurement area which is free from the background noise of the cyclotron accelerator. The Fr^+ is accumulated to the Yttrium foil which has a small work function (E_{WF} = 3.1 eV). Then Fr atoms are release as a neutral atom by heating the foil and load to the laser-trapping area. The size of the yttrium foil is only 10 mm × 10 mm, so that the control and focus of the Fr^+ beam to this small area is important to the efficiency of the number of the Fr loaded to the trapping area.

Also, we need to care about the other ions along with the Fr ions which cause atomic collisions in the trapping area. Typically, the intensity of Fr^+ beam is 10^6 /s and that of other ions (Na^+,K^+) are more than 10^{11} /s. Even light ions can be removed from the Fr^+ beam by Wien filter, ions which comparably close to the mass of Fr^+ such as Au^+ are difficult to remove. Hence beam profile of the Fr^+ is hidden by larger number of ions and unobservable with typical ways. Previously, the beam transport efficiency is measured by the rate of alpha decay from the Faraday cup by the solid-state detector (SSD) after the beam irradiation with enough time. However, this way only measure the total number of the Fr^+ but not measure the profile of the beam. This is the main reason that the optimization of the beam transportation was insufficient [4].

Therefore, we developed the new two-dimensional beam profile monitor for alpha emitter ion beam separated from the other ion beam by using the microchannel plate (MCP) and the phosphor screen.

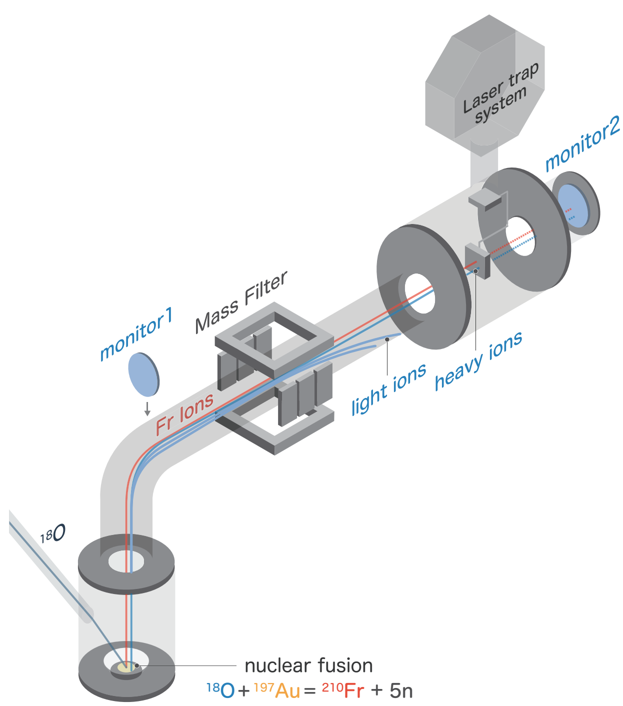

Figure 1: Fr^+ beamline at CYRIC. two beam monitors for alpha-emitter is installed on the beamline.

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DESIGN

Two beam profile monitors (monitor1 and monitor2) are installed on the Fr beamline. monitor1 is loaded on the downstream end of the beamline. the downstream of the neutralizer is free from the electromagnetic field so that the beam profile on the neutralizer can be reconstructed geometrically from monitor1. The monitor2 is used to make a diagnosis of the production distribution of Fr ions and other ions on the target.

Two monitors are consist of a chevron microchannel plate (MCP) and a phosphor screen (as shown in Fig. 2). The MCP is a chevron type (two plates mounted) which has a diameter of 40 mm, and the phosphor screen is used the RHEED screen. Also, SSD is loaded at the viewing angle of the surface of the MCP to measure the absolute number of the alpha-decay. ^{241}Am alpha sources is located in front of the SSD for the energy calibration of the SSD.

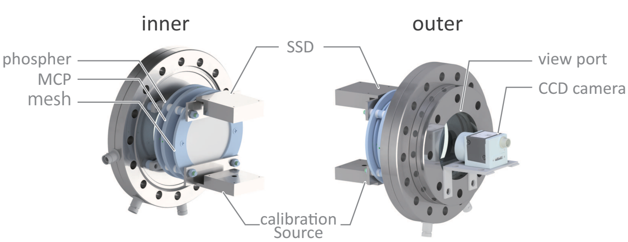

Figure 2: Design of the monitor2. The monitor is consisted of the MCP and the phospher screen. SSD is loaded at the viewing angle of the surface of the MCP to measure the absolute number of the alpha-decay.

The impacts of the ion beam on the MCP produce cascades of electrons that propagate through one of the small channels by applying a strong electric field across the MCP (as shown in Fig. 3). The electron clouds are converted to the visible light by the phosphor screen and observe it by CCD camera (Basler acA2500-14um for monitor1 and acA1300-60gm for monitor2).

Since the intensity of the Fr beam is relatively small compared to the other ion beams, we could not observe the Fr beam directly. Fr beam profile is observable from produce cascade of electrons by decay alpha of Fr instead. The measurement sequence is as follows:

- Inject the ion beam to the monitor. The dominant part of the ion beam is observable.
- Keep injection for 10 minutes which is enough compare to the lifetime of Fr (as shown in Table 1) to accumulate the Fr atoms on the surface of the MCP.
- Stop injection to the monitor. Just after that, we can observe the Fr beam profile.

PERFORMANCE TEST

We test these two monitors with Fr$^+$ beams. Figure 4 shows the typical result of this test measurement on monitor2.

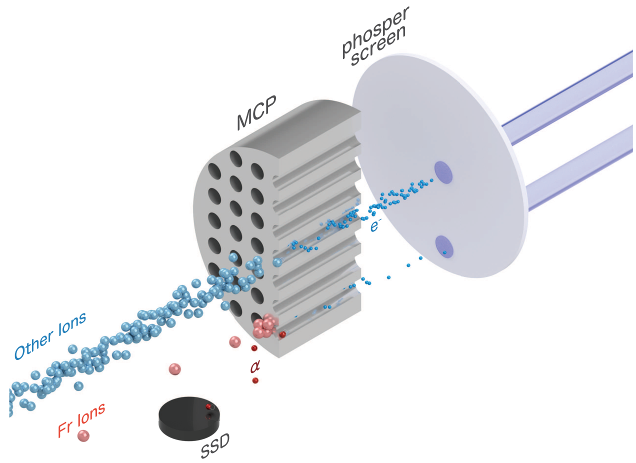

Figure 3: Layout of papers.

The total fluorescence on the monitor is increased by the number of the Fr atoms on the MCP. After the stop beam injection, we can observe only the decay alpha particle from Fr atoms. Therefore, we can obtain both beam profile of Fr and the others simultaneously.

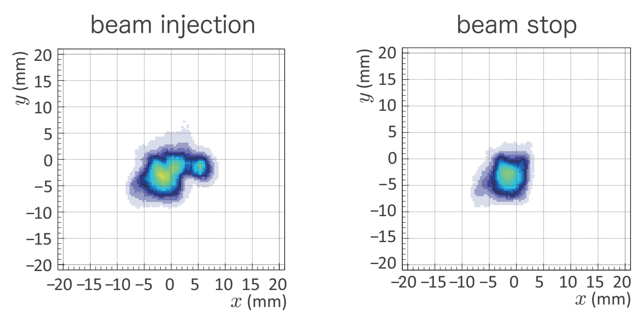

Figure 4: The left image shows the output of the monitor after the beam injection for 10 minutes. The right image is the output of the monitor just after the beam stop. Only the beam profile of Fr$^+$ can be observed.

By this new monitor and the measurement procedure, we achieve to remove most of the ions including heavy ions such as Au$^+$ by Wien filter. Figure 5 shows the typical result after this optimization. The total fluorescence is increased in response to the accumulation of the Fr, and it was almost unchanged after the beam stop because most of the fluorescence is caused by alpha-decay from Fr now. It shows that most of the other ions are removed. The decay curve after the beam stop is expressed as

$$N(t) = N(0)(1 - e^{-t/\tau}), \quad (1)$$

where the τ is lifetimes of composite of several alpha emitters. the measured value of τ is 130 s which is consistent to consider the lifetime of several isotopes of Fr (Table 1).

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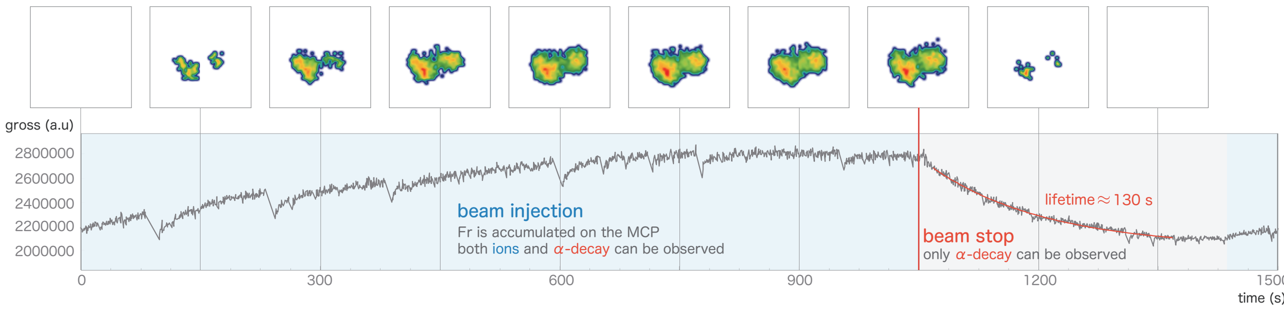

Figure 5: The typical measurement result of the monitor. The total fluorescence is increased in response to the accumulation of the Fr, and it was almost unchanged after the beam stop.

Table 1: Production rates of Fr isotopes generated by a 100 MeV $^{18}O^{6+}$ beam on a thick gold target and decay properties [5].

isotope	production rate	α fraction	lifetime
^{208}Fr	0.025 %	90 ± 2 %	59 s
^{209}F	17 %	89 ± 4 %	50 s
^{210}Fr	64 %	60 ± 30 %	191 s
^{211}Fr	19 %	> 80 %	186 s

CONCLUSION

We developed two-dimensional beam profile monitors for alpha-emitters along with other larger number of ions for the experiment to measure the permanent electric dipole moment of the electron using francium (Fr) atoms at CYRIC in Tohoku university.

By using this monitoring system, we improved the beam transport efficiency by several times and improved beam purity of Fr with Wien filter.

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