Control of ROS and RNS productions in liquid by using a nonthermal high-frequency plasma jet

Giichiro Uchida, Kosuke Takenaka, Yuichi Setsuhara,
Joining and Welding Research Institute, Osaka University
e-mail : uchida@jwri.osaka-u.ac.jp

Atmospheric nonthermal plasma jets have been widely employed in biomedical applications because they induce little thermal damage to biomaterials. Controlling the production of ROS and RNS in aqueous solutions is an important issue from the viewpoint of biomedical application because various cells are activated by ROS and RNS in aqueous solutions. In this study, we successfully control the H_2O_2 and NO_2^- concentrations by using a nonthermal high-frequency plasma jet with a glowlike discharge [1-3]. We compared the developed high-frequency Ar plasma jet with the conventional low-frequency He plasma jet in detail, where the focus is on 1) the discharge characteristics in the gas phase and 2) the ability to selectively produce H_2O_2 and NO_2^- in the liquid phase. Figure 1 shows the photographs of the low- and high-frequency plasma jets. The low-frequency He plasma jet is the most widely used plasma source for biomedical application. The developed high-frequency Ar plasma jet had the same discharge plume length of 40 mm and diameter of a few mm as the low-frequency plasma jet, and can be applied to biomedical experiments in the same manner. In the gas phase, the high-frequency Ar plasma jet had a high $O(^3P_j)$ atom density of 8×10^{14} cm^{-3}, which is two order magnitude higher than that of the low-frequency He plasma jet.

Then, in order to investigate an ability of the high-frequency plasma jet to produce the ROS and RNS in the liquid water, we irradiated the plasma jets to the deionized water. For the low-frequency plasma jet, we directly exposed the plasma jet to the liquid surface, and strong optical emissions were observed near the liquid surface. In contrast, for the high-frequency plasma jet, we did not expose the plasm jet to the liquid surface, and no optical-emission area was observed on the liquid surface. The two distinct plasma-irradiation conditions, with plasma contact and no observable plasma contact, could be distinguished between with the naked eye or from CCD images. On the direct contact of the low-frequency plasma jet, the H_2O_2 concentration was higher than NO_2^- concentration for all gas condition of He, He/O_2, He/N_2, and He/N_2(80%)O_2(20%) as shown in Fig. 2(a). On the other hand, on the no observable contact of the high-frequency plasma jet, NO_2^- concentration linearly increased with an increase in the gas flow rate of N_2(80%)O_2(20%), and NO_2^- became more dominant compared with H_2O_2 in the plasma treated water (see Fig. 2(b)). Our experiments clearly demonstrated that the selective H_2O_2 and NO_2^- productions in the plasma treated water can be realized by using the high-frequency plasma jet with high plasm density. We will also show experimental results on a biomedical application of the plasma-treated liquid and a material joining process with the high-frequency plasma jet in the presentation.

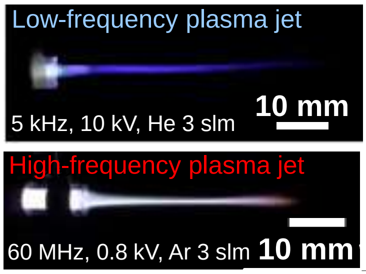

Figure 1. Photographs of the low- and high-frequency plasma jets [3]. Copyright (2018) The Japan Society of Applied Physics.

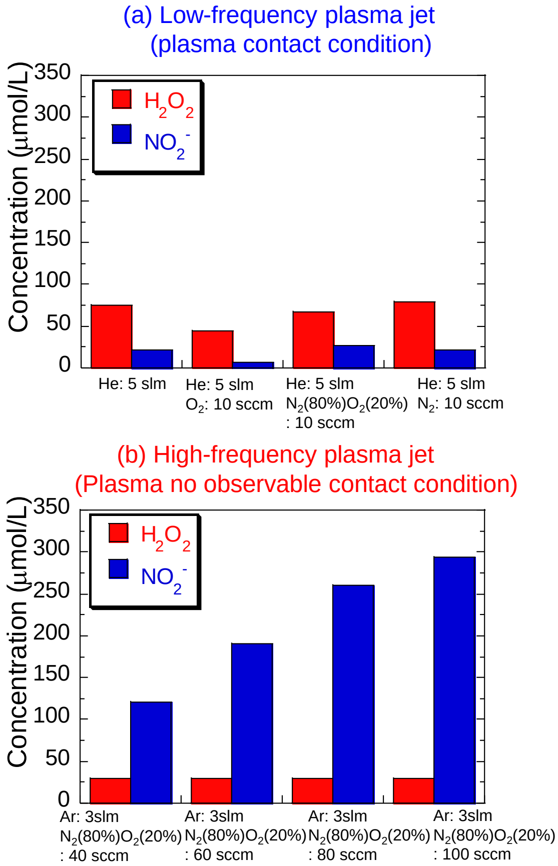

Figure 2. Concentrations of H_2O_2 and NO_2^- in the plasma treated water [3]. Copyright (2018) The Japan Society of Applied Physics.

References

[1] G. Uchida, A. Nakajima, T. Ito, K. Takenaka, T. Kawasaki, K. Koga, M. Shiratani, Y. Setsuhara, J. Appl. Phys. 120, 203302 (2016).

[2] G. Uchida, K. Kawabata, T. Ito, K. Takenaka, Y. Setsuhara, J. Appl. Phys. 122, 033301(2017).

[3] G. Uchida, K. Takenaka, K. Takeda, K. Ishikawa, M. Hori, Y. Setsuhara, Jpn. J. Appl. Phys. 57, 0102B4 (2018).