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Saturation Spectroscopy for Measuring Electron Density in Argon-Containing Plasmas

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1. Introduction

Saturation spectroscopy is widely used in the field of fundamental spectroscopy to identify the wavelengths of transition lines buried under the Doppler broadening. However, the application of saturation spectroscopy to plasma diagnostics is rather rare. We investigate the application of saturation spectroscopy to the measurement of electron density in argon-containing low-temperature plasmas. In this work, we propose a method for evaluating the saturation parameter from the spectrum of saturation spectroscopy in the presence of velocity changing collisions. We examined the relationship between the electron density and the saturation parameter.

2. Experiment

We used an inductively-coupled plasma source with an internal antenna in this experiment. The antenna was connected to an RF power supply at 13.56 MHz via a matching network. The light source of absorption spectroscopy was a diode laser. The diode laser beam was divided into two beams, and the diode laser beams with higher and lower intensities were used as the pump and probe beams, respectively. The pump and probe laser beams were injected into the plasma from the contour directions. The intensity of the probe laser beam passing through the plasma was detected using a photodiode. The electron density was measured using a Langmuir probe.

3. Results, discussion, and conclusions

According to the theory of saturation spectroscopy, the saturation parameter is given by $S_0 = B_{12} I_\nu / cR^*$, where S_0 is the saturation parameter at the line center, B_{12} is the Einstein's B coefficient, I_ν is the spectral intensity of the pump laser beam, R^* is the effective relaxation frequency of relevant energy system. In this work, we proposed a new method to evaluate saturation parameter from the measured saturated absorption spectra with considering velocity changing collisions, given by $S_0 = [(\sqrt{\ln 2/\pi})(2/\Delta\nu_D)(\pi\gamma/2)][(\alpha_0 - \alpha_D)/\alpha_S]$, where α_0 and α_S are the absorption coefficients at the line center observed with and without the presence of pump laser beam, respectively, α_D is the estimated value of the line-center absorption coefficient in an imaginary situation that the population difference between the upper and lower levels in the presence of the pump beam makes a Doppler broadened absorption spectrum without the Lamb-dip, and as a coefficient of the second equation, γ and $\Delta\nu_D$ are FWHM of homogeneous broadened Lamb-dip and Doppler broadened spectrum, respectively. We employ the $4s[3/2]_2^0 - 4p[3/2]_2$ absorption line of argon. The lower energy state is metastable, and the effective relaxation frequency is determined by the relaxation frequency of the metastable state. In this case, the relaxation frequency of the metastable state is dominantly determined by electron impact quenching and the transit time of metastable argon through the diameter of the pump laser beam such that $R^* = k_q^e n_e + \bar{v}/a$, where k_q^e is the rate coefficient of electron impact quenching, n_e is the electron density, a is the diameter of the pump beam, and $\bar{v}$ is the mean velocity of metastable argon. Therefore, by evaluating α_0, α_S, and α_D on the basis of experimental spectra, we can evaluate the electron density n_e.

The relationship between $1/S_0$ and n_e is shown in Fig. 1. We found linear relationships between $1/S_0$ and n_e, which are reasonable according to the aforementioned relationships among S_0, R^*, and n_e. It is confirmed that the slopes of the linear curves in Fig.1 are proportional to the inverse of the pump intensity which is consistent with proposed theory. Therefore, in conclusion, the experimental results indicate that the proposed method can work as a method for the electron density measurement in argon-containing plasmas.

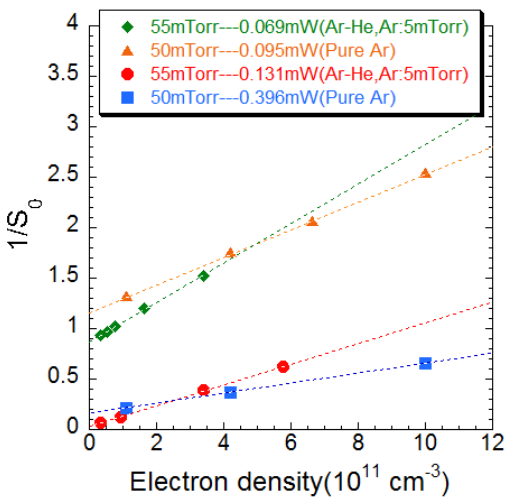

Fig. 1 Relationship between the reciprocal of the saturation parameter and the electron density.