Efficiency of Micro Discharge on Plasma Catalytic Nitrogen Fixation

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Highlights

- Sharp μ-tips on electrodes promote the electron impact dissociation of nitrogen molecules.
- Excitation of nitrogen is higher in pyramid shaped μ-electrodes as compared to flat electrode.
- Nitrogen fixation is improved by 80% and energy yield by 51% in pyramid electrode.
- Maximum NO_X synthesis is found at 60% to 70% of oxygen concentration in nitrogen feeding gas.
- Micro-electrodes can reduce the energy cost of plasma-assisted nitrogen fixation.

1. Introduction

Conventional nitrogen fixation methods often incur substantial energy costs and environmental impact, necessitating a paradigm shift toward more resource-conscious alternatives. The utilization of the pyramid-shaped micro-electrode aims to amplify the efficacy of nitrogen fixation by enhancing the generation of vibrational nitrogen species plasma. A carefully designed charge injector leverages the distinctive electric fields generated by the pyramid-shaped configuration, thereby augmenting the rate of secondary electron emission. This exploration not only investigates the energy efficiency and cost-effectiveness of such a system but also delves into its potential to yield heightened conversion rates of nitrogen oxides, signaling a promising advancement in the sustainable agriculture discourse.

2. Methods

Two identical setups, flat electrode DBD, and pyramid electrode DBD were employed in the experiment. Pyramid tips were engraved in a Titanium coin to demonstrate charge injection phenomena. The experiment explored eight different oxygen and nitrogen admixtures, varying flow rates while maintaining a constant total flow rate. Optical emission spectroscopy (OES) and Fourier transform infrared spectroscopy (FTIR) for analyzing plasma discharge chemistry and gas composition, respectively. The results included current-voltage waveforms, Lissajous figures, and spectroscopic data, providing insights into the efficiency and energy costs of plasma-assisted nitrogen fixation using pyramid-shaped micro-electrodes.

3. Results and discussion

Pyramid-shaped micro electrodes, featuring sharp microtips, play a crucial role in enhancing the electron impact dissociation of nitrogen molecules and promoting higher excitation levels in nitrogen compared to flat electrodes. This configuration results in a remarkable 80% improvement in nitrogen fixation and a 51% increase in energy yield when utilizing pyramid electrodes as compared to the flat electrode. The optimal conditions for maximum NOX synthesis are identified at 60% to 70% oxygen concentration in the nitrogen feeding gas.

The concentration of electric field around sharp tips or edges enhances the surface charge density, increasing the likelihood of vibrational excitation or ionization of surrounding gas molecules. In contrast to the uniform electric field around flat electrodes, sharp edges with small curvature on pyramid electrodes result in higher charge density and a stronger electric field at the tip, impacting the velocity of ions and

intensifying the process of secondary electron emission. Pyramid micro electrodes, characterized by a high intensity of local electric fields, exhibit a notable rate of secondary electron emission and field emission, enhancing electron density and temperature.

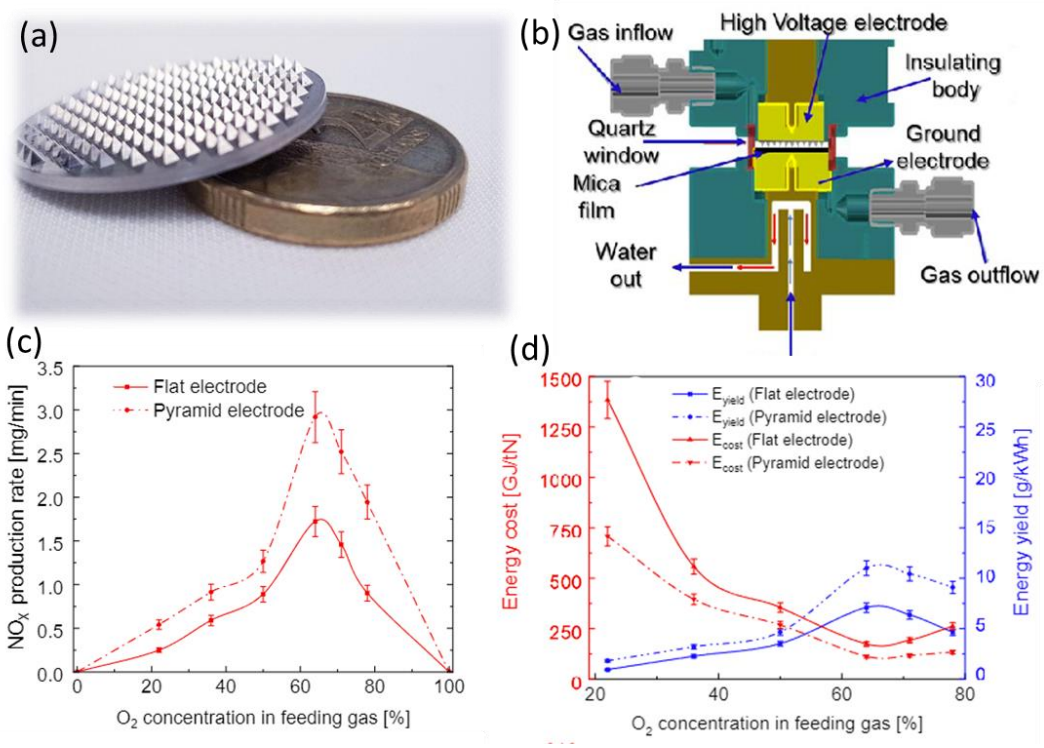

Fig. (a) Photograph of engraved electrode. **(b)** Experimental set-up. **(c)** NOx production and **(d)** energy cost at various oxygen concentrations in both flat and pyramid electrode.

4. Conclusions

The research proposes a new method for nitrogen fixation using a pyramid micro-electrode in dielectric barrier discharge, which generates more vibrational nitrogen species plasma. A charge injector enhances secondary electron emission by leveraging high-intensity electric fields from the pyramid electrode. Experimental results show that this approach is energy-efficient and cost-effective, producing up to 80% more nitrogen oxides with 34% less energy cost. Mixing 60-70% oxygen in the nitrogen feeding gas optimizes gas phase nitrogen oxides output. In conclusion, the pyramid micro-electrode presents potential for sustainable and localized nitrogen fixation in the micro-fertilizer industry.

References

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Keywords
Nitrogen fixation, Fast-modulated, Surface-confined, Sustainable