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Hot Hydrogen Atoms in a Microwave Ar – N_2 – H_2 Wave Driven Plasma Torch

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1. Introduction

Nonthermal atmospheric plasmas have attracted much attention in recent years due to many industrial applications such as the creation of nanostructures, decontamination processes, hydrogen production, etc. For such purposes, waveguide-based, atmospheric plasma torches driven by surface waves are an attractive alternative to conventional plasma torches since they are compact, electrodeless, economical, and simple to operate [1]. In this study, non-intrusive 2D-resolved emission spectroscopy techniques have been used to map the spatial structure of Ar – N_2 – H_2 plasma torches driven by an azimuthally symmetric surface mode at 2.45 GHz.

2. Experimental Set-Up

A surface wave induced microwave plasma torch is created using a conventional discharge set-up. The field applicator is a wave launcher of the surfaguide type [2]. Microwave power is provided by a 2.45 GHz generator (Sairem GMP 20 KED), at levels varying between 200 W and 2000 W. A cylindrical, fused quartz discharge tube (with internal and external radii R_1 = 7.5 mm and R_2 = 9.0 mm, respectively) is filled by the working gas mixture of Ar(78%) – N_2(20%) – H_2(2%) at atmospheric pressure. The plasma column is generated within this tube. An overdense discharge plasma is sustained by the electric field of a surface wave guided along the interface between the plasma and the surrounding dielectrics. Due to axial transport, the plasma expands and a post-discharge plasma is formed beyond the discharge zone. Gas flows are controlled via a MKS 247 Readout coupled to three MKS flow meters, the total flow varying between 500 sccm and 10 slm.

A spectroscopic imaging system able to couple the plasma-emitted radiation into a SPEX 1250M spectrometer equipped with a nitrogen cooled CCD camera was used to measure 2D(r, z) profiles of emission intensities and line profiles. Abel inversion has been applied to derive the radial profiles from the side-on measurements.

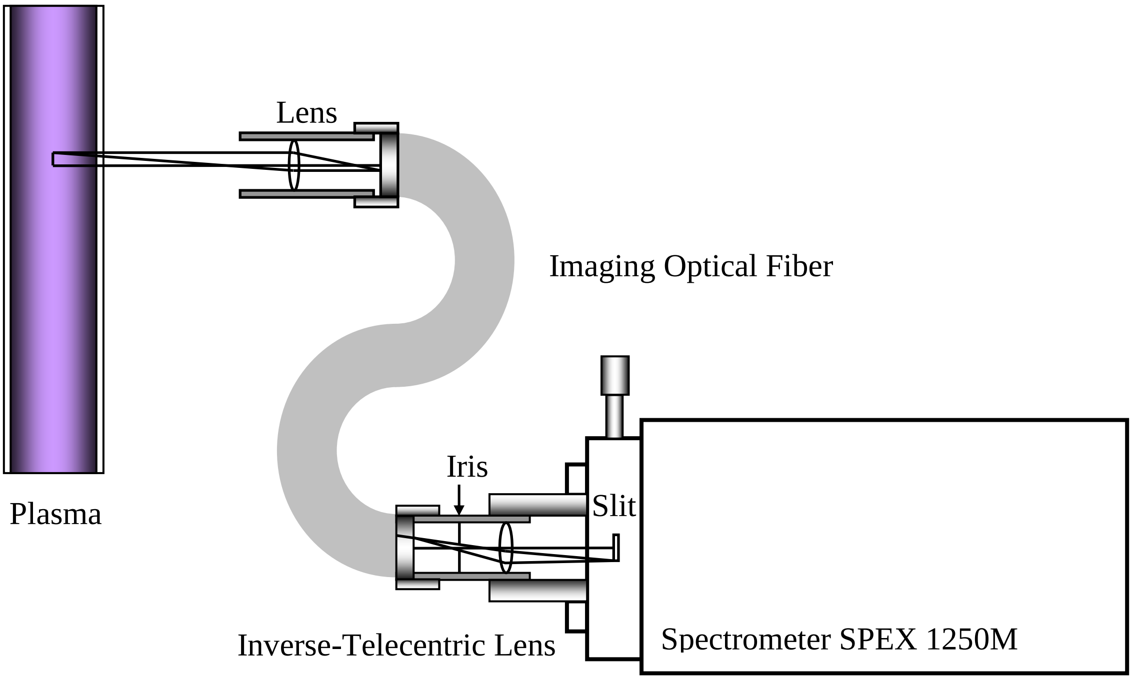

Fig. 1: 2D imaging optical system

The system includes: i) an objective lens with a 3:1 ratio, which matches the plasma and the fiber sizes (see next); ii) an imaging optical fiber, which rotates the image by 90 degrees; iii) a 1:1 inverse-telecentric lens, which effectively couples light into the input slit of the spectrometer while ensuring the most possible uniform spatial response. The above inverse-telecentric arrangement is made possible using an iris at the appropriated position. The optical system was designed using a high resolution flexible Schott optical fiber, model IG-567-36, made of 10 μm individual fibers with extended UV transmission. The cryogenic, back illuminated, UV sensitive CCD camera has a 2048×512 matrix with a 13.5 μm pixel-size, which provides high spatial and spectral resolutions.

3. Experimental results and discussions

3.1. Kinetic temperature of the atoms

Doppler broadening of atomic lines, which is directly related to the random (thermal) atomic motion, can be used to obtain the kinetic temperature. The measured Balmer H line profiles have been fitted by a Voigt function, which results from the convolution of a Gaussian profile (due to Doppler and instrumental broadening) with a Lorentzian one (due to Stark, and van der Waals broadening). A GRAMS/32® software has been used to this end. Therefore, the Lorentzian (Δ_{L}) and Gaussian full widths at half maximum (Δ_{G}) have been separated. A deconvolution procedure has been used to determine pure Doppler and Stark broadenings. Fig. 2 shows a measured H line profile fitted by a Voigt function. The fitting so achieved is very good ($R^2 > 0.99$) and the error in determining the Gaussian full width is less than 3%. The 2D profile of H atom kinetic temperatures is shown in Fig. 3 [Ar(88%) – N_2(10%) – H_2(2%), P = 500 W]. As seen, the temperature ranges from about 8,000 K close to the launcher to about 5,000 K at the discharge end. A strong radial gradient of H atom temperature, as for the gas temperature, is also observed. As shown in Fig. 3, the kinetic temperatures corresponding to the Doppler broadening of Balmer- lines are higher than the measured rotational temperatures. Thus, hyperthermal hydrogen atoms with temperature as high as twice the gas temperature have been detected. These hot hydrogen atoms may be formed by exothermic dissociative processes involving hydrogen molecular ions.

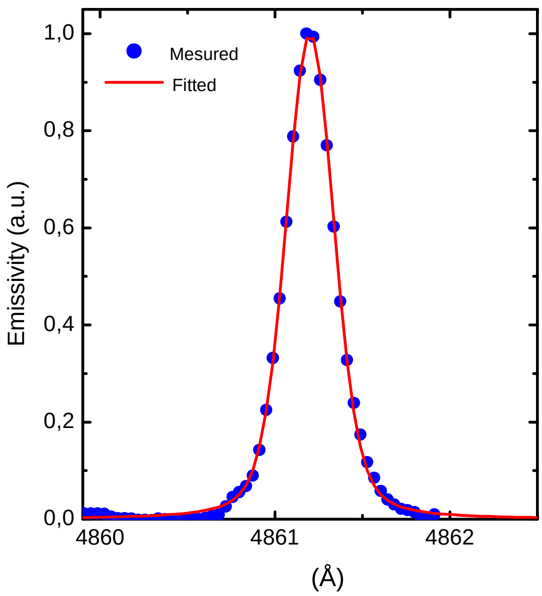

Fig. 2: H line profile (r/R = 0.3)

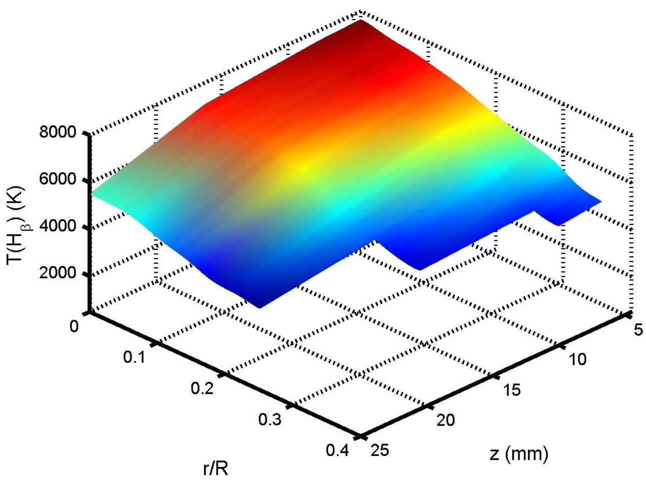

Fig. 3: 2D profile of H atom temperature

3.2. Electron density

Stark broadening of an atomic line, which is proportional to the local charge density around the emitter, is frequently used to determine the electron density. Stark broadening of the H line has been used to determine the electron density in the present work. In order to determine pure Stark broadening, the Van der Waals broadening has been deconvoluted from the Lorentzian full width at half maximum. The 2D map of the electron density is shown in Fig. 4. The measured electron densities are in the range 5×10^{13} cm^{-3} to about 5×10^{12} cm^{-3} at the discharge end.

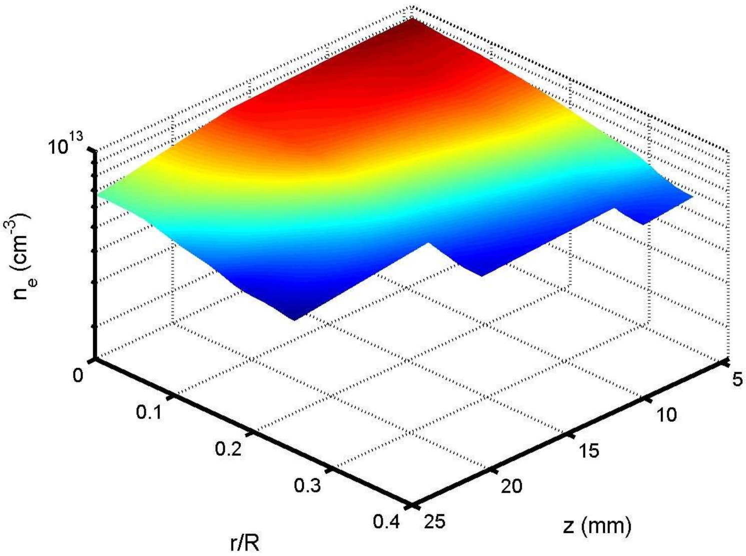

Fig. 4: 2D map of the electron density

4. Conclusions

An experimental study has been performed to investigate the spatial structure of a surface wave driven N_2–Ar–H_2 plasma torch. The H line profiles have been measured to determine the corresponding Doppler temperature and the electron density. The measured profiles are well fitted by Voigth profiles, and the Gaussian and Lorenzian part of the profiles have been deconvoluted. In this way, hyperthermal hydrogen atoms have been detected. The measured Doppler temperatures (T_D ~ 8,000 – 5,000 K) are higher than the rotational ones by a factor of about 2.

References:

[1] E. Tatarova, F. M. Dias, E. Felizardo, J. Henriques, C. M. Ferreira, and B. Gordiets, Plasma Sources Sci. Technol. (2008) **17**, 7.

[2] M. Moisan, M. Chaker, Z. Zakrzewski, and J. Parasczak, J. Phys. E: Sci. Instrum. (1987) **20**, 1356.