Nondestructive Diagnostics of Strongly Coupled One Component Plasma Confined in RF Trap

M. Aramaki, S. Kameyama, Y. Sakawa[a], T. Shoji, A. Kono

Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-8603, Japan
[a] *Institute of Laser Engineering, Osaka University, Yamadaoka, Suita, Osaka, 565-0871, Japan*

aramaki@nuee.nagoya-u.ac.jp

An rf trap is a device that confines ions using rf quadrupole electric field. The trapped ions can be cooled to lower than 1 K by applying laser-cooling technique. One component plasma composed of laser-cooled ions is suitable for the detailed research on strongly-coupled plasma, since the ion temperature can be controlled during several figures, where the transition between a weakly-coupled state and a strongly-coupled state exists. We aim to study the effect of the long-range correlation among ions on its statistical characteristics. Observation of the velocity distribution function of laser-cooled ions is fundamentally important for the purpose; however, non-destructive diagnostics of laser cooled ions has not been reported so far, because the very low temperature plasma is very fragile. We have developed a non-destructive Doppler laser-induced fluorescent (LIF) system for laser-cooled ions using a modulated probe-laser technique.

$^{40}Ca^{+}$ ions are used in this work. The main laser cooling transition $S_{1/2}$-$P_{1/2}$ is excited by a 397-nm laser. The natural line width of the transition is about 22 MHz. A part of the ions in $P_{1/2}$ state falls into the meatastable $D_{3/2}$ state, therefore a 866-nm laser is used for repumping the $D_{3/2}$ state ions to the $P_{1/2}$ state. The LIF signal emitted by the de-excitation of the $S_{1/2}$-$P_{1/2}$ transition is used for ion detection. In our non-destructive observation method, ion temperature is fixed by the cooling laser, and the LIF spectrum is probed by using an additional weak 397-nm laser. The power of the probe laser was minimized to avoid the change of ion temperature by the cooling and heating effect of the probing laser. The probe laser is chopped by an optical chopper, and the slightly-modulated component of LIF signal excited by both of the cooling and probe lasers is detected by a gated photon-counting system.

Figure 1 shows LIF spectra observed with various ion temperatures. The spectra are decomposed into Gaussian component and Lorenz component by fitting to Voigt function. The ion temperature T_i is derived from the width of the Gaussian component. Here, if we assume that the width of the Lorenz component (γ_L) is the summation of the natural line width (22MHz) and the ion-ion collision frequency, the expected collision frequency is too large as the ion-ion binary collision frequency. The unusual large Lorenz width might be explained by the many body interaction of strongly coupled plasma.

The authors would like to thank Dr. K. Hayasaka for his valuable advice and discussions.

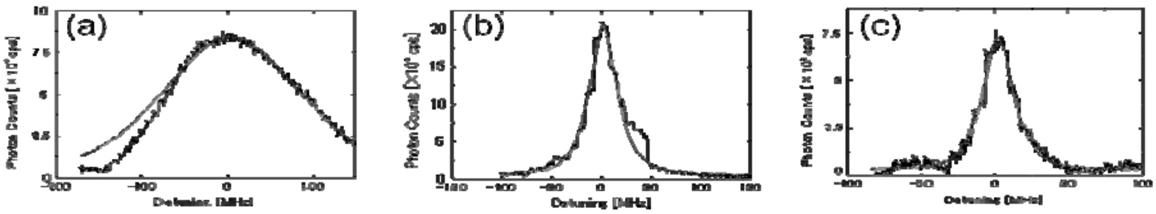

Fig. 1 LIF spectra observed at various ion temperatures. Ion temperature and the width of Lorenz component are derived as following: (a) T_i = 5 K, γ_L = 140 MHz, (b) T_i = 0.3 K, γ_L = 27 MHz, (c) T_i = 0.1 K, γ_L = 23 MHz.