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# MEMS-based microplasma sources for gas analysis

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## Summary:

This paper presents the development of miniaturized microplasma sources for gas analysis based on micro-electromechanical systems (MEMS) technology. We discuss critical device design aspects, from FEM modeling and device concept to fabrication and experimental validation. A functional demonstrator was fabricated, and successful plasma ignition was achieved under controlled conditions. The results suggest that the developed microplasma sources hold strong potential as compact, integrable components for gas analysis systems in various industrial applications.

**Keywords:** MEMS, microplasma, plasma emission spectroscopy, gas sensor, gas analysis

## Introduction

Chemical detection using plasma optical emissions has found multiple applications across environmental and medical fields. Building on earlier work [1-3], we explore three types of microplasma device configurations based on dielectric barrier discharge (DBD). Although interest in this technology dates back two decades, progress has been limited likely due to early challenges in integration and a lack of compelling applications. Recent advances in microfabrication and optical detection techniques now make MEMS-based microplasma devices a promising platform, offering scalability, reproducibility and integration for gas analysis. Miniaturizing this approach enables compact, portable systems capable of real-time gas detection in remote or point-of-need settings.

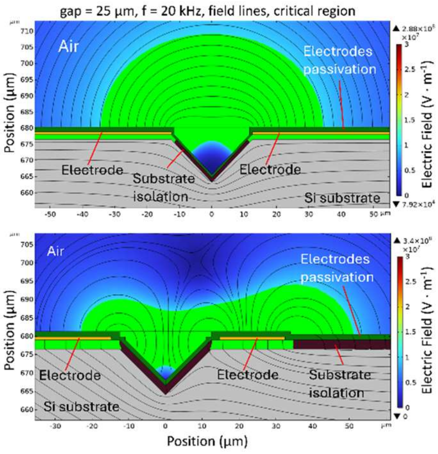

*Fig. 1. Electric field norm in air and field lines for the two of the three geometries studied, and the case study with a cavity size of 25 µm.*

## Modeling

To optimize the design, three FEM models were developed in COMSOL® to investigate electric fields and estimate critical field values for device materials and the surrounding gas, without explicitly simulating generation of species and plasma chemistry. The models focus on identifying conditions favorable for plasma ignition in: (i) flat metal electrodes on an insulated substrate, (ii) a similar setup with a microcavity, and (iii) a setup with a microcavity and substrate electrode. Due to computational constraints, a 3D electric field approximation is used. Parametric sweeps of layer thickness and cavity geometry were performed, driven by sinusoidal voltage excitation. The simulations revealed the regions where plasma is likely to ignite and where insulator breakdown may occur, with examples showing plasma confinement and critical field zones (Fig.1). This approach provides valuable insight into the design parameters and material selection while avoiding complex plasma modeling.

## Design

Several design variants, both as single microplasma and arrays of microplasma sources, were adapted. The most critical design parameters are the microcavity size (10, 25, 50, 100 µm), the distance between the microcavities, and the distance between the electrodes, which define the area of plasma ignition, as well as operating parameters at which plasma would ignite. Fig. 2 shows two examples of implemented designs and HRSEM images, close up on the device active area where the ignition occurs, and plasma confinement is desired.

## Device fabrication

Fabrication was performed in an ISO-certified cleanroom for CMOS / MEMS components on 150 mm Si wafers. The devices were fabricated in 4 and 5 masks processes. The substrate isolation is a dielectric material (e.g. $SiO_2$ or $Si_3N_4$) to minimize leakage currents into the substrate. Thin film aluminum (Al) was used as electrode material, patterned using wet etching, and was protected with another dielectric layer (e.g. $SiO_2$ or $Si_3N_4$) to prevent re-sputtering of the metal. A combination of RIE and wet etching techniques were used for opening contacts to substrate and electrodes. The total chip size is 8 x 8 mm², and the electrical contacts are exposed from passivation for wire-bonding from the outer edges of the chip to a printed circuit board (PCB). Fig.3. (top) shows a testing ready, packaged device.

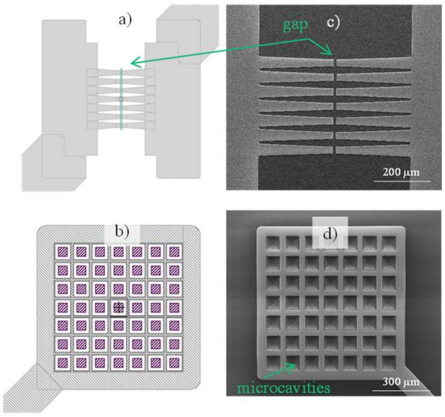

*Fig. 2. Examples of CAD designs and HRSEM images of active device areas: an array of surface metal electrodes only (a and c), and the configuration with a microcavity array with metal and substrate electrodes (b and d).*

## Device characterization

The wafers were electrically characterized (I-V and C-V measurements) prior to dicing. Leakage currents were in the range 10–60 pA. Measured capacitances were in the range 5-20 pF, with higher capacitance observed in arrays compared with single devices with electrodes of equivalent geometry. The plasma was monitored via a microscope connected to a digital camera at peak-to-peak excitation voltages in the range of 0.9-1.4 kV, frequencies in the range of 3-10 kHz and pressures in the range of 100-500 mbar. Fig.3 shows examples of successful plasma ignition tests from two device configurations. We observed stable, continuous plasma for up to 20 min. Efforts to optimize design and fabrication parameters are ongoing and expected to extend device lifetime significantly. Optical emission spectra (OES) were collected using an Ocean-Optics 2000+ spectrometer showing the characteristic wavelength peaks of molecules present in air (Fig. 3). As a reference, a larger-scale, not chip-based prototype using the same detection principle was previously used to obtain data for several VOCs. Fig.4 shows an example of OES for methane in air, highlighting its characteristic peak at 431 nm.

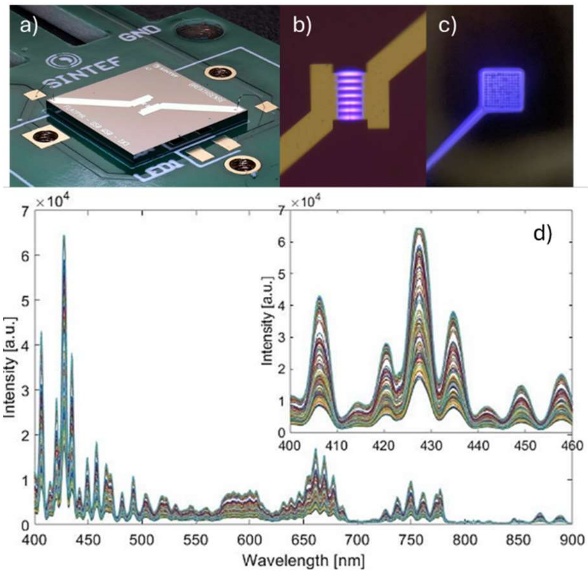

*Fig. 3. A packaged device on a custom-made PCB (a), plasma experiments observed (in air) with array of 7 sources (b), and 13 x 13 array sources (c), example of optical emission spectra collected (d).*

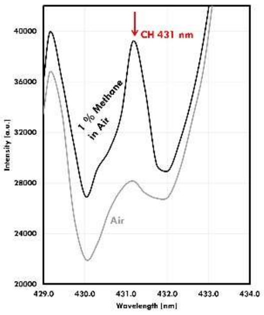

*Fig.4 Example of optical emission spectra collected for methane in air using a reference larger scale plasma emission spectroscopy system (CH peak at 431 nm).*

## Conclusions

The data collected suggests that the developed miniaturized microplasma sources are promising as components of gas analysis systems.

## References

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