2nd Asia-Pacific Conference on Plasma Physics, 12-17,11.2018, Kanazawa, Japan

Surface modifications of materials using high-repetition nanosecond pulsed glow discharges under sub-atmospheric pressure

Yusuke Kikuchi[1], Takuya Maegawa[1], Ryo Hirano[1], Akira Otsubo[2], Yoshimi Nishimura[2], Masayoshi Nagata[1], Mitsuyasu Yatsuzuka[1]

[1] Graduate School of Engineering, University of Hyogo, [2] Kurita Seisakusyo Co. Ltd.

e-mail (speaker): ykikuchi@eng.u-hyogo.ac.jp

This study presents a new novel technique of surface modifications of materials using high-repetition nanosecond pulsed glow discharges under sub-atmospheric pressure. A repetitive nanosecond pulsed glow discharge is one of recent topics in the plasma research community, because it is one of key technologies for production of non-equilibrium plasma under atmospheric/sub-atmospheric pressure [1]. A repetition frequency of nanosecond pulsed voltage application is one of key parameters for determination of discharge characteristics. When the time interval between voltage pulses is shorter than the lifetime of an afterglow produced by a preceding pulsed discharge, charged particles and radicals in the afterglow give rise to a pre-discharge effect for a subsequent pulsed discharge. It is considered that an afterglow lifetime of a nanosecond pulsed glow discharge under atmospheric/sub-atmospheric pressure is of the order of several microseconds [2]. Thus, a repetition frequency of several hundreds of kHz is necessary to utilize the pre-discharge effects. However, such a high-repetition frequency range cannot be driven by conventional nanosecond pulse generators with Si-based switching devices.

Recently, we firstly demonstrated two discharge modes, α and γ, of a repetitive nanosecond pulsed helium (He) glow discharge under sub-atmospheric pressure of 10 kPa in the repetition frequency range from 20 to 600 kHz [3]. The pulsed glow discharge was produced in a pair of parallel plate metal electrodes without insertion of dielectrics. Such kind of the high-repetition frequency can be first achieved using a recently developed SiC-MOSFET inverter supply. It was clarified that the α mode discharge was volumetrically produced in the electrode gap at a low-repetition frequency, whereas the γ mode discharge was localized at the cathode surface at a high-repetition frequency. Spatio-temporal resolved measurements of optical emission intensities of the γ mode discharge using an intensified CCD (ICCD) camera showed that the discharge emission was localized at the cathode surface during the afterglow period. In addition, it continued until the subsequent pulsed voltage was applied. This result suggests that the γ mode discharge is maintained by a large number of secondary electrons emitted from the cathode exposed to high-density ions and metastable He atoms. Similar discharge modes have been reported in radio-frequency (RF) capacitive dielectric barrier discharges (DBDs) in helium [4], but it has not been reported so far that both the discharge modes appear in a repetitive nanosecond pulsed He glow discharge between bare metal electrodes without insertion of dielectrics under sub-atmospheric pressure. The most important finding is that the repetition frequency of the applied pulsed voltage higher than ~ 120 kHz is necessary for the excitation of γ mode discharge. Thus, the recently developed SiC-MOSFET inverter power supply enables us to generate the γ mode discharge.

It is considered that the γ mode discharge is desirable, especially for applications in material processing such as film deposition, in which high-density ions and radicals produced in the vicinity of the cathode can be used for the process. This consideration was supported by our experimental study of diamond-like carbon (DLC) film preparation [5]. In the DLC film preparation experiment, silicon (Si) wafers were installed on the high-voltage electrode. A gas mixture of He and methane (CH_4) with a gas pressure of 1 kPa was used for the process gas. After the plasma exposure for 15 min, the Si substrate surface became visually black in comparison with the virgin Si substrate. As a result, an increase in film hardness to 13 GPa and a decrease in hydrogen content in the DLC film were confirmed by increasing the repetition frequency to 200 kHz. In addition, the deposition rate was 100 nm/min, which was 5 times higher than that of conventional plasma CVD processes under low-gas pressure. On the other hand, the film hardness was about 4 GPa at the repetition frequency of 30 kHz. Thus, high-speed DLC film preparation was successfully performed using the γ mode discharge driven by the high-repetition nanosecond pulsed voltage application.

In the conference, our most recent results for a high-repetition nanosecond pulsed nitrogen glow discharge will be also presented.

References

[1] R. Brandenburg, P. J. Bruggeman, S.M. Starikovskaia, Plasma Sources Science and Technology, Vol. 26, 020201 (2017).

[2] C.G. Schregel, E.A.D. Carbone, D. Luggenholscher, U. Czarnetzki, Plasma Sources Science and Technology, Vol. 25, 054003 (2016).

[3] Y. Kikuchi, T. Maegawa, A. Otsubo, Y. Nishimura, M. Nagata, M. Yatsuzuka, Plasma Sources Science and Technology, Vol. 27, 05LT01 (2018).

[4] S.Y. Moon, J.K. Rhee, D.B. Kim, W. Choe, Physics of Plasmas, Vol. 13, 033502 (2006).

[5] Y. Kikuchi, M. Ogura, T. Maegawa, A. Otsubo, Y. Nishimura, M. Nagata, M. Yatsuzuka, Japanese Journal of Applied Physics, Vol. 56, 100306 (2017).