proceedings

Abstract

Fabrication of 3D Nanostructures via AFM-Based Nanolithography †

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† Presented at the XXXV EUROSENSORS Conference, Lecce, Italy, 10–13 September 2023.

Abstract: The increasing use of nanomaterials in high-tech devices has posed an exciting challenge for the scientific community to develop new, easy, high-throughput nanofabrication approaches. Here, we present an easy AFM-based nanofabrication approach based on Static Plowing Lithography, with which we are able to realize patterns of 3D nanostructures on a thin PMMA layer. By coupling a wet etching process with ultrasound exposure, we effectively removed the polymer bulges at the nanostructure's borders, increasing the quality of the patterned 3D nanostructures, and paving the way for their integration into lab-on-a-chip devices.

Keywords: 3D AFM nanolithography; nanostructures; scratching; Atomic Force Microscopy

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Citation: Vincenti, L.; Pellegrino, P.; Farella, I.; Cascione, M.; De Matteis, V.; Quaranta, F.; Rinaldi, R. Fabrication of 3D Nanostructures via AFM-Based Nanolithography. *Proceedings* **2024**, *97*, 56. https://doi.org/10.3390/proceedings2024097056

Academic Editors: Pietro Siciliano and Luca Francioso

Published: 19 March 2024

1. Introduction

The growing integration of nanostructures into a plethora of devices imposed the rapid development of new easy, accurate, and high-performing nanofabrication methods. In this perspective, AFM-based nanofabrication techniques have attracted the interest of the scientific community, due to the nanoscale fabrication accuracy, in situ imaging of the structures, flexible operations, and low costs [1]. Although many advances have been made in recent years, the fabrication of 3D structures with AFM-based techniques is very challenging [2]. Indeed, to pattern 3D structures, it is necessary to use complex lithography equipment and very laborious processes. Here, we present an optimized patterning process of 3D structures (nanosquares) by exploiting the AFM scratching mode and their full morphological characterization via AFM. In addition, we propose an effective strategy for the removal of polymers debris, in the carved structures as well as at their borders [3].

2. Materials and Methods

Two sets of different 3D nanosquares were patterned on a poly (methyl methacrylate) (PMMA) film. The squares are designed to have an area of 500 nm × 500 nm. Nanolithography was performed at SATP by employing the AFM NTEGRA system (Nova Px 3.4 software) with NSG30 probes. To achieve a better resolution, nanostructures' characterization was obtained with sharp NSG01 tips. Multiple nanostructures are manufactured to optimize the nanofabrication parameter: scanning rate, scanning direction, and normal-force load. After the AFM scratching process, the samples were first immersed in a solution of methyl isobutyl ketone (MIBK) and 2-propanol (IPA) in a 1:3 v/v ratio for 45 s, and then exposed to an ultrasound treatment at 59 kHz for 60 s.

3. Discussion

Static Plowing Lithography (SPL) was used to pattern two arrays of square-shaped nanostructures: on the first line in Figure 1a, the nanostructures were scratched with an increasing setpoint from 0.5 nA to 3.0 nA, in steps of 0.5 nA, keeping constant the scratching rate (0.25 μm/s) and direction (from the left to the right). The same SPL parameters were used for patterning the squares on the second line, but the scratching rate was increased to 0.50 μm/s. The nanostructures appear well defined and their depth increases with the increase in the setpoint and the scanning rate, ranging from about 1 nm to about 50 nm in the upper line, and from 1 nm to 64 nm in the lower one.

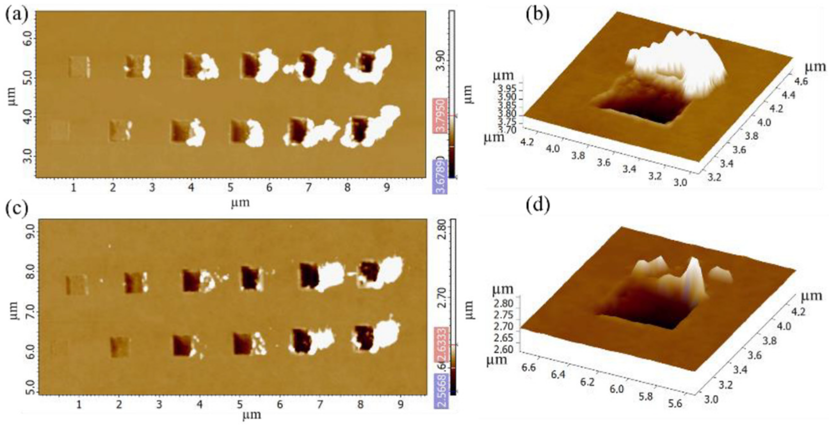

Figure 1. (**a**) SPL of nanosquares array patterned on PMMA; (**b**) 3D image of the square patterned at setpoint of 1.5 nA, scanning rate of 0.50 μm/s; (**c**) AFM image of the nanosquare array after the chemical–physical treatment; (**d**) 3D image of the particular in (**c**) after the chemical–physical treatment.

Debris coming from the removed material accumulates mainly on the right side of the nanostructures (Figure 1b), but it is almost totally removed by the wet etching process with MIBK and IPA, followed by exposure to ultrasounds treatment (Figure 1c,d). The chemical–physical treatment is more effective for the shallower nanostructures and does not affect the overall shape of the nanosquares.

To conclude, the SPL technique could be effectively employed for patterning well-defined 3D nanostructures on a PMMA layer. Through the chemical–physical treatment, the amount of debris surrounding the nanostructures is strongly reduced, and their resulting shape is better refined.

Author Contributions: Conceptualization, L.V. and P.P.; methodology, L.V.; validation, P.P., M.C. and I.F.; formal analysis, V.D.M.; investigation, L.V.; resources, R.R. and F.Q.; data curation, L.V. and P.P.; writing—original draft preparation, L.V.; writing—review and editing, I.F. and M.C.; supervision, R.R.; project administration, R.R.; funding acquisition, R.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding authors.

Conflicts of Interest: The authors declare no conflicts of interest.

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