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Transverse four-dimension phase-space distribution measured by the pepper-pot type emittance meter

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Abstract

We have obtained evolution of the four-dimensional transverse emittance ε_{4D} for $^{40}Ar^{8+,9+ \text{ and } 11+}$ beams with respect to the amount of the residual gas in the low energy beam transport (LEBT) measured by the pepper-pot emittance meter. Natural krypton gas was injected to control amount of residual gases into the LEBT. Collision between the beam and the residual gaseous atoms generate electrons which are expected to cancel out the positive electric potential inside of the beam, in other words, the space-charge compensation. The reductions of emittances of $^{40}Ar^{8+,9+ \text{ and } 11+}$ beams were observed by the krypton-gas injection into LEBT. The trends of reduction of the projected emittances such as ε_x and ε_y were different from each charge state, however, trends of reduction of the ε_{4D} of these charge states were in the same way. Furthermore, the degree of reduction of ε_{4D} was about 50\%. At present, the mechanism of the reduction of the emittance is not clearly described because there is the possibility that this reduction caused by the change of ECR plasma which is induced by the penetration of the injected krypton gas into plasma chamber.

1. Introduction

- *4D emittance* ε_{4D} : a conserved quantity is an essential to improve the beam quality **[1,2]**.
- *Pepper-pot type emittance meter* is one of the best solution for quick ε_{4D} measurements.
- Beam quality is considered to be degraded by
  1. Aberration of beam-optics devices
  2. Space-charge effect

In ref. **[3]**, ^{40}Ar beam + neutral He, N_2 and Ar injected in LEBT to evaluate the *"space-charge compensation"*

In this work, ε_{4D} of $^{40}Ar^{8+}$, $^{40}Ar^{9+}$ and $^{40}Ar^{11+}$ were measured with respect to Kr-gas pressure fed into LEBT.

c.f. the first ionization energy : Kr 1350.8 (kJ/mol)
He 2372.3 (kJ/mol), N 1402.3 (kJ/mol), O 1313.9 (kJ/mol), Ar 1520.6 (kJ/mol)

2. Experimental

1. RIKEN 18-GHz SC-ECR Ion Source

- Parameters were set to optimized the beam of $^{40}Ar^{11+}$.
- Support gas : neutral $^{16}O_2$.
- P_{rf} = 680 W

2. LEBT: Analyser magnet + Solonoid

- Kr gas injected from port 5 in Fig. 1.
- Leak rate of Kr gas was controlled by a variable leak valv
- LEBT pressure is monitored by CCG at port 4.
- ε_{4D} is measured by *the pepper-pot emittance meter* [4].

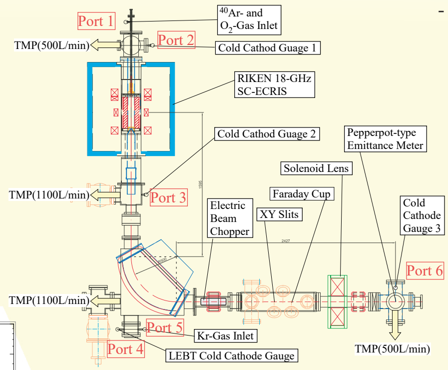


Fig. 1 Layout of the 18-GHz SC-ECRIS + LEBT

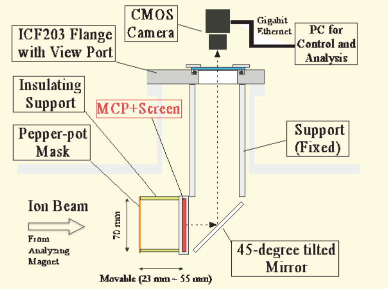


Fig. 2 Schematic of the pepper-pot emittance meter

3. Results

- Range of the LEBT pressure
  1.9x10^{-7} mbar - 1.3x10^{-5} mbar

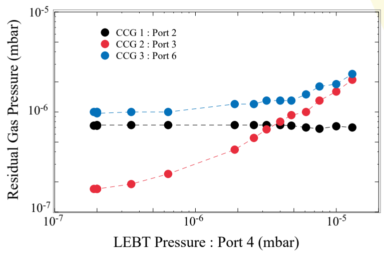
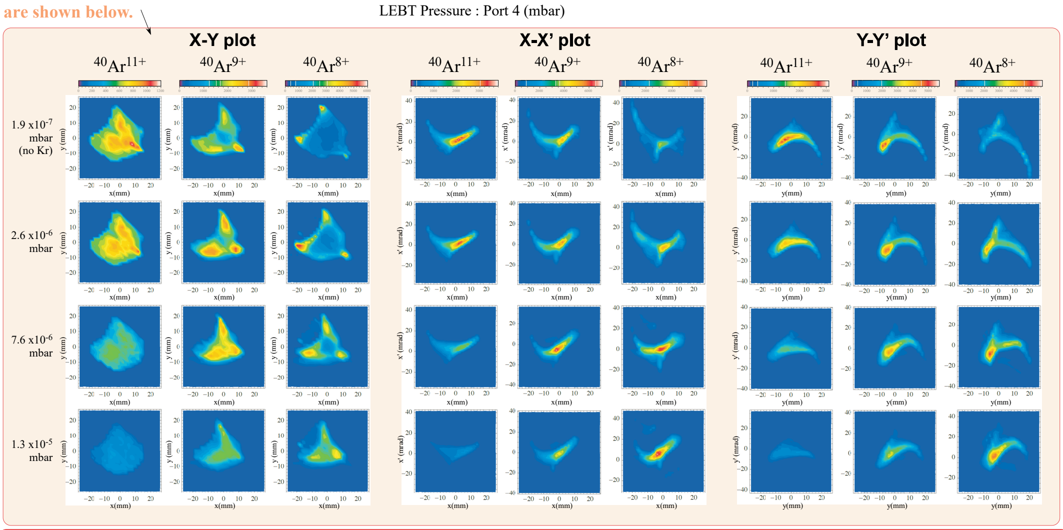


Fig. 3 Residual-Gas-Pressure changes at several points of the *ECRIS* and *LEBT* as shown in Fig. 1

Typical 2-D projections of the phase-space distribution obtained at each LEBT Pressure are shown below.



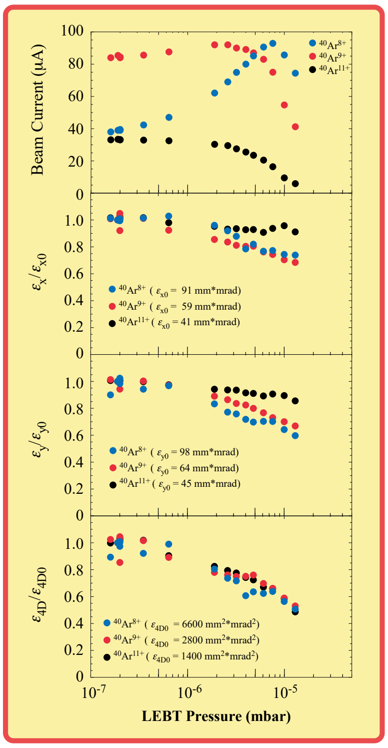


Fig. 4 Obtained LEBT pressure dependencies of *beam currents*, ε_x, ε_y **and** ε_{4D} **of** $^{40}Ar^{8+,9+ \text{ and } 11+}$.

1. **Beam currents of $^{40}Ar^{9+ \text{ and } 11+}$ rapidly keep constant or decrease as the LEBT pressure increase.**
2. **On the other hand, the beam currents of $^{40}Ar^{8+}$ increases below 7x10^{-6}mbar, and over the vacuum level, the beam currents decreases.**
3. **At 1.3x10^{-5}mbar, ε_x and ε_y of $^{40}Ar^{11+}$ decreases by 9% and 14% compared to those without Kr gas injection.**
4. **For the others, ε_x (ε_y) of 9+ and 8+ decreases by 32%(33%) and 26%(44%), respectively. The trends of reduction seems to be different.**
5. **However, ε_{4D} of all charge states decrease by ~50% in the similar way with respect to the LEBT residual gas!!**

4. Discussion and Future prospect

- Does the space-charge compensation happens?

At present, we *are not able to give a clear answer* it, because ...

1) From Fig. 5, krypton peaks obviously appears as the Kr-gas injection increases.
2) The highly charged krypton gas are considered to ionized in the ECR plasma.
3) The effects induced in the LEBT from the ECRIS could not be distinguished.

We are planning to another ***complemental experiment*** with **the krypton-gas injection** from **Port 1.**

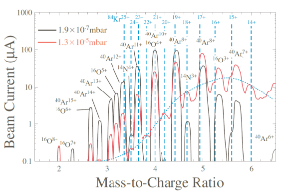


Fig. 5 Charge state distribution together with positions of ^{84}Kr.

References

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[3] V. Toivanen et al., "The effects of beam line pressure on the beam quality of an electron cyclotron resonance ion source", Nucl. Instr. Meth. B, vol. 268, pp. 1508?1516, 2010.

[4] V. Tzoganis et al., in Proc. 7st Int. Particle Accelerator Conf.(IPAC'16), Busan, Koria, May 2016, paper MOPMR048, pp.361?513.