Spatial distribution measurement of H atom density, $CH/C_2/H_2$ vibrational/rotational temperatures, and electron temperature for microwave plasma-activated diamond growth

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Abstract: We investigated spatial distributions of H atom density, $CH/C_2/H_2$ vibrational/rotational temperatures, and electron temperature by optical emission spectroscopy (OES) to understand and control the diamond growth process utilizing microwave plasma-activated chemical vapor deposition (MPCVD).

1. Introduction

Microwave plasma-activated chemical vapor deposition (MPCVD) has been used to grow diamonds by producing gas mixtures rich in atomic hydrogen and carbon radicals. The properties of such grown diamonds heavily depend on the exact fluxes of the plasma-generated radical species as they impact the growing surface. The growth of doped diamonds appears to be sensitive to the ratio of radical species at the surface.

Characterizing spatially distributed plasma parameters critical for MPCVD diamond growth, namely radical species densities, neutral gas temperature, and electron temperature, will validate and improve predictive models.

We have determined the spatial distribution of such plasma parameters by the actinometry method [1-3] utilizing optical emission spectroscopy (OES).

2. Methods

The working condition of MPCVD in this study was the pressure P = 90-150 Torr and microwave power I = 1500-3000 W for H_2-CH_4-Ar gas mixtures. For OES, the light emitted from the plasma was collected by a collimator lens system (2 mm line-of-sight spot diameter) and transported to a low-resolution spectrometer (OceanOptics, HR2000+, 380-800 nm). The measurement location was scanned for radial and axial directions to process the obtained spectra for Abel inversion, converting line-integrated light emission to local emission. Molecular band emissions of C_2, CH, and H_2 were measured and analyzed to determine their rotational and vibrational temperatures. Actinometry utilizing line emission intensity ratios of Hα, Hβ, and Ar 750 nm was applied to determine the H atom density and electron temperature. Our actinometry model includes the de-excitation process by neutral collisions, called quenching, which is a dominant process compared to spontaneous emission in near atmospheric pressure environments. [1]

3. Results and Scope

Abel inversion of the line-integrated radial emission profile was performed to obtain the local emission profile (Fig. 1). For the experimental configurations, the rotational temperature determined by utilizing C_2 or CH bands was up to 3000 K, and actinometry determined the H mole fraction up to ~20%. The results are consistent with previous reports [1,3]. Results from two-photon laser induced fluorescence (TALIF) [2] will cross-check the determined H atom density. We found that H_2 rotational temperature determination has to be carefully applied as the targeted H_2 Fulcher band emission lines could be overlapped by other impurity lines, especially when a higher fraction of Ar or CH_4 species was mixed to plasmas. We will report the determined spatial distribution of plasma parameters for discharge configurations scanned for the total pressure, CH_4 concentration, and input power to be compared with a computational model.

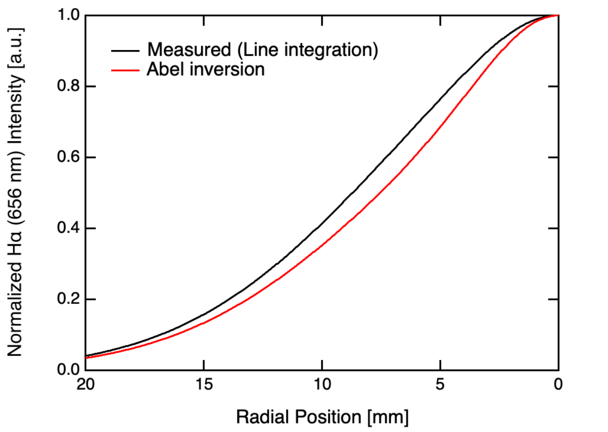

Fig. 1. Comparison between radial Hα (656 nm) intensity profiles before and after Abel inversion for a plasma of P = 150 Torr, I = 2500 W, and flow rates H_2 200 SCCM and Ar 14 SCCM. The radial profile was taken at 7 mm above the substrate surface.

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References

[1] A. Gicquel et al., Chem. Phys. **398**, 239 (2012).
[2] A. Gicquel et al., J. Appl. Phys. **83**, 7504 (1998).
[3] J. Ma et al., J. Appl. Phys. **105**, 043302 (2009).