Characterization of Reversed Arc Hydrocarbon Plasma in Material Synthesis (Supplement to the Abstract # 56553)

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The reversed arc (RA) reactor is shown schematically in Fig.1 [1,2]. In this reactor the primary arc is ignited in the low-pressure primary arc compartment connected to the pumping system. The arc discharge is extended to the remote anode positioned in the high-pressure plasma processing chamber with attached gas supply inlet. The plasma processing chamber is connected to the primary arc chamber via narrow nozzle-orifice. The pressure difference between the plasma processing chamber and the primary arc chamber is holding due to hydraulic resistance of the nozzle and the magnetic pressure generated by the arc current transferring throughout the narrow opening in the nozzle [1]. In one experimental setup, the substrate Si wafer, 3" diameter, is positioned on top of the substrate holder disk, 18 cm diameter at the bottom of the plasma processing chamber. The substrate holder can be optionally connected to the positive terminal of the power supply to serve as remote anode of the reversed arc discharge. In this case the substrate was separated from the anode disk by sapphire wafer spacer. In another experimental setup the substrate is suspended on high temperature dielectric cable. The photograph of the fluidized bed version of this reactor for synthesis of diamond coatings over in-flight aerosol particles confined in the uprising swirling plasma flow of the vertical reactor tube, 1m tall, is also shown in Fig. 1. The IR pyrometer was installed on top of the plasma processing chamber to measure the temperature of substrate positioned in the bottom of the chamber. Another pyrometer port was provided on side wall of the processing chamber to measure temperature of the objects suspended in reversed arc plasma. The low-pressure arc radiation was collected by a collimated lens, at that the arc column was generally aligned along the optical axis. The emission was then focused at the fiber optic cable through an optical vacuum feed through. The fiber optic cable was divided in 4 channels to conduct plasma radiation toward a set of four Ocean Optics spectrometers HR-4000 with bandwidths of 199-428, 399-613, 600-799 and 800-972 nm, respectively. The devices (with gratings of 1200 L/mm) have optical resolutions of ~0.03 nm and have high sensitivity detectors. Relative sensitivity of the devices as a function of wavelength was calibrated using the DH-2000-CAL. A total of five spectra were taken and averaged per scan. The relative standard deviation of the measured intensities of the lines and bands does not exceed 5-7%. Voltage-Current characteristic of the RA discharge shows increase of the voltage when the current increases (Fig.2a). The discharge voltage decreases and the pressure in the plasma processing chamber increases when the Ar concentration in Ar/H_2 gas mixture increases which is attributing to the large molecular thermal thermal conductivity of Ar.

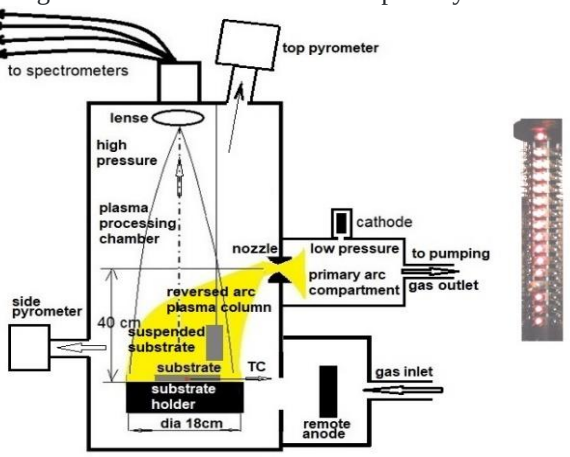

Figure 1. Schematic diagram of a reversed arc discharge reactor with stationary substrate (left); and photograph of the 1 meter tall, fluidized bed reactor tube for diamond growth on in-flight aerosol particles in operation (right).

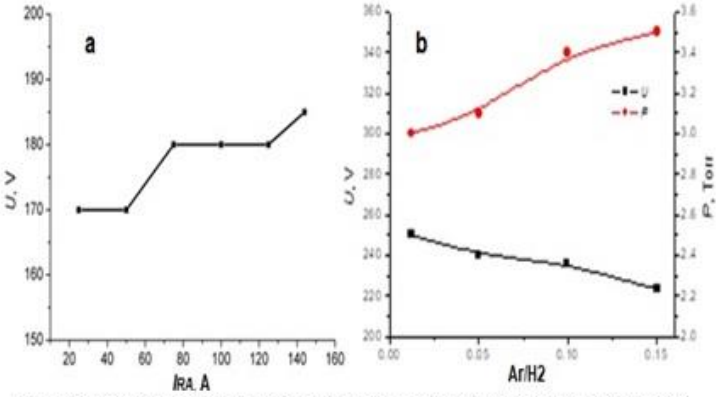

Figure 2. RA discharge voltage as functions of RA current at P=2 Torr and Ar/H2=0.14 (a); discharge voltage and gas pressure in the plasma processing chamber as functions of Ar/H2 ratio at P=2 Torr and I=144A (c).

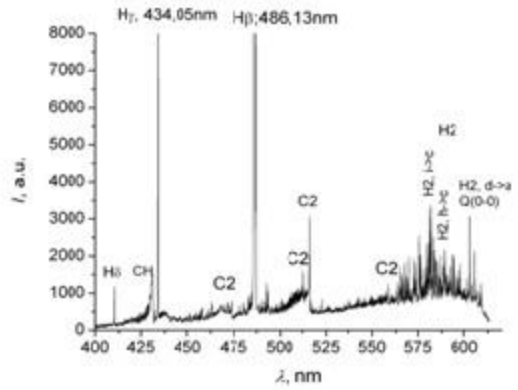

Figure 3. Typical spectrum of reversed arc discharge in Ar+H2+CH4 gas mixture at RA current of 144A.

Typical spectrum of reversed arc discharge is shown in Figure 3. It consists of molecular bands of H_2 and hydrocarbon radicals CH and C_2 in addition to atomic hydrogen lines. In other spectral ranges the additional radicals such as C_2H_2 and the radicals resulting of plasma chemical reactions of hydrocarbons with traces of water and nitrogen such as OH and CN are also presented. The dissociation degree of molecular hydrogen was estimated using the optical actinometry method from intensity ratio IHα/IArI of the Hα and ArI 750 nm lines, showing the dissociation degree of hydrogen in the arc plasma is about 15-20% [3,4].

The reversed arc plasma was modeled in an axially-symmetrical one fluid, one temperature approximation using commercial COMSOL FEM software. The dissociation of the hydrogen across the discharge tube was calculated by thermal dissociation and via LTE calculation based on minimization of isobaric-isothermal potential of the closed thermodynamic system similar to the approach presented in [2,5], using commercial TERRA software (the latest version of the former ASTRA software), developed by Prof. B.G. Trusov. Alternatively, hydrogen thermal dissociation was calculated via 3-body reactions: 2H + M <=> H_2 + M, where M=H_2, H or Ar, where the reaction rates were taken from [6]. The thermal dissociation model relies on solving an advection-diffusion-reaction (ADR) equation for atomic hydrogen that is produced by Ar or H_2 impact and lost in three-body recombination. In this approach, the smaller number of reactions affecting hydrogen dissociation are included compared to LTE calculation, while diffusion losses to the chamber walls are taken into account which is expected to produce less nascent hydrogen than in LTE conditions. On the other hand, LTE gives the dissociation degree coupled to the local temperature while the ADR approach gives broaden spreading of the nascent hydrogen cloud toward the cooler area of the discharge. The results of the comparison of hydrogen dissociation degree across the arc column shown in Fig.4 demonstrate reasonably good agreement both with optical actinometry results and between two modeling approaches.

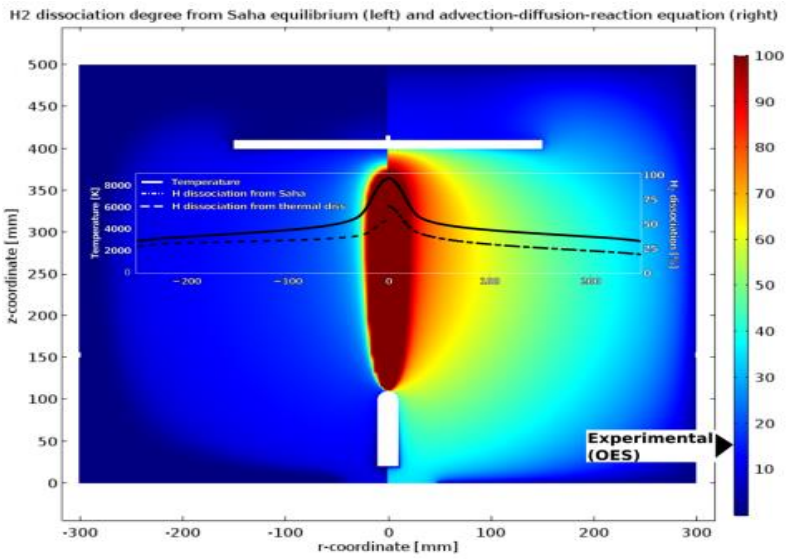

Figure 4. Comparison of the modeling distributions of H_2 dissociation degree across the column of 10%Ar-90%H2 arc at p=2 mTorr and I=150.

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