DOI 10.5162/EUROSENSORS2025/M2.2.3

High-resolution laser ablation of a copper layer for the fabrication of 3D-printed MEMS and microsensors

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Summary :
This paper presents a novel method for structuring metallized layers on a polymer layer using laser ablation. The technique enables the fabrication of metallic tracks with a resolution of about 1 µm with minimal or no damage to the underlying polymer layer. It offers the flexibility required for complex 3D-printed structures and overcomes the limitations of conventional approaches. It will provide an efficient alternative for MEMS fabrication.

Keywords: MEMS, 3D Printing, Laser etching, additive manufacturing, multi-material technology.

Background, Motivation and Objective

3D printing is now established as a key manufacturing technology. Today high-resolution 3D printing produces objects with resolutions down to 1µm [1]. This new capability seems particularly well suited for the design of MicroElectro-Mechanical Systems (MEMS) –devices such as sensors or actuators– that combine mechanical and electrical components at the microscale and require three-dimensional shaping. Traditional cleanroom processes, like photolithography, heavily rely on planar techniques. In contrast, stereolithography, enables to create complex 3D structures. However, surprisingly only a few studies have explored the potential of 3D-printed MEMS [2].

One major challenge lies in the need to integrate both 3D-shaped mechanical structures and electrical circuits for actuation and sensing. It requires the integration of different materials (conducting and non-conducting) in the same structure. Currently, additive manufacturing technologies of multi-materials do not seem mature enough to produce objects at high resolution.

The main strategy involves depositing a metallic layer after printing the mechanical structure. The Deposition of metal in 3D-printing is relatively straightforward using physical vapor deposition (PVD) or wet metallization. Consequently, the present challenge is to pattern the metallic layer into a complex electrical circuit. Traditional processes (e.g. photolithography coupled with lift-off) are poorly adapted for 3D-printing. Recently, alternative techniques have been explored, including laser-activated metallization [3] or shadow masking[4], [5].

We propose a novel strategy for structuring metallized layers on laser ablation to address these challenges. Laser ablation [6] involves locally etching metal by irradiating it with a high-intensity laser beam, resulting in vaporization or plasma formation. Our method enables the rapid structuring of metallic tracks with resolutions of a few microns. Furthermore, it offers the flexibility and versatility of CAD technology compatible with 3D printing.

Description of the Method

Our method has been demonstrated on a 5µm-thick layer of SU-8 photoresist. The SU-8 6005 resist was spin-coated at 950rpm followed by pre-bake, UV-curing and post-bake.

Before metallization, the samples underwent oxygen plasma treatment at 200W for two minutes. Metallization was performed using cathodic sputtering, where a 1µm thick copper layer was deposited onto a 100nm thick titanium adhesion layer.

The metal layers were then patterned using laser etching with the Femtika Nanofactory system. The pulsed laser (wavelength of 515nm) has a beam diameter of approximately 1 µm. We tested the influence of the laser power (ranging from 1mW to 50mW) and the hatching distance (distance between successive ablation lines). The writing speed is set to 10mm/s. Finally, the samples were washed with a mixture of hydrogen peroxide and hydrochloric acid solution for 2’45’’ to complete the process.

Results

Our high-resolution method enables to pattern 10µm wide metallic tracks with great precision [Fig. 1]. The typical processing time is about 5

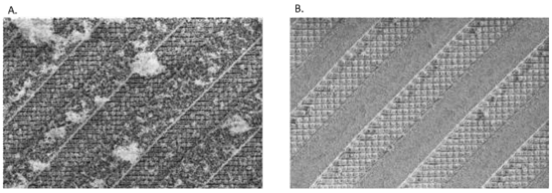

Fig. 1 Two images of the same pattern before (A) and after wet etching (B). Before wet etching, dust particles from the ablation process are visible both on the ablated surfaces and on the copper spirals. After wet etching, a reduction in the amount of dust can be observed.

min to create a square pattern of 500µm side length. Immediately after ablation, we observe the presence of dust deposited on the ablated areas and on the metallic tracks [Fig. 1a]. It consists of copper and resin debris. To address this issue, we subjected the system to a wet etching process using a solution of hydrochloric acid and hydrogen peroxide. This etching effectively removes the dust particles of copper. However, it also results in the etching of ~100 nm of copper.

We investigated the influence of ablation parameters on the ablation depth. Particularly we focused on the laser power and hatching distance to ensure complete removal of the copper layer while minimizing damage to the underlying polymer layer. Once the cleaning process is completed, the surface condition is analyzed [Fig. 2] using SEM imaging and Energy-Dispersive X-ray Spectroscopy (EDX) to confirm the presence of residual copper on the surface.

The hatching distance must be sufficiently small to ensure that no copper remains between adjacent tracks. For large hatching distances [Fig. 2c-d], the laser path is visible. It forms a square grid with the presence of copper between the lines confirmed by EDX analysis. A hatching distance of 0.5µm [Fig. 2a-b] appears optimal, as

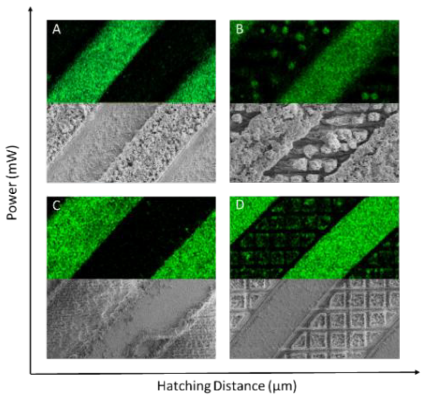

Fig. 2 SEM (bottom) and EDX (top) images of copper tracks created by laser ablation, varying the hatching distance (0.5µm for A and C, 3µm for B and D) and laser power (3mW for C and D, 19mW for A and B). The green dots represent areas where there is copper detected by EDX.

the grid disappears, indicating the absence of residual copper.

The writing power was also fine-tuned. At 19mW, the polymer is also ablated [Fig. 2c] leaving resin debris on the copper tracks that cannot be removed by the cleaning solution. A lower power between 3 to 5mW yields optimal results [Fig. 2a], with no residual copper between the tracks and minimal etching of the resin. Moreover, EDX analysis confirms that the absence of carbon deposition on the tracks.

In conclusion, we successfully developed a process for structuring metallization onto a resin layer. This method enables high-precision hatching with a relatively thick layer of copper of 1µm, and could be adapted for other metals such as gold. An optimization of the ablation parameters (especially laser power and hatching distance) is essential to ensure efficient removal of the metal with minimal damage to the underlying polymer layer. Future work will focus on extending this method onto photoresin 3D-printed parts.

References

[1] C. N. LaFratta and T. Baldacchini, "Two-photon polymerization metrology: Characterization methods of mechanisms and microstructures," *Micromachines*, vol. 8, no. 4, 2017, doi: 10.3390/mi8040101.

[2] M. R. Khosravani and T. Reinicke, "3D-printed sensors: Current progress and future challenges," *Sensors Actuators, A Phys.*, vol. 305, p. 111916, 2020, doi: 10.1016/j.sna.2020.111916.

[3] J. Li *et al.*, "Selectively Metalizable Stereolithography Resin for Three-Dimensional DC and High-Frequency Electronics via Hybrid Additive Manufacturing," *ACS Appl. Mater. Interfaces*, vol. 13, no. 19, pp. 22891–22901, 2021, doi: 10.1021/acsami.1c01199.

[4] S. Pagliano *et al.*, "Micro 3D printing of a functional MEMS accelerometer," *Microsystems Nanoeng.*, vol. 8, no. 1, 2022, doi: 10.1038/s41378-022-00440-9.

[5] S. Kim, C. Velez, R. S. Pierre, G. L. Smith, and S. Bergbreiter, "A Two-Step Fabrication Method for 3D Printed Microactuators: Characterization and Actuated Mechanisms," *J. Microelectromechanical Syst.*, vol. 29, no. 4, pp. 544–552, 2020, doi: 10.1109/JMEMS.2020.2992367.

[6] N. Bellini, R. Geremia, S. Norval, G. Fichet, and D. Karnakis, "Laser thin film patterning for rapid prototyping and customised production of flexible electronics devices," *J. Laser Micro Nanoeng.*, vol. 11, no. 3, pp. 388–394, 2016, doi: 10.2961/jlmn.2016.03.0019.

Acknowledgements

This work was supported by LAAS-CNRS micro and nanotechnologies platform, a member of the Renatech french national network. This work was funded by ANR – FRANCE (French National Research Agency) under grant ANR-23-CE19-0014 (project WISPERS) and ANR-21-ESRE-001 (project Nanofutur Equipex+).