Dry etching study of 3D Grayscale micrometric patterns into a polymer layer

Assia Selmouni, Aurélien Tavernier, Sébastien Bérard-Bergery, Nicolas Posseme

Dry etching study of 3D Grayscale micrometric patterns into a polymer layer

A. Selmouni [a], A. Tavernier [a], S. Berard-Bergery [a], N. Possemé [a]

[a] Univ. Grenoble Alpes, CEA, Leti, F-38000 Grenoble, France

e-mail: assia.selmouni@cea.fr

Three-dimensional (3D) structures are used in numerous promising industrial applications ranging from microfluidics [1] and biology [2] to Fabry-Perot Metal Insulator Metal (MIM) cavities [3] and CMOS Imaging Sensors (CIS) [4]. Hemispherical microlenses for instance, are a key feature of these imagers as they improve light collection and imaging performances. Besides, CIS are one of the leaders of the semi-conductor market. Projections show that they could reach a record revenue of 26B$ in 2024, with an annual growth of 11B$, emphasizing the importance of innovation and development in this field [5].

E-beam lithography (EL) is frequently used to create the complex 3D structures needed for these applications. This direct writing technique consists of a spatial variation of the dose of an electron beam. By tuning precisely polymer chain slicing, EL allows local modulation of development rates, thus creating different height levels [6]. However, this strategy is intrinsically limited, as it has an extremely low throughput; it is not compatible with industrial manufacturing. In this study, we focus on an innovative technique: grayscale photolithography. Thanks to a binary mask and a linear contrast resist, it is possible to achieve various 3D designs with a photosensitive resist. This one step exposure approach theoretically allows to reach competitive throughputs. Resist structures are then to be transferred into different materials chosen carefully for optical properties.

The main goal of this work is to study the dry etching of 3D structures, indeed, precise shape control and knowledge of transfer mechanisms are critical since they could affect device performances. Experiments have been carried out on 300mm silicon wafers with a photosensitive resist (MFR-530-R1) spin coated on top of a non-photosensitive polymer, this is illustrated fig.1 a. 3D structures are formed using grayscale photolithography in resist (fig.1 b). They are then transferred by dry etching into the non-photosensitive polymer, as shown fig.1 c, using an industrial capacitively coupled plasma reactor (CCP). In this work, we performed a parametric analysis by varying etching conditions. Using X-ray Photoelectron Spectroscopy (XPS), Scanning Electron Microscopy (SEM) and 3D Atomic Force Microscopy (3D AFM), we studied three dimensional polymer etching mechanisms, especially in terms of roughness and shape transfer.

For instance, in this abstract, we present two different configurations for microlens etching: recipe A contains NF_3, C_4F_8 and CF_4 and recipe B contains only CF_4. On the one hand, 3D AFM results displayed fig. 3, describe a flattened microlens etched profile for recipe B and a widened one for recipe A. This shows that plasma parameters significantly influence the shape of the transferred structure. On the other hand, SEM and 3D AFM results, displayed respectively fig. 2 and 3, show a smoother profile for recipe B. This sheds light on possible roughness improvements by modifying plasma parameters.
These new observations are still to be strengthened by further studies. However, a first diagnostic tends to indicate that reducing the carbon-to-fluorine ratio limits polymerization during the etching step, thus improving significantly roughness while enlarging the dimension of the etched structure.

[1] Mortelmans T, Kazazis D, Padeste C, Berger P, Li X, Ekinci Y. ACS Appl Nano Mater. 2022;5(1):517-526.
[2] Barr S, Hill EW, Bayat A. Acta Biomater. 2017;49:260-271.
[3] Williams C, Gordon GSD, Wilkinson TD, Bohndiek SE. ACS Photonics. 2019;6(12):3132-3141.
[4] Ristoiu D, Leverd F, Mortini E, Huguenin JL. A DOE study of plasma etched microlens shape for CMOS image sensors. In: Vol 11326. ; 2020.
[5] A. Theuwissen. 2021 IEEE International Solid- State Circuits Conference (ISSCC), 2021, pp. 30-35.
[6] Mortelmans T, Kazazis D, Guzenko VA, et al. Microelectron Eng. 2020;225:111272.

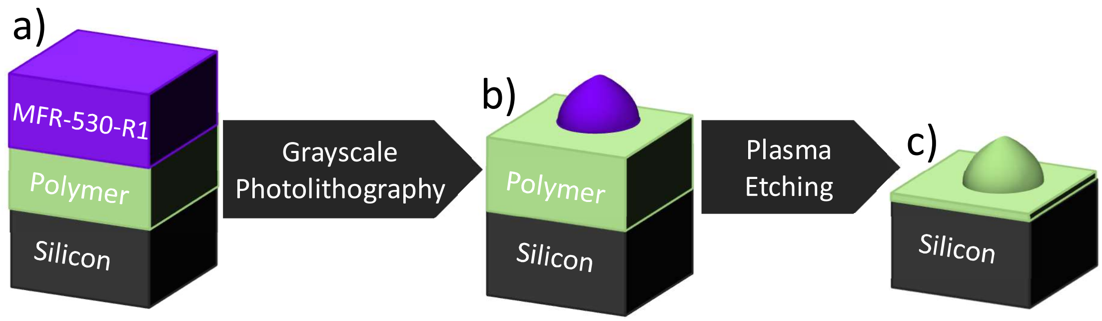

Figure 1. Diagram of process steps

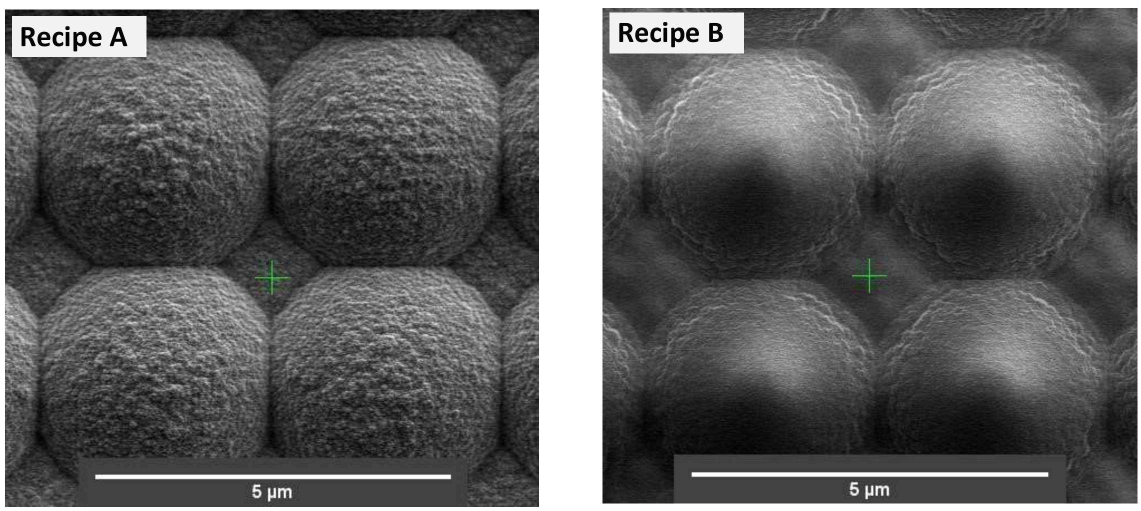

Figure 2. SEM images of etched microlenses showing roughness and shape modification.
Recipe A: $NF_3/C_4F_8/CF_4$. Recipe B: CF_4.

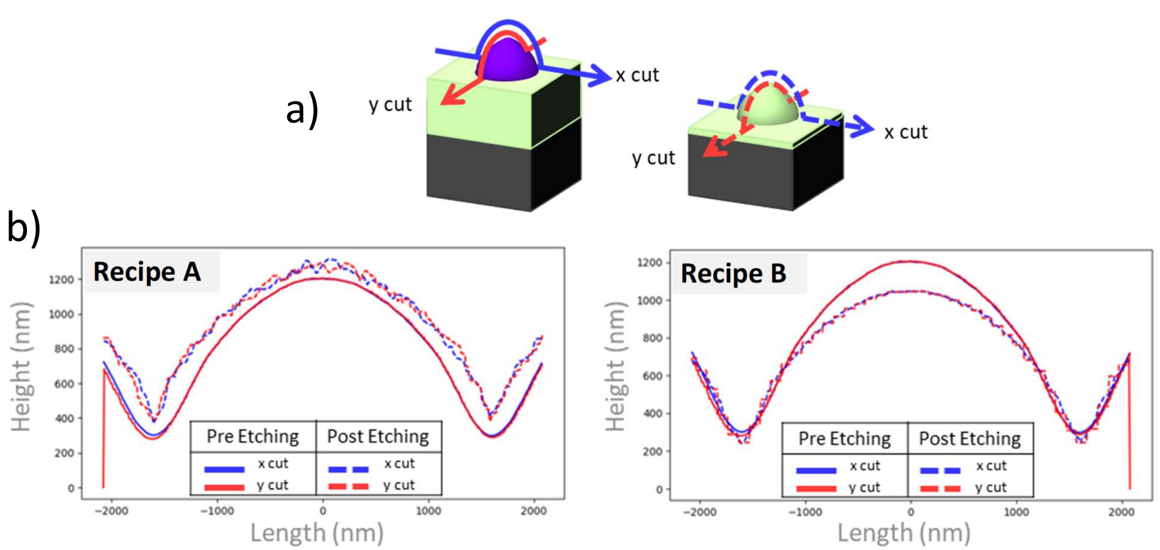

Figure 3. 3D AFM results:
a) Schematic diagram of the measured axis
b) 3D AFM line profiles of microlenses showing showing roughness and shape modification.
Recipe A: $NF_3/C_4F_8/CF_4$. Recipe B: CF_4.