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Hybrid Plasmon-Enhanced Evanescent Microwave Plasma Pen: A Novel Conceptual Design for Safe Clinical Cold Plasma Therapy

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ABSTRACT

Introduction: Cold atmospheric plasma has shown promise for various medical applications. However, current microwave sources often generate excessive thermal loads, while alternative systems frequently suffer from instability. This study proposes a conceptual design that integrated evanescent-field microwave confinement, plasmonic thermal regulation, and intelligent control mechanisms.

Materials and Methods: The proposed architecture includes: (1) A 2.45 GHz evanescent-mode cavity that generates near-field plasma at power levels <5 W; (2) Au-coated alumina microspheres (50-200 µm) that passively damped high-energy electrons through plasmonic resonance, which help suppress gas heating; (3) artificial intelligence-assisted control that utilized optical spectroscopy, thermometry, and power monitoring to enforce safety limits (temperature <40°C, leakage <1 mW/cm²). The theoretical modeling uses Maxwell's equations, Fermi-Dirac statistics, and plasma kinetics, accompanied by simulation optimization.

Results and Discussion: Predictions indicate that field confinement will occur within 2-3 mm, with exponential decay preventing tissue overheating. The plasmonic array is expected to reduce the electron temperature by 30-45% compared to conventional plasma sources. Simulations suggest that ignition power may be reduced by 60%-70%, with projected temperatures <38°C. This design eliminates the need for high-voltage electrodes, operates at atmospheric pressure (0.5-3 SLPM), and enables disposable tips with leakage level <0.5 mW/cm².

Conclusion: Our conceptual design uniquely combines evanescent microwave confinement, plasmonic thermal control, and intelligent monitoring. By applying microwave stability and addressing thermal limitations through passive plasmonic damping, the proposed system has the potential to enable safe and reproducible cold plasma therapy. Future work will focus on prototype fabrication, thermal validation, reactive oxygen and nitrogen species characterization, and biocompatibility assessment.

Keywords: Cold atmospheric plasma, Evanescent field, Microwave plasma, Plasmonic nanoparticles, Plasma medicine

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