

MEMS-based microplasma devices on glass substrates for optical emission spectroscopy

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Summary:

This work presents the design, fabrication, and characterisation of MEMS-based microplasma devices implemented on glass substrates for optical emission spectroscopy (OES). The use of glass substrates is explored to reduce substrate-related leakage currents compared to conventional silicon-based devices. Devices were fabricated using thin-film metallisation and dielectric passivation layers compatible with available processing routes. Plasma ignition was achieved at applied voltages in the kV range and excitation frequencies around 10 kHz. The device behaviour observed indicates that the use of glass substrates does not provide a clear advantage in terms of stability or lifetime under the conditions tested. The results suggest that device performance is primarily governed by dielectric properties and electrode configuration, rather than substrate conduction.

Keywords: MEMS, microplasma, dielectric barrier discharge, optical emission spectroscopy, gas analysis

Introduction

Non-thermal microplasmas have been widely explored for gas analysis using optical emission spectroscopy (OES). Plasma OES enables identification of molecular species through their characteristic emission spectra, providing a compact and versatile approach to gas sensing. Integration of plasma sources into micro-electromechanical systems (MEMS) platforms enables miniaturisation and supports the development of portable, point-of-need systems [1-3].

In this work, we investigate microplasma devices based on the dielectric barrier discharge (DBD) principle, fabricated on glass substrates. The use of glass substrates is explored to reduce substrate-related leakage currents present in silicon-based devices. While silicon substrates are convenient for MEMS processing, their finite conductivity may introduce parasitic losses and influence device operation. Glass substrates provide electrical insulation, potentially reducing substrate coupling and associated losses in the device.

The objective of this study is to assess the impact of substrate choice on device behaviour, focusing on plasma ignition, stability, and qualitative performance under comparable operating conditions.

Design

A minimal configuration for microplasma generation consists of two metal electrodes patterned on an electrically insulating substrate and covered with a dielectric passivation layer. Plasma ignition occurs when the applied voltage generates an electric field in the gas that exceeds the breakdown threshold, while remaining below the limits that would damage the dielectric.

The devices investigated in this work are based on planar electrode configurations with characteristic gap sizes of 10, 25, and 50 μm . Both single devices and linear arrays were implemented. The total chip size is $8 \times 8 \text{ mm}^2$. The dielectric passivation layer consists of an ALD-deposited Al_2O_3 film with thicknesses in the range of 0.25–1 μm .

Compared to silicon-based designs, the use of a glass substrate removes direct electrical coupling to the substrate. Under these conditions, the device capacitance and operating behaviour are primarily governed by the dielectric stack and electrode geometry.

Fabrication

Devices were fabricated using MEMS-compatible processes adapted to glass substrates. Thin-film metal electrodes were deposited and patterned using standard lithographic techniques.

Due to process constraints, gold (Au) was used as the electrode material.

A dielectric passivation layer of Al_2O_3 was deposited over the electrodes to mitigate sputtering-induced erosion and to define the active plasma region. Openings were formed in the passivation layer to provide electrical access for wire bonding. The devices were subsequently diced and mounted on custom printed circuit boards (Fig. 1a).

The fabrication flow differs from the silicon-based process primarily in substrate material, metallisation, and dielectric deposition.

Characterisation

Following fabrication and packaging, the devices were tested for plasma ignition and operation under controlled conditions. A high-voltage excitation setup was used, consisting of a waveform generator and a voltage amplifier providing peak-to-peak voltages in the range of 1.0–2.0 kV at frequencies of 10 kHz. The plasma emission was monitored optically using a microscope and a spectrometer, with integration times in the ms range.

Plasma ignition was observed in ambient air at pressures of 200–500 mbar (Fig. 1c). The plasma emission was monitored optically using a microscope and a spectrometer. Representative emission spectra show characteristic peaks corresponding to species present in air.

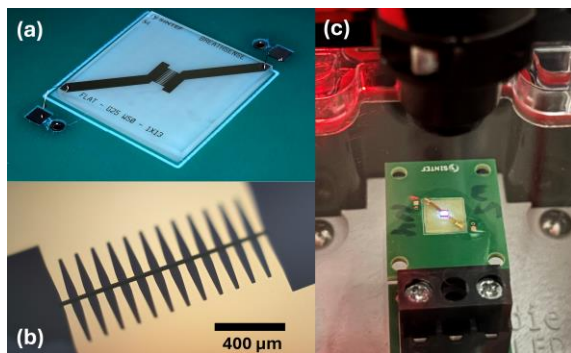


Fig. 1. MEMS DBD microplasma device on glass: (a) chip bonded to PCB, (b) 13-finger electrode array detail, (c) plasma in operation.

In comparison to silicon-based devices with standard dielectric passivation, the glass-based devices exhibited similar qualitative behaviour in terms of ignition and emission. However, no clear improvement in device lifetime or stability was observed. In several cases, localised sparking and degradation of the dielectric passivation were observed during operation.

The increased capacitance associated with the Al_2O_3 dielectric layer is consistent with its higher relative permittivity compared to $\text{SiO}_2/\text{Si}_3\text{N}_4$

stacks used in previous designs [4, 5]. This increased capacitance may influence the electrical behaviour and energy dissipation in the device.

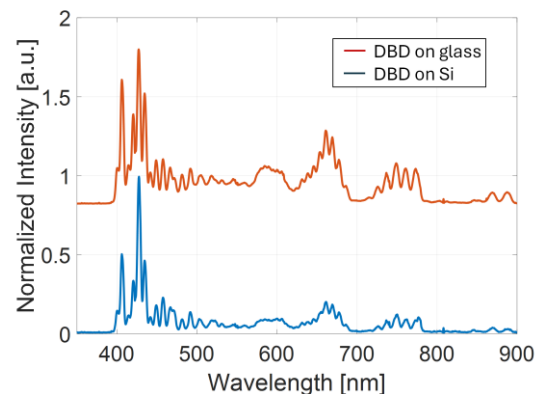


Fig. 2. Comparison of spectra collected in air from DBD microplasmas on glass (red line) and silicon substrates (blue line). The spectrum peaks observed correspond to the emission wavelengths expected for nitrogen.

Conclusion

MEMS-based microplasma devices were fabricated and operated on glass substrates. Under the tested conditions, no clear improvement in performance was observed compared to silicon-based devices. The results indicate that device behaviour is primarily governed by dielectric properties and electrode configuration rather than substrate material. Further optimisation of the dielectric stack and geometry is required to improve stability and lifetime.

References

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