# Status of RIKEN 28 GHz SC-ECRIS towards the production of intense uranium ion beams†

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With plans to upgrade the accelerator at RIBF for nuclear physics experiments, the demand for even higher uranium beam intensities has driven further improvements in the performance of the R28-GHz SC-ECRIS.[1)] The output beam for $U^{35+}$ requires ∼300 electric $\mu$A (e$\mu$A) and continuous efforts in developing the high-temperature oven have allowed achievable beam intensities to reach 250 electric $\mu$A (e$\mu$A).[2)] Based on the accumulated data set for $U^{35+}$ beam production, the beam intensity with respect to microwave power is summarized in Fig. 1(a). Assuming a linear relationship between the two parameters, achieving a beam current of 300 electric $\mu$A (e$\mu$A) would require ∼4 kW of microwave power, with corresponding extraction currents in the range of 10 mA as shown in Fig. 1(b). From the expected beam conditions, ion source parameters and beam quality should be checked thoroughly since high power operation may have some unforeseen issues.

To investigate the beam quality, the beam emittance was measured using a slit-wire-type emittance monitor and the normalized root mean square emittance $\varepsilon_{\mathrm{nrms}}$ for $U^{35+}$ beams was calculated in a systematic study under different beam conditions. One of the observed parameters that greatly influences the beam emittances is the extraction current. As extraction current represents the sum of all ion species present in the extracted beam, this parameter was a useful indicator for estimating the total beam current.

The beam emittance is influenced by different factors such as ion source condition, space charge and other unknown effects.[3–5)] To simplify the measurement analysis, minimal influence from beamline components was assumed, and the normalized beam emittance can be described using a simple equation,

$$\varepsilon = (\varepsilon_0^2 + \mathrm{KI}_{\mathrm{ext}}^2)1/2 \quad [\pi \text{ mm mrad}] \qquad (1)$$

where $\varepsilon$ is the normalized rms beam emittance, $\varepsilon_0$ is an initial beam emittance in $\pi$ mm mrad, K is a constant describing the beam distribution and $\mathrm{I}_{\mathrm{ext}}$ is the extraction in mA.[6,7)] The term $\mathrm{KI}_{\mathrm{ext}}^2$ is assumed to be related to the effect of space charge where $\mathrm{I}_{\mathrm{ext}}$ serves as an indicator of the total beam current. Using Eq. (1), the $\varepsilon_0$ can be determined under the assumption that as $\mathrm{I}_{\mathrm{ext}}$ approaches zero, revealing an initial value for beam emittance. As shown in Fig. 2, experimental $\varepsilon$ beam emittance and calculated values for $\varepsilon_0$ and are plotted against the extraction current.

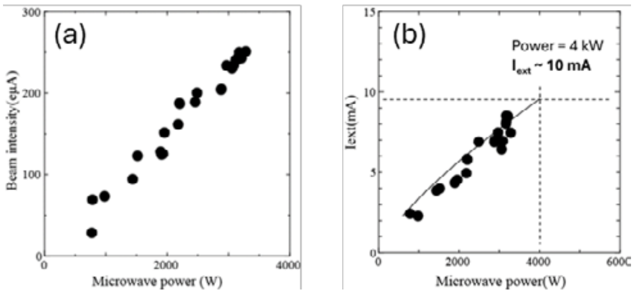


Fig. 1. Measurements of $U^{35+}$ beam parameters with respect to microwave power: (a) beam intensity, (b) extraction current.

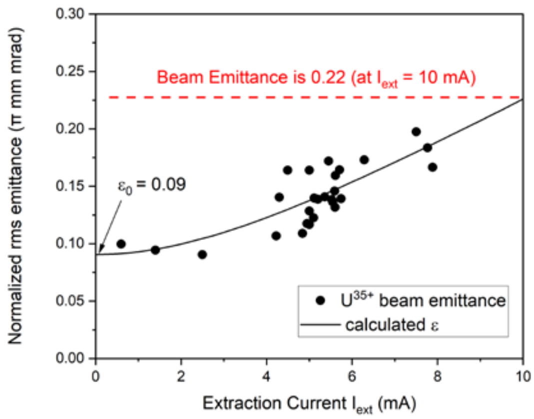


Fig. 2. Normalized rms y-emittance measurements for uranium $U^{35+}$ at different extraction currents with the calculated initial beam emittance $\varepsilon$0 and emittance growth $\varepsilon$.

Using the calculated $\varepsilon$ to estimate beam conditions for an extraction current of 10 mA, the normalized beam emittance was found to reach 0.22 $\pi$ mm mrad. These are the predicted beam conditions for high intensity beam operation of uranium $U^{35+}$ at 300 electric $\mu$A (e$\mu$A) beam current. This semi-empirical method serves as a useful tool for predicting beam conditions based on the extraction current.

As a next step, optimum ECR parameters for producing high-intensity beams will be investigated. A systematic study of the variable ECR parameters such as microwave power, material consumption rates, and magnetic field strength distribution, will be performed to determine an optimization map and identify suitable parameters for high intensity beam operation. Although conditions with low total beam current result in smaller beam emittance sizes, achieving such conditions will be challenging while optimizing for high beam intensities. Additional strategies are being considered, such as space charge compensation techniques

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to further reduce the emittance sizes.

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