# 3d etching of silicon and glass by plasma sheath tailoring

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**Abstract:** In this contribution, we report on a method to 3D etch silicon and glasses in a low-pressure reactive Argon $CF_4$ plasma using a mask and a magnetic field parallel to the surface for microstructure applications. The magnetic field causes an asymmetric ExB drift of the plasma entering the mask geometry when the plasma sheath collapses. This induces a steering of the plasma ions and therefore also a steering of the etching process.

## 1. Introduction

Plasma processing of materials is very advanced in microelectronics to create 2D structures with very high precision by anisotropic etching in silicon or 2D materials. The directed ion flux ensures the directionality of the etch process in plasma-based microstructuring due to the process of chemical sputtering, where the impact of ions and reactive species simultaneously ensures a high etch rate. Plasma processing on the micrometer scale allows to produce micro-electromechanical systems (MEMS) devices, preferably in silicon for sensors or microfluidic devices. However, there is demand for advanced 3D structuring of materials for optical applications such as microlenses, gratings or for illumination. All these applications require 3D shape control with a small surface roughness in the range of $\lambda/100$, with $\lambda$ being the wavelength in the particular application. Another field for 3D structuring is microfluidic fuel cells, where the turnover of an electrochemical reaction is enhanced by replacing a membrane by a diffusion gradient in a microchannel and designing specific 3D electrode surfaces.

Realizing complex structures requires accurate 3D control of plasmas since the sidewalls and the bottom and top of the channel must be processed differently. We proposed the following idea for a flexible 3D pattering process [1]: a magnetic field B is applied parallel to the surface, leading to ExB drifts in combination with the electric fields E in the plasma sheaths. A mask is placed in front of the substrate to design the E fields and thus allow for a 3D control of the plasma density in front of a substrate.

## 2. Methods

The etching experiments are performed in an inductively coupled plasma (ICP) etching setup using an argon-$CF_4$ mixture as a processing gas for silicon and glass etching.

A sample assembly is placed on a substrate holder opposite the ICP dielectric window. At the substrate holder, an external RF bias voltage can be applied. The distance between the RF substrate holder and the ICP dielectric window is 13.5 cm. A schematic of the plasma penetrating the mask region above a silicon substrate is shown in Fig. 1a.

## 3. Results and Discussion

The experiment shows that adding a magnetic field to an etch mask in front of a wafer induces an asymmetry in the incident ion flux onto the wafer. Fig. 1b shows the comparison for silicon etching of a microscopic trench with and without the presence of a magnetic field. The asymmetric etching is caused by an asymmetric penetration of the plasma into the mask structure, due to the ExB drift, which increases the penetration of the plasma on one side of the mask and decreases it on the other side. This effect depends sensitively on the relation between the mask's length scale and the plasma sheath's length scale to allow plasma penetration. The etching asymmetry is rather small for silicon and very large for glass. This is presumably related to the very different etch chemistry of silicon vs. glass. These experiments are accompanied by PIC modelling both e the complete mask geometry as well as chemistry modelling and feature scale modelling.

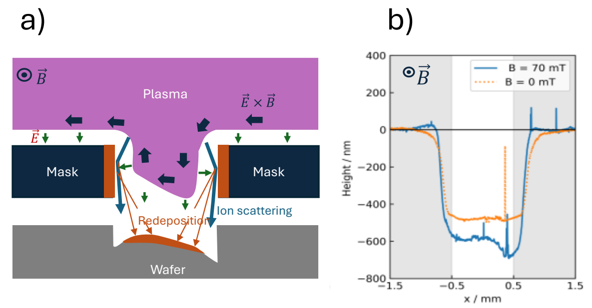


**Fig. 1**. (a) Schematic of the plasma penetrating the mask structure to induce 3d etching. (b) resulting asymmetry in the etch profile of a silicon wafer.

## 4. Conclusion

In the future, it will be necessary to further explore this effect experimentally to optimize the etch asymmetry and complementary develop the PIC/MCC model by including the chemistry directly and a realistic surface model for the different materials which includes the reflection of particles and the emission of secondary electrons...

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**References**

[1] E. Jüngling, S. Wilczek, T. Mussenbrock, M. Böke, A. von Keudell. Appl. Phys. Lett. 12(7), 074101 (2024)