ADDITIVE BATCH MICROFABRICATION OF 3D METAL ELECTROSTATIC SWITCHES TOWARDS 3D PRINTED METAL MEMS

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ABSTRACT

This paper presents the batch fabrication of an additively manufactured metal electrostatic microswitch to demonstrate device scaling and the lower dimensional limit of the process. Optimization in optical and printer parameters resulted in a decreased gap between two printed parts by a factor of six and an increase in resolution by a factor of 2.5 compared to our previous study, without fabrication failure. The electrostatic microswitches were batch fabricated via a Micro Laser Sintering (MLS) process, which is a precision form of metal powder-based additive manufacturing. The use of additive manufacturing to build metal microsystems opens up new avenues toward the low-cost fabrication of prototypes as well as low-volume systems eliminating the constraints of conventional cleanrooms.

KEYWORDS

Additive Manufacturing; Micro Laser Sintering; Electrostatic Switches; 3D Printing;

INTRODUCTION

Microelectromechanical Systems (MEMS) are vital components for a multitude of modern electronic devices [2]. The possibility of direct fabrication of such components from a design file [3] has great potential for the fabrication of electronics, transducers [4], and sensors [5, 6]. Additive manufacturing techniques such as MLS allows the fabrication of devices like electrostatic switches that benefit from higher plasticity and conductivity compared to their silicon counterparts using metal thin films, fabricated in conventional cleanrooms [6]. It also reduces fabrication steps like deposition, photolithography, etching, etc. which are expensive and use hazardous chemicals. MLS also uses a low-cost substrate compared to silicon. Recent advancements in MLS have enabled the fabrication of micro metal parts with features down to 15µm [7] from metal powder [8]. Superior dimensional consistency and improved surface roughness of MLS compared to other additive tools [9] make it a suitable process to fabricate microsystems. In this work, optimized machine settings and device design are employed to reduce the switch gap by a factor of 6 and increase the device resolution by a factor of 2.5 compared with our initial study [1].

An array of electrostatic switches with increased resolution has been batch fabricated utilizing the enhanced feature sizes and resolution of a new MLS system (DMP64, 3D MicroPrint GmbH) in order to investigate the minimum possible feature size. Figure 1 shows the CAD design of the optimized device with key parameters like beam thickness (a), beam gap (X), beam length (L), and length of the capacitive region (L1), all of which together determine the value of pull-in voltage. Switches with 1mm long beams were printed with varying gaps down to 15µm (~40µm previously) and a beam thickness of 40µm (~100µm previously). The process of fabrication involves layer-wise melting and fusing of metal powder in 5µm layers following the digital CAD design. 17-4PH stainless steel powder ($D_{90} < 6$µm) was used as the metal powder due to its optimized dimensional parameters on the system. The finer metal powder was extracted using vibratory

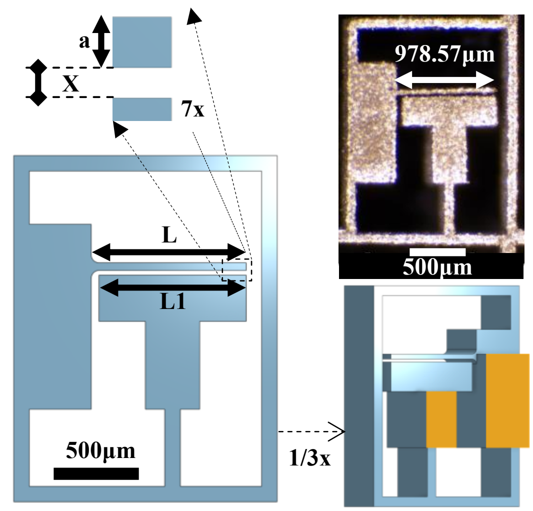

Figure 1: CAD Design of the switch: top view (left), isometric view of switch showing raised contact points in yellow (bottom right), and fabricated single device with dimension (top right).

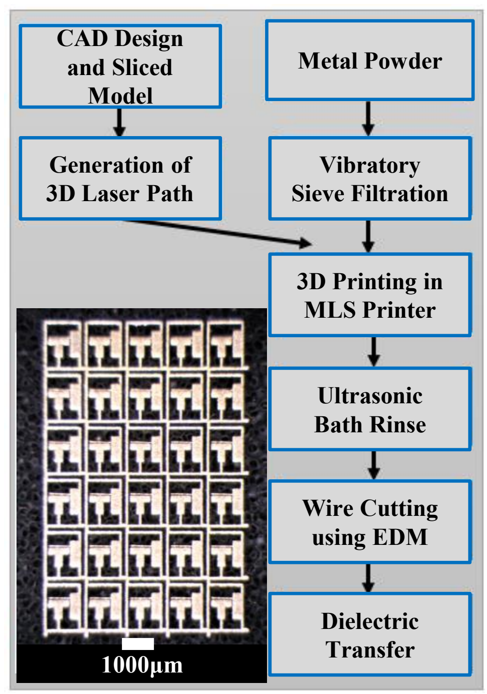

Figure 2: MLS Microfabrication process flow for the electrostatic switches with its dielectric transfer to a final arbitrary substrate. Batch fabricated devices (bottom left)

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mesh sieves. The switches were batch fabricated, rinsed in an ultrasonic bath, separated from the build plate using EDM wire cutting, and separated individually (shown in Figure 1) to be transferred onto a dielectric substrate. The batch fabricated switches and full fabrication and dielectric transfer processes are shown in Figure 2.

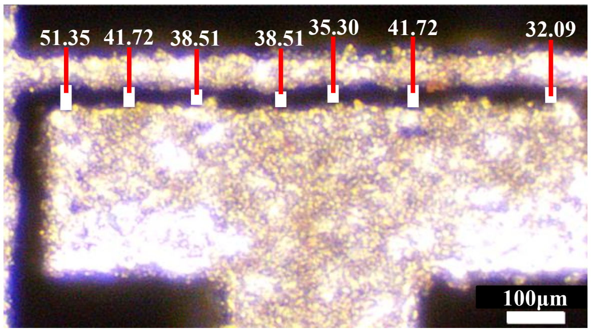

Figure 3: Close-up view of fabricated switch showing the beam and gaps (in µm) at different points along the length. (Average Gap=40.1±6.7µm).

RESULTS

The inset of Figure 2 shows the batch fabricated devices after release from the build plate. Figure 1 shows a single device with its as-printed dimensions. The close-up view of one of the devices is shown in Figure 3. The average deviation of the as-printed gap with respect to the designed gap for the switches was around 2.94%. Simulation of these redesigned switches estimates the device actuation will occur at voltages between 250V to 10kV depending on the gap (X). The simulation result for one of the switches (X=20µm) is shown in Figure 4, which actuates at around 1.3kVolts. Simulated actuation voltage for previous and present are compared for different gaps and to their breakdown voltage values in Figure 5. Although the pull-in voltage values are significantly reduced, they are still above the respective breakdown voltage values and hence require more work towards

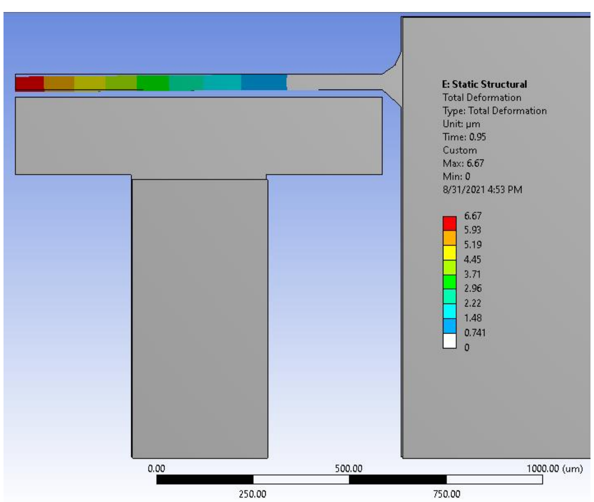

Figure 4: ANSYS electromechanical simulation results for a microswitch with a gap of 20µm demonstrating the tip of the cantilever beam deflecting by 6.67µm implying the gap reduces by 2/3rd when the pull-in voltage of 1.3kV is applied.

the development of the MLS system to increase resolution. However, this work demonstrates a large increase in the resolution of metal 3D printing for microfabrication with many microsystems applications.

CONCLUSION

This work demonstrates a new metal 3D microfabrication capability for the field, which may compete with subtractive manufacturing if the resolution is increased by improving the optics system and optimizing the slicing and print parameters. An improvement of the device gap by a factor of 6 and a decrease of minimum feature size by a factor of 2.5 were achieved in this work over previous investigations. The possibility of using metal additive manufacturing could reduce cost of fabrication, use of expensive substrate and hazardous chemicals for processing, and the procedure could be performed in a small controlled and contained environment as compared to conventional clean room. Focused research towards the development of this process, might lead to it not only complementing present conventional subtracting manufacturing but also competing with it.

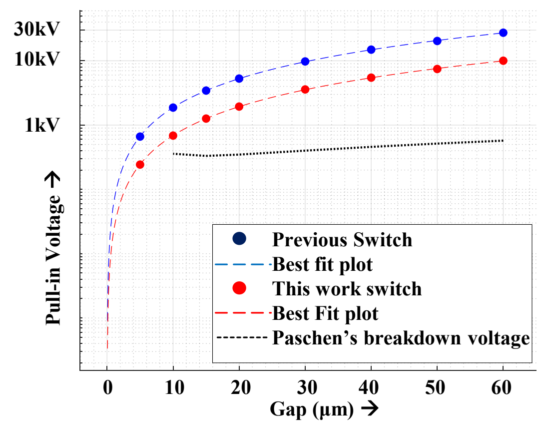

Figure 5: Pull-in Voltage versus electrostatic switch gap for the design of the work (red) and previous work [1] (blue). Paschen's breakdown voltage for 1atm in air is also shown

REFERENCES:

[1] B. Lohani *et al.*, *Journal of Microelectromechanical Systems*, vol. 29, no. 5, pp. 972–977, Oct. 2020.
[2] O. Ulkir, *Mater. Res. Express*, vol. 7, no. 7, p. 075015, Jul. 2020.
[3] T. Blachowicz and A. Ehrmann, *Micromachines*, vol. 11, no. 4, Art. no. 4, Apr. 2020.
[4] R. C. Roberts and N. C. Tien, in *2017 19th Intl. Conf. on Solid-State Sensors, Actuators and Microsystems (TRANSDUCERS)*, Jun. 2017, pp. 1233–1236.
[5] B. R. Liyarita, A. Ambrosi, and M. Pumera, vol. 30, no. 7, pp. 1319–1326, 2018.
[6] Y. Xu *et al.*, "The Boom in 3D-Printed Sensor Technology," *Sensors*, vol. 17, no. 5, Art. no. 5, May 2017.
[7] "Products - 3D MicroPrint GmbH." https://www.3dmicroprint.com/products/.
[8] P. Regenfuß, R. Ebert, and H. Exner, *Laser Technik Journal*, vol. 4, no. 1, pp. 26–31, 2007.
[9] V. Fiorese *et al.*, in *2020 IEEE/MTT-S International Microwave Symposium (IMS)*, Aug. 2020, pp. 1168–117