The study of plasma jet of argon and carbon dioxide gas mixture

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ABSTRACT

This study aims to investigate the effects of argon and carbon dioxide gas flow rates on the properties of plasma jets and the efficiency of carbon monoxide production at room temperature. A cold atmospheric plasma jet was employed as a chemical reaction activator under ambient conditions. The experiment involved varying the flow rates of argon 1 to 7 Lit per min and carbon dioxide 100 to 500 cc per min. The plasma characteristics analyzed through high-speed imaging and Optical Emission Spectroscopy (OES). In addition, the effects of plasma exposure on surface properties examined by measuring the contact angle of treated glass substrates. The results revealed that gas flow rate significantly affected the plasma jet length, brightness, and stability. For pure argon plasma, the electron temperature decreased with increasing flow rate, while the variation in temperature became smaller. When CO_2 introduced, the electron temperature further decreased depending on the Ar/CO_2 ratio. The highest CO production efficiency obtained at an argon flow rate of 7 Lit per min and CO_2 flow rate of 100 cc per min at power level 3 (0.62 W). Moreover, plasma treatment on glass surfaces reduced the contact angle, indicating enhanced surface wettability. These results demonstrate that cold plasma can be used as an effective method to produce CO at room temperature, as CO has properties such as reducing inflammation and promoting wound healing, providing an initial idea for further medical applications of argon–carbon dioxide plasma produced by plasma jet.

THEORY

Compact air plasma jet

Plasma jets operating under atmospheric pressure and near-room temperature are classified as Cold Atmospheric Plasma (CAP). These can generate plasma plumes with specific properties, such as length, conductivity, and light emission, without damaging the contact surface. This makes them suitable for applications in biomedicine and low-energy chemistry, such as microbial inhibition or specific chemical catalysis.

Electron Temperature

The Boltzmann plot method can be used to calculate electron temperature (T_e) by relating the population of excited energy levels to the intensity of emission lines, based on the Maxwell-Boltzmann distribution.

$$\ln\left(\frac{I_{ki}\lambda_{ki}}{g_k A_{ki}}\right) = -\frac{E_k}{k_B T_e} + C \qquad T_e = -\frac{1}{slope}$$

Assuming a quasi-steady-state, the plasma releases constant energy and follows Boltzmann statistics within the measurement region.

Carbon dioxide Production

The production of carbon monoxide (CO) from carbon dioxide using plasma is a process that does not rely on high heat, but instead uses electronic excitation and an excited state to break the bonds of CO_2 to produce CO under room temperature conditions.

$$CO_2 + e^- \rightarrow CO + O + e^-$$

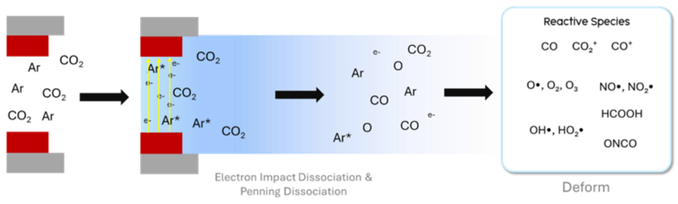
Electron Impact Dissociation

$$Ar^* + CO_2 \rightarrow Ar + CO_2^+ + e^-$$

$$Ar^* + CO_2 \rightarrow Ar + CO + O$$

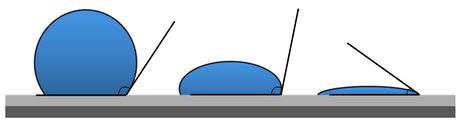
Penning Ionization & Penning Dissociation

Carbon monoxide (CO) can be produced from CO_2 using plasma at room temperature, The Plasma jet operates by accelerating electrons to excite Ar atoms, providing sufficient energy to break CO_2 bonds, and then the plasma is emitted as a flow through the gas stream.



wettbility changing surface

Wetting ability refers to the tendency of a liquid to spread across a surface. The wetting behavior of a liquid on a solid can be quantified by the contact angle; a contact angle below 90° indicates good wetting, while an angle above 90° indicates poor wetting.



It is measured by the contact angle a small angle indicates good wetting (hydrophilic), while a large angle indicates poor wetting (hydrophobic).

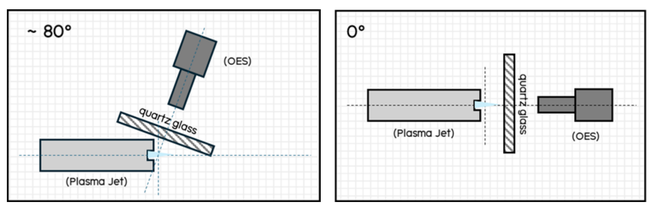
METHODS

Analysis of the properties of argon gas plasma jet.

The experiment used only argon (Ar) as the starting gas, with the flow rate adjusted from 1 to 7 liters per minute and the power level adjustable to 3 levels, to study the effect of flow rate on the plasma beam properties and calculate the electron temperature (Te) using the Boltzmann plot.

The experiment involves mixing carbon dioxide gas to produce carbon monoxide.

The experiment involved mixing carbon dioxide gas with argon, using CO_2 flow rates of 100 to 500 cc/min, to study the effect of the gas mixture on CO_2 decomposition and carbon monoxide production under cold plasma.



Experimental preparation for OES plasma measurements in a straight line at 0° and an oblique line at approximately 80°.

Wettability Analysis

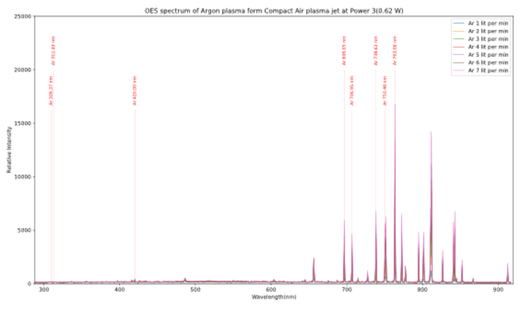
The experiment uses a plasma jet machine under efficient conditions to generate the highest possible carbon monoxide concentration from the plasma jet, which is then treated onto a glass slide. The surface energy of the material is then analyzed to determine its wetting ability.

RESULTS

Plasma jet with pure argon gas



The typical characteristics of the plasma jet generated by argon gas with Power 3 (0.62 W) show a significant increase in plasma beam intensity and length, and maximum discharge stability.

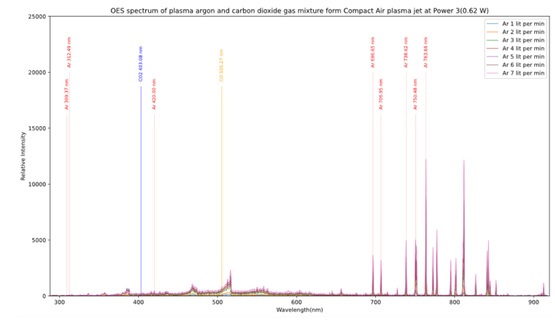


The emission spectrum of a linear argon gas plasma jet at Power 3 (0.62 W) under different argon gas flow rates of 1 to 7 L/min

Plasma jet mixed with carbon dioxide gas to produce carbon monoxide

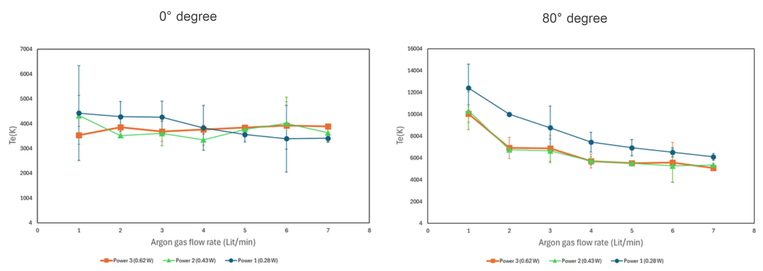


This demonstrates the characteristics of a plasma flame between argon and carbon dioxide gases at Power 3 (0.62 W). The brightness decreases as the carbon dioxide gas flow rate increases.



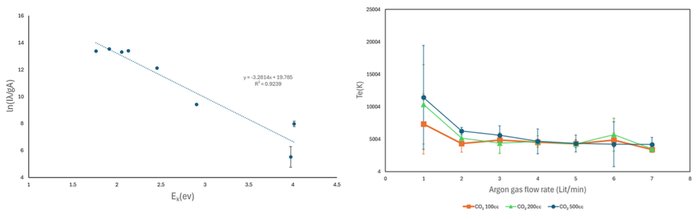
The emission spectrum of a linear argon gas plasma jet at Power 3 (0.62 W) under different argon gas flow rates of 1 to 7 L/min and carbon dioxide gas flow rates of 100 cc/min is shown.

OES plasma measurements in a straight line at 0° and an oblique line at approximately 80°



The graph shows the electron temperature (T_e) of the plasma jet in a straight line at Power 1 (0.28 W) to Power 3 (0.62 W) under argon gas flow rates between 1 and 7 L/min.

Examples of Boltzmann plots and comparisons of electron temperatures.

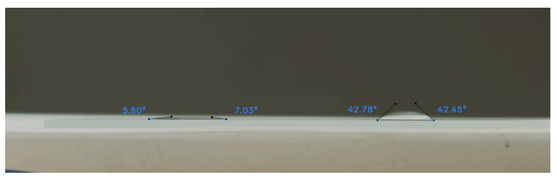


The graph shows the electron temperature (T_e) of the plasma jet in a straight line at Power 3 (0.62 W) and carbon dioxide flow rates of 100, 300, and 500 cc/min, respectively.

A comparison using carbon dioxide gas to measure the efficiency of carbon monoxide production revealed that increasing the carbon dioxide flow rate resulted in a decrease in CO2 intensity and ratio. The analysis showed that an argon flow rate of 7 liters per minute and a carbon dioxide flow rate of 100 cc per minute yielded the most efficient carbon monoxide production.

Wettability Analysis

The contact angle measurements of the glass panels in two conditions were shown using the plasma jet condition with the highest carbon monoxide production efficiency.



The untreated surface had a contact angle of 6.38°, and the plasma-treated surface had a contact angle of 42.20°. The contact angle reduction was approximately 0.126 N/m for the untreated surface and approximately 0.145 N/m for the plasma-treated surface. Analysis of the significant reduction in contact angle after plasma treatment indicates that the glass panel surface has undergone chemical and physical changes.

CONCLUSION

In experimental analysis of the argon gas plasma jet temperature using optical spectroscopy, it was found that the argon gas flow rate increased with the applied power level. As the argon gas flow rate increased from 1 to 7 liters per minute, the signal intensity tended to increase with the argon gas flow rate.This indicates changes in electron density and energy within the plasma beam, suggesting the presence of higher excited states of argon atoms. In experimental analysis of the effect of a carbon dioxide-mixed plasma jet for carbon monoxide production using optical spectroscopy, it was found that increasing the carbon dioxide gas flow rate resulted in a decrease in plasma brightness, indicating increased density and energy competition of carbon dioxide.A comparison of the carbon monoxide production efficiency was then conducted. It was found that a flow rate ratio of argon gas at 7 L/min and carbon dioxide at 100 cc/min, using power 3 (0.62 W), resulted in the most efficient carbon monoxide production, as analyzed by optical spectroscopy. This led to experiments and analysis of the contact angle to test the wetting ability on glass slides. Plasma jet surface treatment significantly increased the wetting ability of the surface, with the contact angle decreasing from 42° to approximately 6° and the surface tension increasing from 0.126 to 0.145 N/m. This confirms that cold plasma can modify material surfaces to have hydrophilic properties.

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