§34. Spectroscopy of Molecular Hydrogen in a Low-temperature Recombining Plasma

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Recombining plasmas are important in nuclear fusion research since they are closely related to 'plasma detachment', which is considered to be a hopeful operation scenario of a nuclear fusion machine to avoid the excess heat flux to the divertor plate. In this work, we observed an optical emission spectrum from molecular hydrogen in a recombining hydrogen plasma.

Pure hydrogen plasmas were produced in a linear machine with a uniform magnetic field of 350 G along the cylindrical axis by helicon-wave discharges. At rf powers lower than 1.5 kW, we obtained ionizing plasmas at all the gas pressures. Ionizing plasmas were also observed at rf powers higher than 1.5 kW if the gas pressure was lower than 56 mTorr. We obtained recombining plasmas at rf powers higher than 1.5 kW and gas pressures higher than 56 mTorr.

The optical emission spectrum in a ultraviolet wavelength range observed at an rf power of 2.5 kW and a gas pressure of 63 mTorr was composed of many lines corresponding to the Balmer series of atomic hydrogen. We detected optical emission intensities from highly excited states having principal quantum numbers up to n=18. The population distribution of excited states deduced from the optical emission spectrum agreed well with the Saha-Boltzmann equation, indicating that the plasma is a recombining plasma at the local thermal equilibrium.

We shifted the wavelength range of the spectrograph to the Fulcher-α system of molecular hydrogen. Figure 1 shows an optical emission spectrum observed at an rf power of 1 kW and a gas pressure of 63 mTorr. The plasma produced at this discharge condition was an ionizing plasma. The several lines shown in Fig. 1 are perfectly assigned as the transitions of the Fulcher-α system ($a^3\Sigma_g^+$ - $d^3\Pi_u^-$).

Figure 2 shows an optical emission spectrum observed from a recombining plasma produced at an rf power of 2.5 kW and a gas pressure of 63 mTorr. It is clearly understood that the spectrum shown in Fig. 2 is completely different from Fig. 1. A part of the lines shown in Fig. 2 is assigned as the transitions of the Fulcher-α system, but the intensities of the Fulcher-α lines shown in Fig. 2 are weaker than those shown in Fig. 1. In other words, the intensities of the Fulcher-α lines in the ionizing plasma produced at 1 kW were stronger than those in the recombining plasma produced at 2.5 kW. The other many lines included in Fig. 2 were assigned as various triplet and singlet transitions of molecular hydrogen. It should be emphasized that the intensities of the lines other than Fulcher-α ones are negligible in ionizing plasmas.

The spectrum governed by the Fulcher-α lines shown in Fig. 1 can be explained qualitatively by analyzing the potential curves of molecular hydrogen, if the dominant production process of electronic excited states of molecular hydrogen in the ionizing plasma is electron impact excitation from the ground state. The unique spectrum shown in Fig. 2 reveals that the production process of electronic excited states in the recombining plasma is not electron impact excitation but recombination. The detailed investigation on recombination processes for producing the electronic excited states of molecular hydrogen is an important subject in future works.

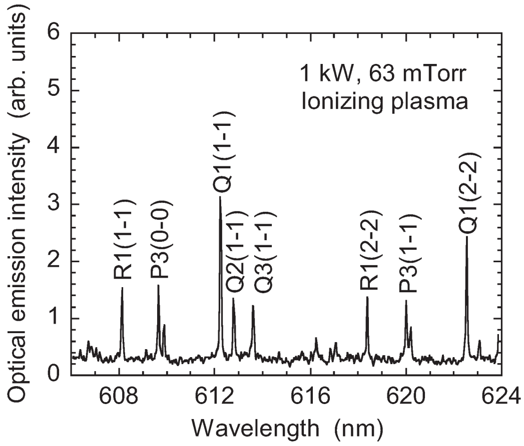

Fig. 1 Optical emission spectrum from molecular hydrogen observed at an rf power of 1 kW and a gas pressure of 63 mTorr (an ionizing plasma).

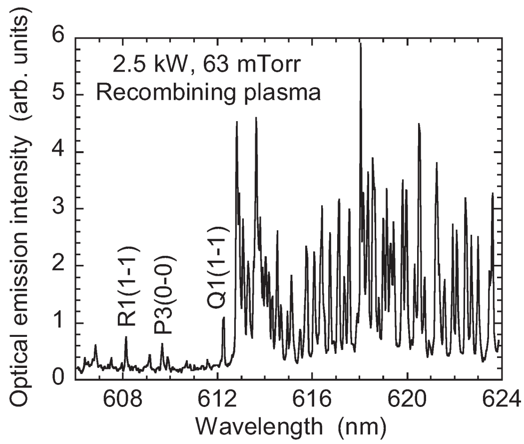

Fig. 2 Optical emission spectrum from molecular hydrogen observed at an rf power of 2.5 kW and a gas pressure of 63 mTorr (a recombining plasma).