Development of the Surface Ionizer for the Fr Production to Search for \( \theta_\theta \) from Sakemi Y., Hayamizu T., Oikawa A., Itoh M., Yoshida P.H.

<table>
<thead>
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<th>著者</th>
<th>サケミ汚流、ハヤミズ、オイカワ、イトウ、ヨシダ</th>
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<tbody>
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<td>タイトル</td>
<td>ファレル産業における表面イオン板の開発</td>
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<td>作者</td>
<td>サケミ</td>
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<td>CYRIC年度報告</td>
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I. 4. Development of the Surface Ionizer for the Fr Production to Search for the EDM

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An Electric Dipole Moment (EDM) of the elementary particle is a good prove to observe the phenomena beyond the Standard Model (SM), since the SM predicts quite small EDM such as less than $10^{-37}$ e · cm for the electron. A non-zero EDM is considered as a background free signal of CP violation beyond the SM. In paramagnetic atoms an electron EDM results in an atomic EDM enhanced by the factor $\sim Z^3 \alpha^2$. The element which has largest enhancement factor is a heaviest alkali element and the radioactive atom francium (Fr). However the EDM for the Fr have not yet been measured because it is difficult to make a concentrated sample due to a short life time for the standard experiment. Then, we started to construct a high intensity laser cooled Fr factory at CYRIC for the first challenge to perform the search for the unstable atom Fr. The key points of this successful next generation experiment are the high intensity Fr source and the laser cooled/trapped equipments to achieve the small statistical and systematic errors. In this report, the present status of the developments of the thermal ionizer to produce the Fr ions is described.

The Fr is produced by a heavy-ion fusion reaction between an oxygen beam and a gold target ($^{18}$O+$^{197}$Au → $^{210}$Fr +5n etc.) with the primary beam energy ($E_{180}$-100 MeV) just above the coulomb barrier. The target consists of a lump of gold melted and flattened onto the end of a nickel rod with a thickness of 50 $\mu$m (97 mg/cm²). The cartridge heater is configured inside the nickel rod for heating the gold target to diffuse Fr ions produced in fusion reaction with surface ionization, but it was found to be not necessary to heat up the target because the target itself could be heated by the primary beam power and the radiation from the oven described below. The embedded Fr in the target diffuses rapidly to the surface and evaporates as the ions with the fraction according to the Langmuir-Saha equation:
\[
\frac{n_+}{n_0} = \frac{\omega_+}{\omega_0} \exp\left(\frac{E_{WF} - E_{IP}}{k_T}\right),
\]

where \( n_+/n_0 \) is the ratio of ions to atoms desorbed, \( \omega_+ / \omega_0 \) is the ratio of the statistical weights and equals 1/2 for alkali atoms, \( E_{WF} \) is the work function of the surface, and \( E_{IP} \) is the ionization potential of the desorbed atom. The target is surrounded by the high temperature oven to collect all the Fr ions in the limited space. The oven is heated by the 4 cartridge heaters installed in it. The Fr ions are extracted from the extraction electrode placed in the side face of the oven. The shape and size of the extraction electrode is designed and optimized to realize the small Fr beam emittance with \( \sim 15\pi \text{ mm–mrad} \) with the Fr ion track simulation using the realistic electric field as shown in the Fig. 2. The structure of the thermal ionizer is shown in the Fig. 1.

We constructed the beam line for the Fr production at the 34 course in the target room 3. The developed thermal ionizer was installed in the end of the beam line with the beam viewer and beam stopper to monitor the primary beam current just before the ionizer. The experiments to observe the Fr production and check the extraction efficiency have been done. We set the SSD detector along with the extracted Fr beam axis with the adjustable distance to measure the alpha decay with the energy 6.5MeV from the produced\(^{210}\)Fr which were stopped on the surface of the detector. The temperature of the detector became high due to the radiation from the ionizer, then it was cooled by the peltier device attached to the bottom of the SSD to keep the high energy resolution. The measured spectrum is shown in the Fig. 3, and it is clearly seen that we have succeeded to extract the Fr from the ionizer without background of other radioisotopes. The detailed analysis to estimate the extraction efficiency is now in progress.

**Reference**

Figure 1. The structure of the thermal ionizer.

Figure 2. The left figure shows the Fr ion track simulation around the extraction electrode. The right plot shows the distribution of the emittance of the extracted Fr ion beam.

Figure 3. The α decay energy spectrum of the $^{210}$Fr extracted from fusion reaction with $^{18}$O and $^{197}$Au.