Residual Gas Effect in LEBT on the Transverse Emittance of Multiply-Charged Heavy Ion Beams Extracted from ECRIS†

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When operating the electron cyclotron resonance ion source (ECRIS) with high-intensity beam extraction, we often experience the beam current changing in accordance with the pressure of the low energy beam transport (LEBT). After the LEBT is vented, the beam intensity is sometimes higher than usual, before we evacuate it to the reachable vacuum degree. Space-charge compensation is the one of the possible mechanism that cause the phenomenon as discussed by Toivanen *et al.*,[1] and it should be an advantage when high-intensity ion beams are extracted from the ECRIS. Thus, we investigated the effects of residual gas in the LEBT on the transverse phase space distribution of the ^{40}Ar beam, *e.g.*, correlation between the beam profile and emittance, by using the pepper-pot emittance meter (PPEM).[2]

Figure 1 shows the RIKEN 18-GHz superconducting ECRIS (SC-ECRIS) with the following LEBT. Initially, without the gas injection into the LEBT, the SC-ECRIS was tuned for the Ar^{11+} beam current to be maximum, typically ~ 70 μA, with a 10-kV extraction voltage and a 600-W microwave. The total beam current extracted from the SC-ECRIS was estimated as 0.9 mA from the electric current of the extraction voltage source. The PPEM, by which the four-dimensional transverse phase space distribution was obtained, was positioned before the solenoid lens to avoid the beam-optics complications caused by the helical motion of the beam traveling through the lens. In order to control the residual gas pressure from 10^{-5} to 10^{-3} Pa, we intentionally injected the neutral Ar gas through the variable leak valve attached at the gas injection port of the magnet chamber in Fig. 1.

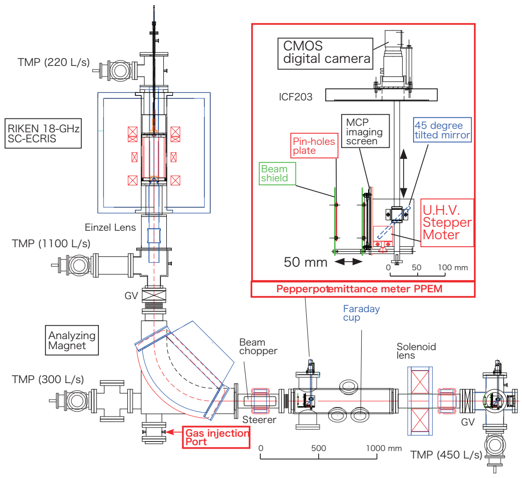

Fig. 1. Schematic of the RIKEN 18-GHz SC-ECRIS, LEBT, and PPEM.

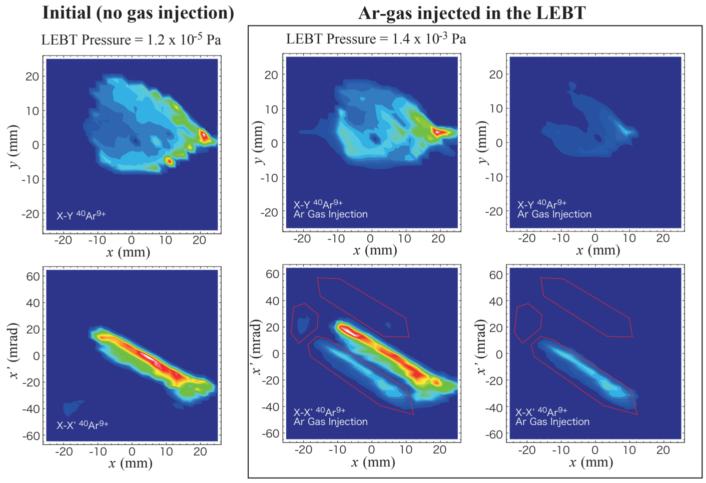

Fig. 2. Obtained beam profile (upper) and horizontal emittance (lower) of $^{40}Ar^{9+}$ beam by using PPEM.

Figure 2 shows the beam profile (x-y plot) and the horizontal emittance (x-x' plot) of $^{40}Ar^{9+}$ beam at the LEBT pressure of 1.2×10^{-5} Pa (no gas injection) and 1.4×10^{-3} Pa (Ar-gas injection). From Fig. 2, the beam intensity of the central area of the hollow triangle-shaped beam profile appears to increase with Ar-gas injection. However, by selecting a minor component in the emittance plot, a similarly shaped beam profile is clearly separated from the main component. From the systematic studies on the Ar beams from 7+ to 12+, the parasite component is concluded as the Ar beam with other charge that captures an electron before the analyzing magnet. For example, the Ar^{10+} beam, which is extracted as Ar^{11+} from the ECRIS, captures an electron during the travel to the magnet, and is bend by the magnet with the charge of 10+, can mix in the Ar^{9+} beam because of their similar $B\rho$'s. In addition, from the obtained M/Q spectra, the valleys between the Ar peaks become shallower as the LEBT pressure exceeds 10^{-4} Pa by the Ar-injection. Thus, we found that the other charge exchanges and the multiple scatterings with the residual gas are no longer negligible at the LEBT pressure of 10^{-4} Pa. In the case of $\sim 10^{-5}$ Pa, we detected no significant signs of these effects nor the space-charge compensation.

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