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4.26 Study of Plasma Polarization Spectroscopy

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Nitrogen gas target was irradiated by a linearly polarized ultra-short pulse of Ti:Sapphire laser light with duration of 50fs and energy of 150 mJ. We changed the direction of the polarization of the incident laser light and observed the emission of the resonance series lines of the lithiumlike ions and radiative recombination spectrum from recombining helium-like ions.

Keywords: plasma spectroscopy, polarization, optical field ionization

I. INTRODUCTION

Recent advent of ultra-short-pulse lasers makes it possible to generate highly charged ions ionized by the high laser electric field; this mechanism is called the optical field ionization (OFI). [1-4] Characterization of the plasmas thus produced, especially that of the electron velocity distribution, is essential for the purpose of developing a novel x-ray source such as x-ray lasers. Therefore, clarification of the electron velocity distribution is an important objective of plasma polarization spectroscopy (PPS). In the high laser field, an electron in an atom is quivered by the periodic laser field and has a pondermotive potential energy. With an increase in the laser electric field strength, the pondermotive potential energy becomes comparable with or even exceeds the ionization potential of the atom, and tunneling ionization occurs with a substantial probability. In the case that the laser light is linearly polarized, ionized electrons would have velocities only in the direction of the laser field, so that the electron velocity distribution would be strongly anisotropic. In the classical model, if we consider a radiative recombination process into the $^1S_0$ state, the recombining continuum electron can be regarded as a classical oscillator oscillating in the *x* or *y* or *z*-direction (See Fig. 1.), where we take the z-direction as the quantization axis. Under such a condition, since electrons quivered in the *z*-direction and the *x*-direction emit π and σ light due to the radiative recombination process, the population imbalance between these two components leads to the polarization of the free-bound spectrum. Therefore, it is expected that, by observing the temporal change of the emission polarization, we can investigate relaxation process of the anisotropic electron velocity distribution due to electron-electron and electron-ion scattering. In the following, we report on our preliminary experiment toward the polarization measurement of the OFI plasma.

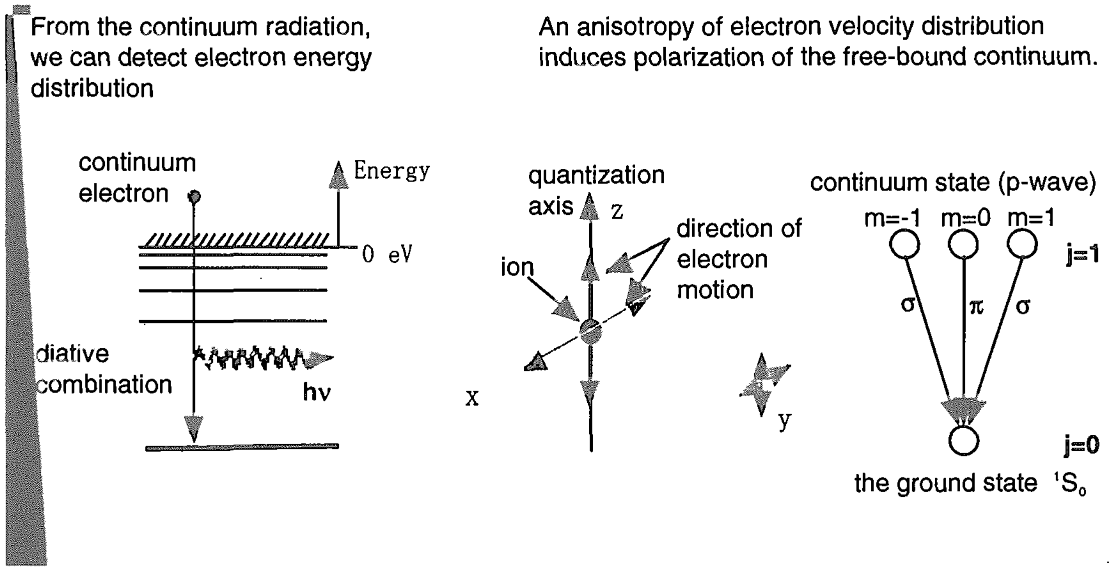

Fig.1 Schematic of polarization in free-bound transitions due to the anisotropic electron velocity distribution. In this figure, we take the z-axis as the quantization axis. An electron oscillating in the z-axis emits π-light and that in the x- or y-axis emits σ-light.

II. PRELIMINARY EXPERIMENT

A seed light at wavelength of 800 nm with 20 fs duration and 80 MHz repetition rate is generated by a mode-locked Ti:sapphire oscillator (Femto-source technology) pumped by a 5 W diode-pumped solid state laser (Spectra Physics Millenia V). The typical power of the seed light is 250 mW and the spectral bandwidth is 40 nm (full-width at half maximum (FWHM)). A four-path stretcher based on a spherical mirror and a grating with 1200 grooves/mm generates a chirp of 50 ps/nm. The regenerated amplifier is a 10 Hz Ti:sapphire laser pumped by a Nd:YAG laser (B.M. Industries). In order to reduce the ASE level and to achieve a high contrast ratio, we have optical shutters just before and after the regenerative amplifier. The typical output energy and the spectral bandwidth of the regenerative amplifier is 1 mJ and 30 nm (FWHM), respectively. The output laser pulse is further amplified by the two stage amplifiers, a 4 path and a 3 path Ti:Sapphire amplifiers, both pumped by Nd:YAG lasers, and the maximum output energy is 300 mJ/pulse. A pulse compressor, which is placed in a vacuum chamber, has an efficiency of about 60 % and provides an output laser pulse with maximum energy of 180 mJ, diameter of 50 mm, and pulse duration of 50 fs.

The laser pulse was steered by a plane mirror, went through a zero-order 1/2 wave-plate (CVI optics), and was focused by an off axis parabolic mirror with *f* number of 4. The focus spot size was measured to be about 50 μm-diameter (FWHM) with an imaging system having magnification of 10. The maximum irradiance was estimated to be 2×10^{17} W/cm^2. The target gas was nitrogen, which was injected into the focusing area by a pulse gas nozzle (General Valve) having an output aperture size of 800 μm. This gas valve was synchronized with the pumping YAG laser and was opened at 400 μs before the laser pulse and was closed at 600μs after the pulse. Backing pressure of the nozzle could be varied from 1 atm through 20 atm. Gas density was determined from the line density map taken with a Mach-Zehnder type interferometer at wavelength of 633 nm for several backing pressures. [5]

The experimental set-up is shown in our previous report [7]. The emission from the plasma was observed by use of a grazing incidence spectrometer in the direction of 90° with respect to the laser propagation direction. It consisted of a concave mirror with curvature of 3240mm, a 200 μm-width entrance slit and an uneven spacing flat-field grating with 1200 grooves/mm. The grazing incidence mirror and the grating may have different reflectivities or efficiencies for different polarization directions. Emission radiation was expected to be polarized in the direction parallel or perpendicular to the laser propagation direction. In order to compensate the differences, we tilted the spectrometer by 45° around the observation axis. We attempted to observe temporally resolved spectra by using an x-ray streak camera. We found, however, that our streak camera had a too low sensitivity in the wavelength region of interest. Instead we used a CCD in the present experiment. This was a back-illuminated CCD and we took time-integrated spectra.

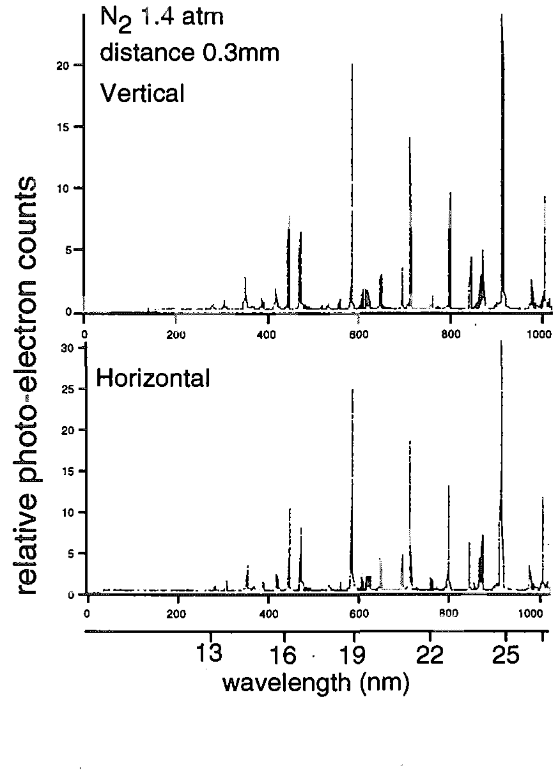

Fig.2. Typical spectra of the hydrogenlike helium ions in recombining OFI plasmas. "Horizontal" and "vertical" is shown in Fig.2.

By rotating the zero-order $\lambda/2$ wave-plate, the polarization direction of the linearly polarized laser light was set to be horizontal or vertical, and we compared the spectra of the plasma emission between the horizontal and vertical cases.

Figure 2 shows typical spectra for the nitrogen gas target. The laser intensity was 5×10^{16} W/cm^2, and gas density is estimated to be 3×10^{18} cm^{-3}. The resonance series lines and $2p\ ^2P_{1/2,3/2}$ - $nd\ ^2D_{3/2,5/2}$ and $2p\ ^2P_{1/2,3/2}$ - $ns\ ^2S_{1/2}$ series lines together with the continuum of lithium-like nitrogen ions are seen. In view of these time-integrated spectra, no significant difference could be seen. This may be due to the followings; Firstly, relaxation time of the anisotropic electron velocity distribution of the OFI plasma is estimated to be much faster than the duration of the recombination of the ions. Thus, we need time-resolved measurement to clarify the anisotropy in the velocity distribution. Secondly, in the case of lithium-like ions, since the spectral lines are doublet lines, the anisotropy of the electron velocity distribution becomes indirect to the polarization of the emission due to the mixture of fine structure components. Rather spectral lines from helium-like ions, which are singlet, should be used. In order to accomplish that, much higher laser intensity is needed at around 10^{17} W/cm^2. This would be the next step of this research.

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