Effects of Discharge Gas Metastable Energy level on the Nitric Oxide Radical Generation in Atmospheric Pressure Plasma Jet for Oral Bacteria Removal*

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Atmosphere Pressure Plasma Jet (APPJ) can be a promising tool for non-thermal microorganism removal because the enormous radical production, such as Nitric Oxide (\textit{\textsuperscript{\scalebox{0.7}{\textbullet}}NO}). The effects of metastable energy level of discharge gases on the \textit{\textsuperscript{\scalebox{0.7}{\textbullet}}NO} generation are studied by using the helium (He) and argon (Ar). Since the energy level of He metastable (He*), 23.1 eV, is higher than the nitrogen molecule (N_2) ionization energy level, 14.5 eV, the He* is able to penning ionize the N_2. In case of Ar, however, the energy state of metastable is 14.1 eV and it is not enough to cause the penning ionization on the N_2. The APPJs with He and Ar are generated by inducing the sinusoidal LF voltage on the APPJ generator. The APPJ generator consists with concentric \textphi 0.2 mm tungsten wire and quartz gas guiding tube with inner diameter of 2 mm and outer diameter of 4 mm. The ground electrode wraps the quartz tube, 2 mm from the end of the tube. The tungsten electrode is covered with Al_2O_3 ceramic tube to concentrate the plasma discharge at the end of the electrode. The range of applied voltage amplitude, operating frequency, and gas flow rate are 2-3 kV, 20 kHz, and 3 L/min, respectively. The APPJ produced excited species and density of \textit{\textsuperscript{\scalebox{0.7}{\textbullet}}NO} with discharge gases are measured by using Optical Emission Spectroscopy (OES) and Laser Absorption Spectroscopy (LAS). In order to evaluate the effect of \textit{\textsuperscript{\scalebox{0.7}{\textbullet}}NO} on oral bacteria removal, Colony Forming Units (CFU) number of \textit{P.gingivalis} is counted after APPJ irradiation, \textit{in vitro}. The characteristic times of oral bacteria removal by He- and Ar- APPJ irradiation are 1.63 and 12.1 min, respectively. Those values are inversely proposed to the LAS measured \textit{\textsuperscript{\scalebox{0.7}{\textbullet}}NO} densities. OES measurements show that the He-APPJ generates the He*, N_2^+, O_2^-, and \textit{\textsuperscript{\scalebox{0.7}{\textbullet}}NO}. However, only the Ar* and O_2^- are generated in Ar-APPJ. Since the O_2^- is generated by electron attachment, it can be observed in both APPJs. The absence of the N_2^+ in the Ar-APPJ indicates that the no energetic electrons inside APPJ are involved in N_2^- production and \textit{\textsuperscript{\scalebox{0.7}{\textbullet}}NO} is generated by recombination of N_2^- and O_2^- . Thus the penning ionized at the boundary of APPJ by metastable with higher energy level than N_2 ionization energy is the key factor to produce the \textit{\textsuperscript{\scalebox{0.7}{\textbullet}}NO} generation in APPJ.

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