Atmospheric pressure radio frequency hydrogen induction thermal plasma diagnostics by optical emission spectroscopy

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Abstract: The atmospheric pressure radio frequency (RF) induction thermal plasma has been extensively used for many industrial processes. In order to understand the physical-chemical mechanism involved in the discharge process of the atmospheric pressure RF induction thermal plasma, *in situ* optical emission spectroscopy (OES) is carried out to diagnose and determinate the active particles and electron excitation temperature in this plasma. Several active particles such as Ar^*, Ar^+, H_α, and H_β are detected in the emission spectrum of an atmospheric pressure RF hydrogen induction thermal plasma. Based on the Boltzmann plot method, the electron excitation temperature and thermal efficiency of atmospheric pressure RF hydrogen induction thermal plasma are evaluated. It is obtained that the electron excitation temperatures in atmospheric pressure RF hydrogen induction thermal plasma varies from 9651.70 K to 16691.91 K when the applied power was in the range of 8 kW to 15 kW, which is significantly higher than the electron excitation temperature in pure argon induction thermal plasma at the same applied power. Besides, the thermal efficiency is changed from 17.19 % for the RF argon induction thermal plasma to 30.69 % for the RF hydrogen induction thermal plasma. These results shall be beneficial for understanding of the discharge process in atmospheric pressure RF hydrogen induction thermal plasma.

Keywords: Atmospheric pressure radio frequency induction thermal plasma; Diagnostics; Optical emission spectroscopy (OES); Electron excitation temperature; Thermal efficiency

1. Background

Thermal plasma at atmospheric pressure with the characteristics of ultra-high temperature and ultra-strong reactivity has been extensively used for high temperature pyrolysis process intensification, thermal spraying, hazardous waste materials treatment and nanoparticles or ultrafine powder synthesis. Compared to the general direct current (DC) thermal plasma, the radio frequency (RF) induction thermal plasma, without the electrode contamination in the plasma system, is very suitable for the synthesis of high purity nanomaterials [1-3]. Especially, RF induction thermal plasma discharged in the hydrogen atmosphere, which is called as hydrogen thermal plasma generally, possesses some special feature, for example, high temperature, high enthalpy, high heat and mass transfer ability, high reductive ability [4-5]. However, it is still difficult to directly detect the plasma temperature due to the ultrahigh temperature in the atmospheric pressure thermal plasma. In present work, OES diagnostic was adopted to collect the spectra in the atmospheric pressure hydrogen induction thermal plasma, where the hydrogen induction thermal plasma was generated by adding hydrogen into argon atmospheric pressure induction thermal plasma. The plasma temperature in hydrogen induction thermal plasma was calculated based on Boltzmann plot method. The thermal efficiency of hydrogen induction thermal plasma was also obtained by calculation.

2. Experimental setup and methods

The hydrgon thermal plasma was generated in a homemade RF induction thermal plasma system at an atmospheric pressure. The system mainly consists of a 10 kW of rated power, and 8~13 MHz of RF power supply, a quartz tube system, a four-tune antenna, a gas supply system and an off-gas exhaust system. The detailed operation parameters for stable RF induction thermal plasma process were listed in Table 1. OES diagnostic system in RF induction thermal plasma consists of three parts: emission spectrometer, optical fiber and computer. The emission spectra are recorded via a five-channel optical emission spectrometer (Avantes AvaSpec-2048×14-5-USB2, with the wavelength range from 200 nm to 900 nm). The emission lights are collected by an optical fiber and transported to the spectrometer. The distance between the optic fiber to the plasma quartz tube was 500 mm. The obtained data were processed directly by computer. The active components in plasma were analyzed based on the wavelength of spectral lines, and then the electron excitation temperature was calculated from the relative intensity strength of lines based on the Boltzmann plot method.

Table 1. Parameters of the thermal plasma process.

Parameters	Values
Plasma power	8~15 kW
Central gas, H_2	0~0.1 m^3/h
Plasma gas, Ar	0.5 m^3/h
Sheath gas, Ar	5 m^3/h
Working pressure	1 atm

3. Results and discussion

In atmospheric pressure RF induction thermal plasma, the plasma mode is in local thermodynamic equilibrium (LTE) owing to the fast interspecies collisional exchange at the high pressure, which means the temperature of heavy particles and electrons in plasma system are approximately equilibrium. In order to get the electron excitation temperature in RF hydrogen induction thermal plasma, five atomic spectral lines with central wavelengths of 675.28 nm, 687.13 nm, 696.53 nm, 738.47 nm and 751.51 nm were selected and then calculate the temperature based on the Boltzmann plot method. The electron excitation temperatures in RF argon induction thermal plasma at different applied power are shown in Fig. 1. The electron excitation temperature was varied from 10670.07K to 9952.45K when the applied power was raised from 8 kW to 15 kW. When the applied power was increased to 10 kW and 12 kW the electron excitation temperature was varied from 8923.70 K to 9575.34 K, respectively. It indicates that the electron temperature was strong relevant to the applied power.

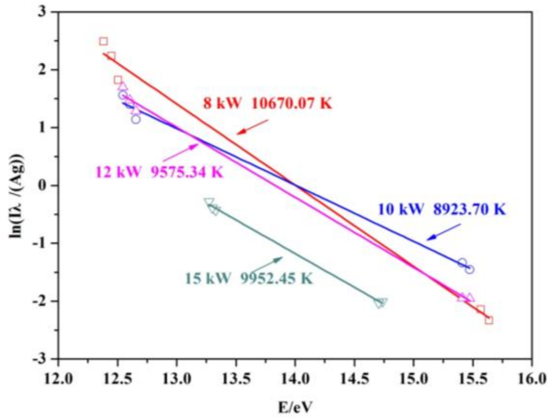

Fig. 1 Boltzmann plot for RF Ar induction thermal plasma versus the input power

When Hydrogen gas was added into Ar to form RF hydrogen induction thermal plasma, the variation of electron excitation temperatures with applied plasma power were shown in Fig. 2. The electron excitation temperature was varied from 9651.70 K to 16691.91 K when the applied power was raised from 8 kW to 15 kW. It was obviously higher than that in RF argon induction thermal plasma. The exact reason is that H_2 a diatom molecule has a higher specific heat than Ar. Similar reason to that in Ar induction thermal plasma, the highest electron excitation temperature in RF hydrogen induction thermal plasma was also appeared in 8 kW applied power condition.

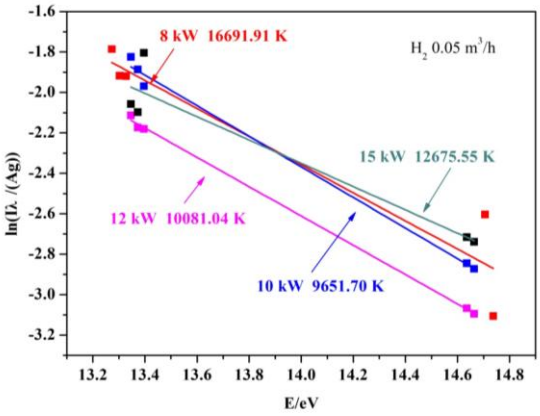

Fig. 2 Boltzmann plot for RF Ar/H_2 induction thermal plasma versus the input power

4. Conclusions

In summary, in order to determine the temperature in RF hydrogen induction thermal plasma, in situ OES diagnosis method was carried out by OES technique in RF hydrogen induction thermal plasma. Based on Boltzmann plot method the calculated electron excitation temperature in RF argon induction thermal plasma was varied from 8923.70 K to 10670.07 K, while they was varied from 9651.70 K to 16691.91 K in RF hydrogen induction thermal plasma when the applied powers were raised from 8 kW to 15 kW. The electron excitation temperature in RF hydrogen induction thermal plasma was higher than that in RF argon induction thermal plasma. The thermal efficiency of 8 kW RF argon inducted thermal plasma was estimated at 17.19 %, whereas it was 30.69 % for RF hydrogen induction thermal plasma. It resulted that hydrogen gas improved the thermal efficiency in RF induction thermal plasma.

5. References

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