Abstract

The primary objective of our work is the research and development of high-pressure microplasma devices as a compact and efficient ultraviolet (UV) lamp suitable for advanced optical applications. High-pressure microplasma offers significant benefits, including enhanced excimer emissions and elevated electron densities. As such, these devices are emerging as promising candidates for next-generation UV radiation sources. However, maintaining stable plasma operation at elevated pressures poses some peculiar challenges, including the potential for glow-to-arc discharge transitions and electrode degradation. Furthermore, encapsulating these devices with a UV-transparent thin film is implemented using sol-gel films that are optimized for optical transparency and mechanical robustness.

In this research, thick electroplated copper electrodes fabricated using the UV-LIGA process are utilized to investigate the performance of high-pressure microplasma devices. A pulsed DC power supply is used to maintain a stable glow discharge at high pressures. The formation of Argon excimer enhances UV emission. Excimer formation is a three-body reaction and is enhanced at higher pressures. With this view, the characteristics of discharges at higher pressures are investigated. We show that microplasmas can achieve consistent performance up to 2 atm with optimized geometries.

Plasma inside nanoporous channels is investigated for increasing the device longevity and reducing electrode degradation. It is observed that nanoporous electrodes not only increase longevity, but they also result in high plasma density, temperature, and more stable plasma discharges.

A novel micro-shell packaging approach is introduced to tackle the challenge of UV-transparent encapsulation. A process of fabricating a UV-transparent porous silica cap, synthesized via a sol-gel method at low thermal annealing temperatures, is developed and optimized. The process is optimized for both porosity and UV transparency, leading to an encapsulation that ensures minimal optical loss while providing adequate structural integrity. This balance between porosity and optical transmission is critical for the successful packaging of microplasma devices. A controlled pore distribution of porous silica film is achieved, which facilitates 55 % UV transparency. Further, the pores in the encapsulation act as natural etch-release holes, simplifying one of the most complicated steps of fabrication process.

Overall, this research aims to develop a stable, high-pressure microglow discharge device with enhanced durability and minimal electrode degradation. The findings highlight that by integrating thick-film copper electrodes, nanoporous materials, and UV-transparent encapsulation, a scalable solution for reliable, high-performance microplasma-based UV lamp devices can be developed. The robust and scalable fabrication strategies developed herein may find application in environmental sensing, water purification, and other applications requiring reliable, high-performance UV sources.