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Original research article

The effect of power supply parameters on spectral lines in atmospheric pressure plasma jets (APPJs) using the He Stark broadening in optical emission spectroscopy

E. Sadeghzadeh Lari[a], H.R. Askari[a,*], M.T. Meftah[b], M. Shariat[a]

[a] Department of Physics, Faculty of Science, Vali-e-Asr University of Rafsanjan, Rafsanjan, Iran
[b] Department of Physics, LRPPS, University Kasdi Merbah, Ouargla 30000, Algeria

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ABSTRACT

In this work, contribution of all the broadenings in the emission line broadening in atmospheric pressure plasma jets (APPJs) have been determined for the cases of 667 nm and 728 nm lines. By fitting the experimental data with Voigt function, the experimental broadening have been obtained. By calculating Instrumental, Doppler, Resonance and Van Der Waals broadenings, and using experimental broadening, Stark broadening have been obtained. Finally, by using Griem's formula, the electron density and temperature have been determined and the effect of supply power parameters, voltage amplitude, frequency and pulse width, on the lines intensities and Stark broadening and the electron density and temperature have been investigated.

1. Introduction

Atmospheric pressure plasma jets (APPJs) has recently been of significant interest due to its low temperature plasma with a significant number of active species such as electrons, ions and radicals in ambient air [1]. APPJ is frequently used for fundamental studies and some applications such as plasma medicine, surface modification, material processing, synthesis of nanomaterial, material growth, pollution control and etc [2–9]. So plasma diagnostic of electron density and temperature is an essential work. Considering non- hydrogenated line Stark broadening is important when hydrogenated lines are not present in the plasma emission spectrum [10].

One of the most widely used techniques for plasma diagnostics is Optical emission spectroscopy (OEP). In this way, the Stark broadening of lines is achieved based on the convolution of Lorentzians, Gaussians and Starks profiles [11]. The Stark broadening of spectral line is due to the interaction of the radiating atoms with charged particles [12]. The measurement or calculation of this broadening is the most important in various fields such as plasma diagnostics [13].

Branimir Blagojević et al. [14] calculated the Stark broadening parameter of He I lines using numerically improved semiclassical formalism of Griem and compared with other sets of data. Griem et al. [12,15] calculated the Stark broadening for hydrogen and helium lines that broadened by local field of electrons and ions in plasmas in the classical path approximations. Brissaud et al. [16] presented the semiclassical theory of Stark broadening. They used a model of the actual microfield to get an exact calculations without approximations in high and low density limits for Hydrogen and Helium lines. OKS et al. [17] developed an improved semiclassical theory of Stark broadening of spectral lines emitted by Hydrogen-like ions. They achieved this improvements by taking into account a dynamic and quasistatic splitting of Stark sublevels caused by electrons and ions, respectively. Gigosos et al. [18]

* Corresponding author.
E-mail address: hraskarivaliasr@yahoo.com (H.R. Askari).

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presented the Stark width for the first three lines of Lyman and Balmer series of Hydrogen in a set of tables using a fully recognized computer simulation techniques.

Yongjie Wang et al. [1] used the optical emission spectroscopy to find the exited electron temperature and electron density in an atmospheric pressure argon plasma jet. They found that these parameters increase with increasing the gas flow rate. Alkhawwam et al. [19] used the optical emission spectroscopy to study the spatial and temporal behavior of the laser-induced plasma of tantalum. They used the Boltzmann plot and Saha–Boltzmann equation to calculate the electron temperature and density, respectively.

In this work, the Stark broadening of various Helium lines in atmospheric pressure helium plasma jet are obtained using the optical emission spectroscopy. In this way, various broadenings (Gaussian broadening consists of Instrumental and Doppler broadening, Lorantzian broadening consists of Van Der Waals, Resonance and Stark broadening) except Stark broadening are calculated or measured. By measuring the experimental broadening that is obtained by fitting the spectrum of each line and the results of other broadening, the Stark broadening is evaluated with a good accuracy.

This paper starts with the theory of various broadenings which contribute in experimental broadening in Section 2. The details of experimental setup and its results are in Section 3. The next section deals with the calculation of various broadenings according to Section 2. The calculation of Stark broadening are in Section 5 that are the main part. The conclusion is in Section 6.

2. Theory

The profile of experimental line is well-known Voigt form which is the convolution of Gaussian and Lorentz profiles. The relations between the experimental, Gaussian and Lorentz broadenings are introduced as [10]:

$$\Delta\lambda^{\exp} = 0.5\Delta\lambda_{1/2}^{L} + \sqrt{(0.5\Delta\lambda_{1/2}^{L})^2 + (\Delta\lambda_{1/2}^{G})^2} \tag{1}$$

where $\Delta\lambda_{exp}$, $\Delta\lambda_{1/2}^{L}$ and $\Delta\lambda_{1/2}^{G}$ are experimental, Lorentzian and Gaussian broadening, respectively. Experimental broadening of atmospheric pressure plasmas phenomena is due to the following broadenings:

- Instrumental broadening
- Natural broadening
- Doppler broadening
- Pressure broadening which is a combination of van der Waals broadening, resonance broadening and Stark broadening

where Doppler and Instrumental broadening have a Gaussian broadening, but the pressure broadenings (Van Der Waals, Resonance and Stark) have a Lorentzian broadening which can be written as below [10]:

$$\Delta\lambda_{1/2}^{G} = \sqrt{\Delta\lambda_I^2 + \Delta\lambda_D^2} \tag{2}$$

and

$$\Delta\lambda_{1/2}^{L} = \Delta\lambda_{\mathrm{VDW}} + \Delta\lambda_R + \Delta\lambda_{\mathrm{Stark}} \tag{3}$$

where $\Delta\lambda_I$, $\Delta\lambda_D$, $\Delta\lambda_{VDW}$, $\Delta\lambda_R$ and $\Delta\lambda_S$ are Instrumental, Doppler, Van Der Waals, Resonance and Stark broadening. In the following, these broadenings are explained theoretically. Here we must calculate all the broadening mentioned to obtain first Stark broadening and then calculate electron density and temperature.

2.1. Doppler broadening

The emitters in the plasma are in thermal motion. Doppler effect arises from the relative motion of an emitter to the detector that leads to a shifted line. The line profile due to the presence of Doppler effects is Doppler broadening and has a Gaussian line shape if their velocity distribution is Maxwellian. This broadening has a FWHM (nm) as below [10]:

$$\Delta\lambda_D = \lambda_0\left(8\ln 2\frac{k_B T_g}{m_a c^2}\right)^{0.5} \tag{4}$$

where λ_0, k_B, T_g, m_a and c are the wavelength, the Boltzmann constant, the gas temperature, the mass of the emitter and the light speed.

2.2. Resonance broadening

Resonance broadening occurs when the perturber and emitter are alike and either the upper or lower transition level has an allowed transition to the ground state (these transitions involving a level that is dipole-coupled to ground state). It has a Lorentzian shape. Resonance broadening for hydrogen Balmer lines at atmospheric pressure is negligibly small and can be excluded from calculation. Nevertheless, the resonance broadening of non-hydrogenated lines of Ar or He can be comparable with other broadening components at atmospheric. The FWHM of the resonance broadening is given by [20]: