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Selective Production of Reactive Species for Plasma Medicine Using Vacuum Ultraviolet Photodissociation
プラズマ医療のための真空紫外光による選択的活性種生成

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A production method for producing reactive species (OH, H, O, O_3, and $O_2(a^1\Delta_g)$) using vacuum ultraviolet (VUV) photolysis with an excimer lamp is proposed. It can be used for studying effects of the reactive species on plasma medicine. Densities of reactive species produced by the VUV method are calculated using a simulation and the validity of the simulation is verified by measuring O_3 and OH densities using UV absorption and laser-induced fluorescence.

1. Introduction

In plasma medicine, reactive species produced in the plasma are considered to have therapeutic effects. However, the effect of each kind of reactive species on plasma medicine is still not clear because many kinds of reactive species are produced in plasma, and their individual medical effects are difficult to isolate. For investigation of the effects of reactive species on plasma medicine, another production method of reactive species is needed that has a much simpler reaction system than plasma. In this paper, a production method of reactive species using vacuum ultraviolet (VUV) photolysis is proposed.

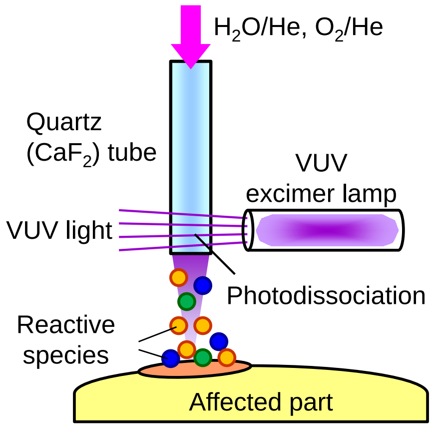


Fig.1. Schematics of the VUV method.

2. Simulations

The VUV method is shown in Fig. 1. It is similar to a He atmospheric-pressure plasma jet (APPJ) used for plasma medicine. Helium-buffered mixture (H_2O/He or O_2/He) flows in a quartz tube of 2 mm diameter. The VUV light from the excimer lamp (Xe_2 lamp at 172 nm or Kr_2 lamp at 146 nm) irradiates the flowing gas near the quartz tube nozzle to photodissociate H_2O and O_2 to produce OH, H, O, O_3, and $O_2(a^1\Delta_g)$. When an O_2/He is used, O_2 is photodissociated by the VUV light as

$$O_2 + h\nu \rightarrow O(^1D) + O. \qquad (1)$$

The resulting $O(^1D)$ reacts with O_2

$$O(^1D) + O_2 \rightarrow O + O_2(X, a, b). \qquad (2)$$

$O_2(b^1\Sigma_g^+)$ is deactivated to $O_2(a^1\Delta_g)$ as

$$O_2(b) + M \rightarrow O_2(a) + M. \qquad (3)$$

$O_2(a^1\Delta_g)$ is produced via reactions (2) and (3). O atoms produced by reactions (1) and (2) react with O_2 to produce O_3

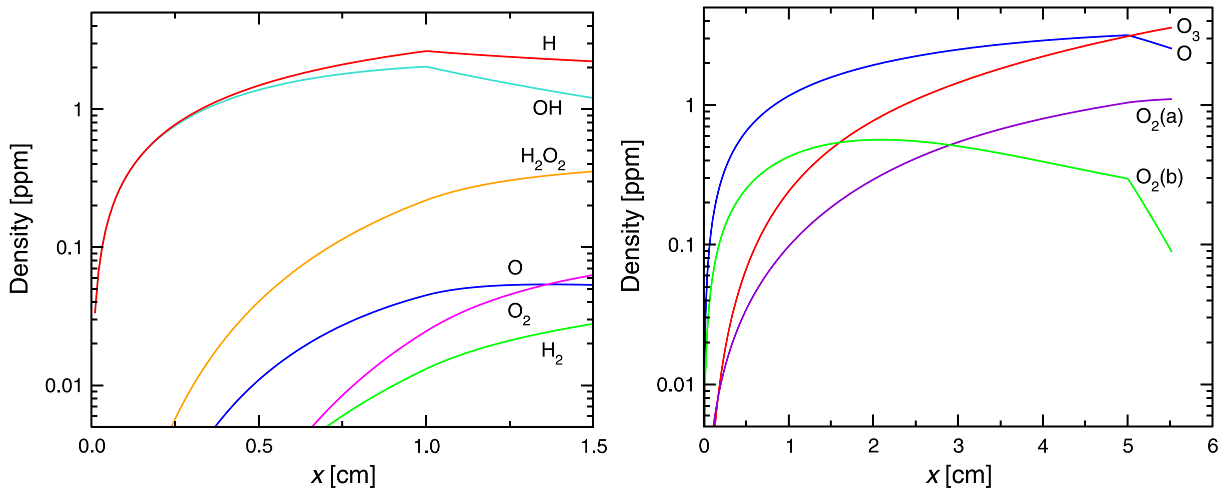
$$O + O_2 + M \rightarrow O_3 + M. \qquad (4)$$

Thus, O, O_3, and $O_2(a^1\Delta_g)$ are produced as a result of the VUV photodissociation of O_2 (reaction (1)).

When an H_2O/He is used, photodissociation of H_2O leads to production of OH and H

$$H_2O + h\nu \rightarrow OH + H. \qquad (5)$$

Figure 2(a) shows a simulation result when the VUV light from a Xe_2 lamp irradiates a H_2O(2.8%)/He mixture. The simulation is one-dimensional, including 42 photolysis and chemical reactions and 4 wall reactions. The inner diameter of quartz tube is 2 mm, the gas flow rate is 2 L/min (= 1.06 cm/ms), and the illuminance of the



(a) H_2O(2.8%)/He, Xe_2 lamp (b) O_2(0.2%)/He, Kr_2 lamp

Fig.2. Simulation results for Xe_2 lamp and Kr_2 lamp methods.

Xe_2 lamp is 50 mW/cm^2 which is approximately the maximum illuminance provided by commercially available Xe_2 lamps. The VUV light is irradiated for 1 cm length (x = 0 to 1 cm in Fig. 2) and the target is assumed to be placed at 0.5 cm from the quartz tube nozzle (x = 1.5 cm in Fig. 2). The nozzle is at x = 1 cm. Figure 2(a) shows that 1–2 ppm of H and OH radicals are supplied to the target. The OH density is on the same order of that produced by a He-APPJ [1].

Figure 2(b) shows a simulation result when the VUV light from a Kr_2 lamp irradiates an O_2(0.2%)/He mixture. The Kr_2 lamp has a large cross section for O_2 photolysis, while the Xe_2 lamp has a large cross section for H_2O photolysis. The VUV irradiation length is increased to 5 cm. When the Kr_2 lamp (146 nm) is used, a MgF_2 of a CaF_2 tube should be used instead of the quartz tube. Figure 2 shows that 2 ppm of O atoms are supplied to the target, but it is an order of magnitude smaller than that produced by a He-APPJ [1]. If the gas flow rate is reduced to 0.1 L/min to increase the VUV light irradiation time, high densities of O_3 and $O_2(a^1\Delta_g)$ are obtained: higher than 1000 ppm and 10 ppm, respectively, which are equivalent to or higher than those produced by a He-APPJ [2, 3].

3. Experiments

To verify the validity of the simulations, the O_3 and OH densities produced by the Xe_2 lamp method are measured. A Xe_2 excimer lamp (Min-Excimer, Ushio) is used as the VUV source. The O_3 density is measured using 254 nm absorption from a low-pressure mercury lamp when dry or humid O_2(0–100%)/He mixture is irradiated with the Xe_2 lamp, and the OH density is measured using laser-induced fluorescence (LIF) at 2 mm distance from the quartz tube nozzle when H_2O(2.8%)/He is irradiated with the Xe_2 lamp. The measured O_3 densities are slightly higher than the simulated results but the difference is within 35%. It is allowable. The difference for OH density is 3–4 times, which is not negligible but understandable if measurement errors are considered.

4. Conclusions

The production of OH, H, O, O_3, and $O_2(a^1\Delta_g)$ using the VUV photodissociation of H_2O and O_2 was proposed. It was studied using simulations and measurements. The VUV method produced sufficient amount of OH, O_3, and $O_2(a^1\Delta_g)$ compared with He-APPJ. However, the density of O atoms was much smaller than He-APPJ. Instead of the VUV method, we are at present developing another method for O atoms production. According to a simulation, the alternative method can supply more than 100 ppm of O atoms continuously to a target. We are now planning experiments to verify the simulation of the method.

References

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