OR0909

Source gas depletion in narrow metal tube during internal DLC coating with microwave-excited high-density near plasma

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Recently, internal coating of DLC (Diamond-Like Carbon) to mm-sized narrow metal tubes is desired. In our previous work, we deposited DLC on the inner surface of metal tube by using MVP (Microwave-sheath Voltage combination Plasma) method. In addition, axially uniform distribution of film thickness was obtained by taking plasma-off time T_{off} (enough to homogenize the source gas in the tube) and plasma-on time T_{on} (enough to deplete the source gas in the tube). However, the depletion of source gases has not yet observed directly. Thus in this work, we tried to observe the depletion of source gases using optical emission of plasma.
We deposited DLC on the inner surface of a stainless-steel tube 4.4 mm in inner diameter and 100 mm in length with small holes of Φ=0.4 mm at 10 mm intervals by MVP method. In the coating process, the flow rates of gases, Ar, and methane were controlled to be 14 and 2 sccm, respectively, at a total gas pressure of 80 Pa. In order to conduct DLC coating, a pulsed negative voltage of –200 V was applied to the pipe at a pulse frequency of f_{pulse}=10 Hz and duty ratio of D_v=3.2 %, synchronizing a pulsed injection of 2.45-GHz microwaves at the same pulse frequency and duty ratio of D_m=4 % (T_{on}=3.2 ms and T_{off}=96.8 ms). In order to observe the depletion of source gas, the image of optical emission leaking from the small holes was taken by using a high-speed camera with 460-480 nm and 690-710 nm bandpass filters. Note that emissions from Ar atom (696, 706 nm) and C_2 dimer (468-474 nm) are detected with 460-480 nm and 690-710 nm bandpass filters, respectively. As a result, the brightness of Ar atom, which is not consumed for film formation, was approximately constant during plasma-on time. On the other hand, The brightness of C_2 dimer was decreased until T_{on} =1.5 ms, and then converged in a constant value. The decrease in the brightness of C_2 dimer is ascribed to the consumption of CH_4 gas which is considered to be a main source of C_2 dimer formation.

Keywords
Internal coating of mm-sized metal tube
DLC
Microwave
High-density plasma
Optical emission spectroscopy