§18. Plasma-quenching Efficiency of CO_2 by Estimation of C_2 Rotational and Vibrational Temperatures in High-pressure High-power Ar-CO_2 Induction Plasmas

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High-power and high-pressure inductively coupled plasmas are widely used in various fields such as material processings, the destruction of waste, etc.. Such high power induction plasmas have some advantages such as no contamination, good repeatability and high heat flux. On the other hand, the investigation of plasma-quenching efficiency of gases is nowadays very important in various fields. For example, in a high-voltage circuit breaker field, a circuit breaker must extinguish an arc plasma formed between the electrodes during a large electric-current interruption process. The recent gas circuit breaker extinguishes the arc plasma by blowing SF_6 gas. However, SF_6 has been specified as one of greenhouse effect gases whose emission to the atmosphere should be reduced. Thus, alternative gases of SF_6 for arc plasma quenching are greatly required in a circuit breaker field. Another field in which plasma-quenching gases are needed is the divertor fusion plasmas. The divertor is exposed to high heat flux that has to be quenched.

In our previous work, we used the inductively coupled plasma technique to investigate the plasma-quenching efficiency of various molecular gases, and found that CO_2 has a high plasma-quenching efficiency compared with other natural environmental-friendly gases such as N_2, O_2, Air, Ar and He [1]. In this experiment, the CO_2 injection was found to decreases Ar excitation temperature and the diameter of the high-power plasma region. However, we only estimated Ar excitation temperature on the assumption of local thermal equilibrium.

In the present work, we focus C_2 vibrational and rotational temperatures in high-power Ar-CO_2 induction plasmas to study plasma-quenching efficiency of CO_2 in detail from the observed C_2 Swan spectra. Rotational temperature is considered to be close to heavy particle temperature, while vibrational temperature to electron temperature because of rate of rotational and vibrational excitation and de-excitation processes by electrons or heavy particles.

The plasma torch used in the experiment is composed of two coaxial quartz tubes. The length of the inside tube is 161 mm, and its diameter is 82 mm. Argon and CO_2 gas mixture is supplied as a sheath gas along the inside wall of the inside tube. The total gas flow rate was fixed at 100 slpm(=liters/min). The gas flow rate of CO_2 gas was set to 0, 2, 5 and 10 slpm. The pressure of the torch is fixed at atmospheric pressure. The input power at the plate terminal in the vacuum tube oscillator was set to 50 kW. Spectroscopic observation was carried out for wavelength range of 400-800 nm to measure C_2 Swan molecular spectra and Ar I line spectra in Ar-CO_2 induction plasmas. Such C_2 spectra were found to have an increased radiation intensity with increasing CO_2 gas flow rate. On the contrary, the radiation intensities of Ar I spectra was seen to decrease with increasing CO_2 gas flow rate.

The emission coefficient of C_2 Swan spectra can be calculated theoretically using molecular structure data. We assumed that the population of excited C_2 particles follows the Boltzmann law, but with different temperatures T_{ex}, T_{vib}, T_{rot} for electronic, vibrational and rotational excitations, respectively. Vibrational and rotational temperatures T_{vib} and T_{rot} were estimated by fitting the theoretically calculated emission coefficient to the experimentally observed radiation intensity. Fig.1 shows comparison of the theoretically calculated radiation intensity of C_2 Swan spectra to the experimentally observed one at 10 mm below the coil end in 90%Ar-10%CO_2 plasmas. From this figure, we estimated T_{vib} to be 9000 K, while T_{rot} to be 5000 K. The similar estimation was carried out for different CO_2 gas flow rate and different spectroscopic observation positions. Fig.2 indicates the estimated radial distribution of T_{vib} and T_{rot} at 40 mm below the coil end. It is noted that T_{vib} is always higher than T_{rot}, which may mean thermal non-equilibrium state even in such high-power atmospheric pressure induction plasmas. Another important point is that increasing CO_2 decreases T_{vib}, which indicates that CO_2 decreases T_{vib}, then electron temperature by the CO_2 high plasma-quenching efficiency. This high plasma quenching efficiency is considered mainly to arise from energy consumption by dissociation of CO_2 to CO and O by another numerical simulation.

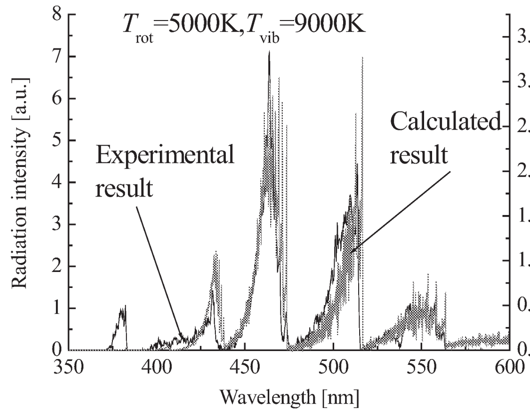

Fig.1 Comparison of C_2 Swan Spectra calculated and observed at 10 mm below the coil end in 90%Ar-10%CO_2 induction plasma.

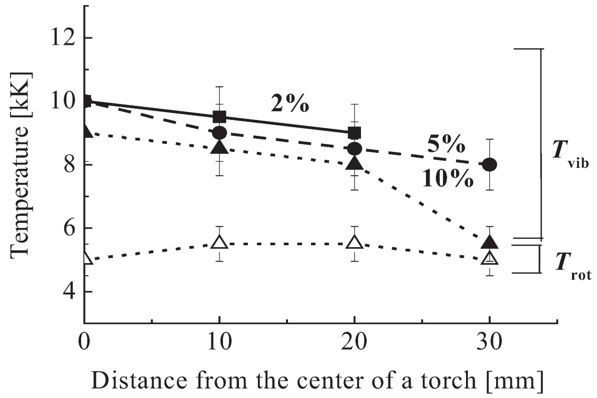

Fig.2 Radial distribution of vibrational and rotational temperatures at 40 mm below the coil end in Ar-CO_2 induction plasmas.

Reference

[1]Tanaka, Y.,Sakuta T., J.Phys.D:Appl.Phys. **35**, (2002) 2149