Depolarization of emission lines from polarized neon $2p_{10}$ atoms due to radiation re-absorption in a glow discharge plasma

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Introduction

The atomic polarization in plasmas is recognized as being important for the study of the anisotropy in plasmas. Plasma polarization spectroscopy (PPS) and a collisional-radiative model including polarization generation effects have been developed recently [1]. The depolarization effect on the polarized atoms is also important for a quantitative analysis of the PPS. The depolarization of the atomic emission lines due to radiation re-absorption may be substantial in the case where the plasma itself or its surrounding gas is optically thick.

So far we have succeeded to separate and evaluate the depolarization rates due to the atomic collision and radiation re-absorption for the neon $2p_2$ atom (in Paschen notation) in a glow discharge plasma [2, 3].

This paper reports measurements of disalignment rates of the neon $2p_{10}$ atoms. The atomic disalignment represents a depolarization mechanism for an ensemble of atoms which has the Zeeman states $|J\ M_J\rangle$ and $|J\ -M_J\rangle$ of the same fine-structure J state evenly populated, where J and M_J are the total angular momentum and magnetic quantum numbers, respectively. The disalignment rate coefficient of the $2p_{10}$ state due to atomic collisions is one order of magnitude smaller than that of the $2p_2$ state, and thus the effect of the radiation re-absorption may be substantial.

Experiment

In the positive column of a glow discharge, a linearly polarized laser pulse produces alignment of neon atoms of the $2p_{10}$ state. We measure the subsequent radiation of fluorescence with its polarization components resolved. The experimental set-up is almost the same as described in ref. [4]. The discharge channel is filled with a mixture of neon and helium gases. The partial pressure of neon gas is fixed at 0.09 Torr, while that of helium gas is varied from about 1.6 to 6.1 Torr. We set the temperature of the discharge channel to be 180 K. The DC discharge current is 0.70 mA.

The active medium of the excitation laser is LDS751 dye solved in methanol. In order to excite the neon atoms from the $1s_3$ ($J = 0$) metastable level to the $2p_{10}$ ($J' = 1$) level, we set the wavelength of the laser at 743.9 nm.

We observe the fluorescence (of 724.5 nm) for the transition from the $2p_{10}$ ($J' = 1$) level to the $1s_4$ ($J = 1$) level. We use a photomultiplier tube (Hamamatsu, H6780-02) and a digitizing signal oscilloscope (Agilent, DSO5054A) to record the polarization resolved fluorescence intensity with a temporal resolution of 2 ns. The digitized signals are accumulated over 2048 laser pulses. The relative sensitivity of the σ- to π-component is 0.426 at a wavelength of 724.5 nm, and the intensities of the π- and σ-components are calibrated with their relative sensitivity.

We also measure the line absorptions for the emissions from the $2p_{10}$ to $1s_5$, $1s_4$ and $1s_3$ states by the self re-absorption method, described in ref. [2], to evaluate the effect of radiation re-absorption.

Results and discussion

Fig. 1(a) shows an example of the temporal evolution of the fluorescence intensities. Since the excitation is done with π-polarized light for the $J = 0$ to $J' = 1$ transition, only the $M_J' = 0$ sublevel, is initially populated, where the prime indicates the upper level of the transition. In this case, the fluorescence of the $J' = 1$ to $J = 1$ transition has only the σ-component due to the selection rules. During the lifetime of the upper level, the excitation transfer from the $M_J' = 0$ sublevel to M_J' = +1, -1 sublevels, or the disalignment, takes place. In consequence, a π-component appears in the radiation of fluorescence.

The degree of polarization can be evaluated quantitatively from measurements of temporal evolution of the longitudinal alignment, A_L, of the emitted radiation as

$$A_L(t) \equiv \frac{I_\pi(t) - I_\sigma(t)}{I_\pi(t) + 2I_\sigma(t)} \propto \frac{n_0(t) - n_1(t)}{n_0(t) + 2n_1(t)} \propto e^{-\gamma t} \qquad (1)$$

after the cessation of the excitation laser pulse (for $t >$

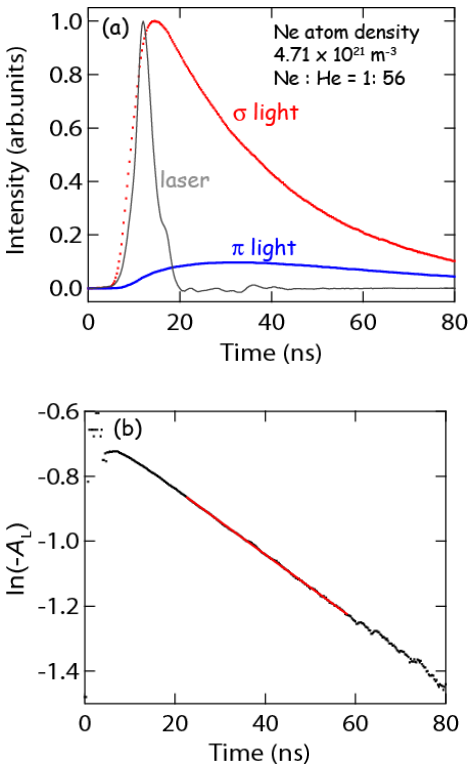

Fig.1 *Temporal evolution of (a) the polarization resolved fluorescence intensities and (b) longitudinal alignmen.*

22 ns in Fig. 1(a)), where γ is the disalignment rate, which is proportional to the excitation transfer rate between the $M_J' = 0$ and $M_J' = +1$ (or $M_J' = -1$) sublevels, I_π and I_σ are the fluorescence intensities of the respective polarizations and n_0 and n_1 are the populations of the $M_J' = 0$ and $M_J' = +1$ (or $M_J' = -1$) sublevels, respectively.

Fig. 1(b) shows the temporal evolution of $\log[-A_L(t)]$ calculated from the fluorescence intensities presented in Fig. 1(a). From the slope of the linear fit, we determine the disalignment rate. The fit is done for a time period between the cessation of the laser pulse and the time when the scatter of the data points becomes too large. The closed circles in Fig. 2(a) show the disalignment rate as a function of the helium atom density.

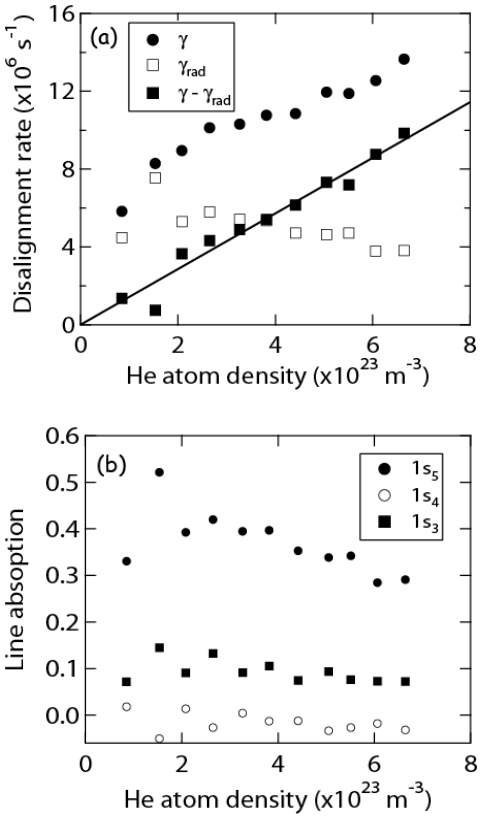

Fig.2 *(a) The disalignment rate and (b) the line absorptions of the emission from the $2p_{10}$ to$1s_5$ (closed circles), $1s_4$(open circles) and $1s_3$(closed squares) states as a function of the helium atom density.*

The disalignment rate contains the rates due to helium collisions, neon collisions, electron collisions and the effect of the radiation re-absorption. The disalignment rates due to neon atom collisions and electron collisions are estimated to be of the order of 10^4 s^{-1} for the excited neon atoms in the same electron configuration [4], which is negligibly small for the rate shown in Fig. 2. Then the disalignment rate is expressed as

$$\gamma = \gamma_{\mathrm{He}} + \gamma_{\mathrm{rad}} \qquad (2),$$

where γ_{He} is the disalignment rate due to helium atom collisions and γ_{rad} is the effect of the radiation re-absorption.

Fig.2(b) shows the line absorptions defined as

$$\alpha = 1 - \frac{I_2 - I_1}{I_1} \qquad (3),$$

for the emission from the $2p_{10}$ to $1s_5$, $1s_4$ and $1s_3$ states, where I_1 and I_2 are the observed emission intensities without and with the concave mirror, respectively[2]. The observed negative value for the emission line from the $2p_{10}$ to $1s_4$ states may be due to the experimental

inaccuracy because of the very small optical thickness of the line. The optical thickness for the $2p_{10}$-$1s_2$ transition line is thought to be smaller than that for the $2p_{10}$-$1s_4$ transition line.

Seo and his co-workers developed a simulation code which evaluates γ_{rad} from the optical thickness.[2] We evaluate γ_{rad} with this code, and the result is shown in Fig.2(a) by the opened squares. We neglect the contribution of the radiative re-absorption for the emission lines from the $2p_{10}$ to $1s_4$ and $1s_2$ states. We subtract γ_{rad} from γ to estimate γ_{He}. In Fig. 2(a) the results are shown by the filled squares, and they show linear dependence on the helium atom density. From the slope of the linear fit shown in Fig. 2(a) with a solid line, we determine the experimental value of the disalignment rate coefficient.

The experimental rate is 1.43 x 10^{-17} m^3/s, which is about 40% lower than the theoretical value of 2.39 x 10^{-17} m^3 s^{-1} calculated for 180 K with a close-coupling many-channel quantum model and a model potential for the interaction between the He and $Ne^*(2p^5\ 3p)$ atoms[5]. Theoretical analysis done in ref.[5] led to the conclusion that the small value of the disalignment rate coefficient for the $Ne^*(2p_{10})$ atoms is due to a very small anisotropy between the $2p_{10}$ molecular channels as compared to any other $2p_i$ [J=1] molecular channels (see Fig. 10(b) from ref. [5]).

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