Thinning effect of gas strippers for high-intensity very heavy ion beams

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Intensity upgrade of very heavy ions beams, such as U and Xe beams, is one of the main concerns at the RIKEN Radioactive Isotope Beam Factory (RIBF). In the acceleration of the very heavy ion beams, the possible output intensities have been limited mainly by the lifetime problem of the carbon foil strippers. In previous years, the realization of gas strippers was an important breakthrough for the intensity upgrade of very heavy ion beams[1,2]. In order to achieve higher intensities of very heavy ion beams, we must understand the application limit of the gas stripper. Density reduction of the gas along the trajectories of the beams, caused by the heat load (thinning effect), is a factor determines the application limit of the gas stripper. To validate the thinning effect at the present intensities, we measured the velocities of the uranium beams after the stripper as a function of the beam intensities.

In the measurements, $^{238}U^{35+}$ beams up to 1-particle μA at 10.8 MeV/u were injected into the helium gas stripper placed after the RIKEN ring cyclotron. The arrival time of the beams before and after the stripper were measured using the phase probe. The measured time difference ($\propto$ gas density and gas temperature) depends on the output beam current, as shown in Fig. 1, where the beam current is changed with the duty of a beam chopper. For the higher beam current, the velocities of the output beams are higher because of gas density reduction due to higher heat deposition. The saturation of the time difference depends on the chopping frequency f, as shown in Fig. 1. The beam structure for the chopping frequency f is also shown in Fig. 1. A simplified differential equation for the temperature rise T is given as $dT/dt = Q/C - c_p\dot{m}/C$, where Q is the heat load of the beams, C is the heat capacity of helium, c_p is the specific heat of helium for constant pressure and $\dot{m}$ is the mass flow rate. At Q=0 (timing of beam off), the temperature reduces with the time constant $\tau = C/c_p\dot{m} = M/\dot{m}$. The saturation also depends on $\dot{m}$ in the beam region.

Figure 2 shows the dependence of the temperature rise of the helium gas stripper on the beam current. The chopping frequency was fixed with 1 kHz in these measurements. Although the temperature rise depends slightly on the beam profile, all measured values were lower than those expected from the calculations (dotted line) with flow-3D (computational fluid dynamics simulation software). A possible explanation may be some suppression mechanisms of heat on helium due to vacuum ultraviolet light emission from the excited helium atoms and molecules or energetic delta electrons emission.

In summary, we clearly observed the thinning effect of helium gas stripper by 1-particle μA uranium beams. Our results have important implications for lower heating efficiencies obtained with some suppression mechanisms.

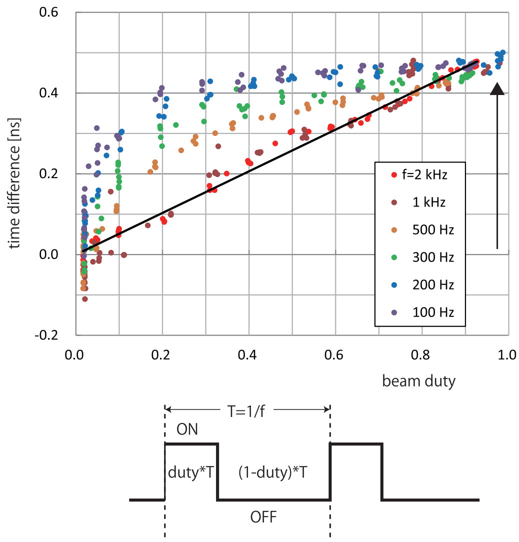

Fig. 1. The dependence of the arrival time difference on the beam duty for various chopping frequencies (up) and the beam structure of the chopped beam (down).

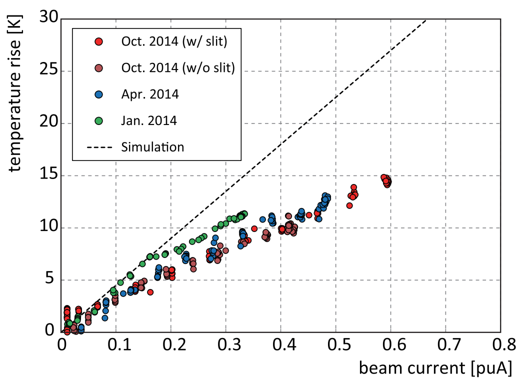

Fig. 2. Dependence of the temperature rise of helium on the beam current. Dotted line indicates the calculated values.

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References

1) H. Imao et al., IPAC 2013, Shanghai (2013).
2) H. Imao et al., IPAC 2014, Dresden (2013).