Four-dimensional transverse phase space distribution changes with respect to degree of vacuum of LEBT†

T. Nagatomo,[*1] V. Tzoganis,[*1,*2,*3] M. Kase,[*1] T. Nakagawa,[*1] and O. Kamigaito[*1]

The four-dimensional transverse emittance ϵ_{4D} is a fundamental quantity, which is the degree of beam quality, and is invariant under linear symplectic transformations, such as beam optics components including solenoid lenses and skew quadrupole lenses. The emittance indicates the area of distribution in the phase space; thus, the smaller ϵ_{4D} is, the better the beam transport efficiency is. Because ϵ_{4D} is not decreased during the beam transport unless special techniques of beam cooling are used, it is essential to provide a beam having an emittance as small as possible at the extraction area of the ion source. Especially, at the beam-extraction area, the total current of the extracted ions reaches the order of milli-amperes; thus, the importance of the space-charge effect is considered to be serious at the present intensity.

The space-charge effect is induced by the repulsive forces between the positively charged ions inside of the beam and causes degradation of the beam quality, namely the emittance growth. The possibility to compensate for the space-charge effect by injecting a neutral gas into the low-energy beam transport (LEBT) following the ion source was discussed by Toivanen et al.[1] The electrons produced through collisions between the neutral gas and the beam are considered to moderate the electric repulsive forces. Based on that report, we intend to clarify how the ϵ_{4D} of multiply charged argon beams evolves with respect to the amount of krypton (Kr) gas injected in the LEBT of the RIKEN AVF cyclotron. The LEBT is connected to the 18-GHz superconducting ECR ion source (SC-ECRIS) and the RIKEN AVF cyclotron. We have measured ϵ_{4D} by the pepper-pot emittance meter[2] installed immediately behind a solenoidal lens following the analyzing magnet.

Figure 1 shows the change of emittances of $Ar^{8+,9+,11+}$-ion beams with respect to the gas pressure of LEBT, which represents the amount of injected Kr gas. The Kr gas was injected from a port attached at a vacuum chamber of the analyzing magnet, and the LEBT pressure was measured by a cold cathode gauge, which was also attached to the camber of the analyzing magnet. In Fig. 1, the emittances of $\epsilon_{x,y}$ and ϵ_{4D} were normalized by the values obtained under the condition of no Kr-gas injection, which were ϵ_{x0}, ϵ_{y_0}, and ϵ_{4D0}, respectively. In Fig. 1, all the obtained emittances decrease as the amount of Kr gas increases. Especially, it is noteworthy that the emittances decrease in spite of the increases of the observed beam currents in the Ar^{8+} and Ar^{9+} cases. Further, it is interesting that the ϵ_{4D} of all charge states seem to decrease similarly to each other, despite the fact that their projections ϵ_x and ϵ_y decrease differently for each charge state. In order to clarify the emittance-reduction mechanism, we are planning to conduct further experiments that would arrow us to distinguish between the space-charge compensation effect in the LEBT and the gas mixing effect of Kr gas penetrating the ECR plasma.

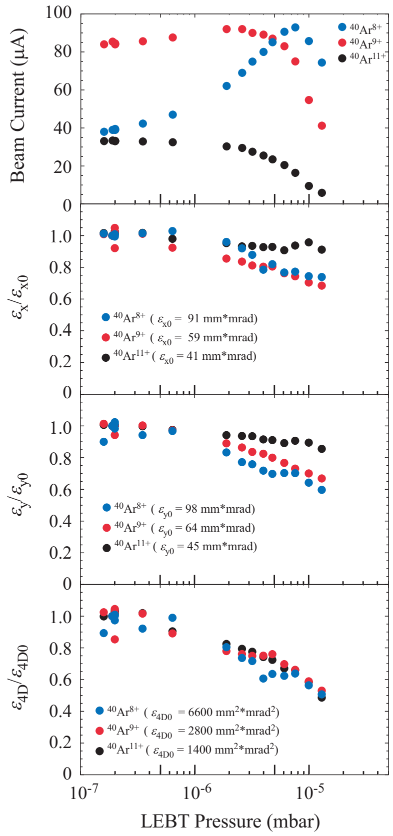

Fig. 1. Obtained beam currents and rms emittances ϵ_x, ϵ_y, and ϵ_{4D} of $^{40}Ar^{8+,9+,11+}$ with respect to the LEBT residual gas pressure.

† Condensed from the article in the Proc. of 22nd Int. Workshop on ECR Ion Sources (ECRIS2016), Busan, Korea, August 2016, paper WEPP35, in press

*1 RIKEN Nishina Center
*2 Cockcroft Institute, Daresbury, Warrington
*3 Department of Physics, University of Liverpool

References
1) V. Toivanen et al., Nucl. Instr. Meth. B **268**, 1508 (2010).
2) V. Tzoganis et al.: Proc. 7st Int. Particle Accelerator Conf. (IPAC'16), Busan, Korea, paper MOPMR048 (2016), p. 361