FIRST CONTACT: DESIGN AND FABRICATION OF THE FIRST 3D PRINTED MEMS G-SWITCH

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ABSTRACT

This work introduces a new microscale g-switch designed to activate at a specific acceleration threshold. The switch is fabricated on lightweight PET film and directly 3D printed using two-photon polymerization, then metalized through sputter deposition. The first contact of the switch was confirmed by manually displacing the proof mass until continuity was observed with a contact resistance of 7 Ω. The force required to make electrical contact was tested to determine the equivalent g-force required to activate the sensor. This force occurred at 250 μN resulting in an acceleration threshold of 157,000g for this proof mass and gap.

KEYWORDS

MEMS, 3D Printing, Sensor, Switch, Two-Photon Polymerization

INTRODUCTION

G-switches are common in high-acceleration environments, where they monitor and respond to rapid changes triggering safety mechanisms, control systems, or data logging functions. The design and fabrication of g-switches have traditionally leveraged silicon-based MEMS technologies, which offer the advantages of miniaturization, scalability, and integration with electronic circuits. However, evolving demands for g-switches in a variety of configurations have spurred innovation beyond conventional fabrication methods.

The advent of 3D printing presents a transformative approach to MEMS device fabrication, offering flexibility in design, cost and time to implementation. This paper introduces an advancement in the field of MEMS g-switches: the development of the first 3D printed MEMS g-switch designed for high-acceleration threshold applications. This novel design is fabricated using two-photon polymerization (TPP) on a lightweight polyethylene terephthalate (PET) film, followed by metallization via sputtering. This technique not only circumvents the limitations of traditional MEMS fabrication processes but also enables the creation of devices with complex geometries and tailored mechanical properties.

The significance of this contribution lies in its demonstration of the feasibility and benefits of applying 3D printing technology to MEMS g-switch fabrication. The design also exploits contact in the direction orthogonal to the substrate in contrast to previous devices that make contact parallel to the substrate [1]. This vertical contact is attributed to the unique 3D design and sputtering deposition. Through exploring this innovative fabrication method, the study opens new pathways for the design and development of various MEMS devices and holds the potential to enhance the performance and application scope of g-switches for scenarios requiring robustness to high accelerations and design adaptability.

This paper details the design, fabrication, and testing of a newly developed g-switch, highlighting its operational parameters, such as activation force and contact resistance, and its suitability for applications requiring high acceleration thresholds.

METHODS

Sensor Design

The design of the g-switch features a cantilevered flexural beam with a proof mass affixed to the end of the cantilever. Switch contacts are integrated into the proof mass and on the contact pad beneath the proof mass (Figure 1). When a change in acceleration occurs, the proof mass displaces, resulting in contact between the proof mass and the contact pad.

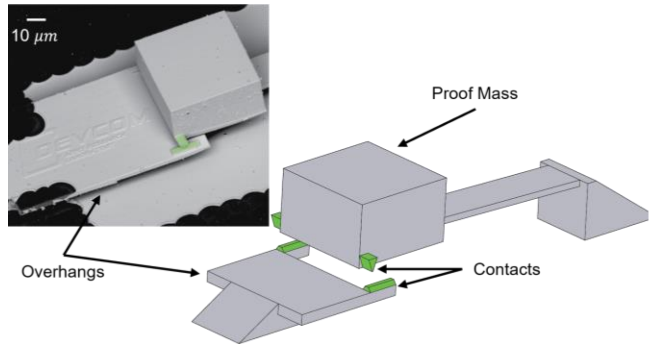

Figure 1. G-Switch design. The contacts of the switch are highlighted in green. Overhangs are directly 3D printed, providing masking during the sputtering process. The inset shows an SEM image of the g-switch after the laser ablation process.

Fabrication Process

The fabrication of the g-switch leverages TPP 3D printing [1][2]. Initially, an ITO-coated PET film is precisely cut to the required dimensions using an LPKF U4 laser cutter. This film is then placed, ITO side facing down, onto a droplet of IP-S resist (Nanoscribe). The ITO/IP-S interface creates a strong signal during the interface finding for the first print layer [3]. Subsequently, another droplet of IP-S resist is applied atop the PET film for printing. Printing directly onto PET has multiple benefits over printing on glass slides such as a flexible substrate and improved adhesion to the substrate. Moreover, printing on a non-conductive substrate is critical for the fabrication of functional, electrically isolated MEMS devices.

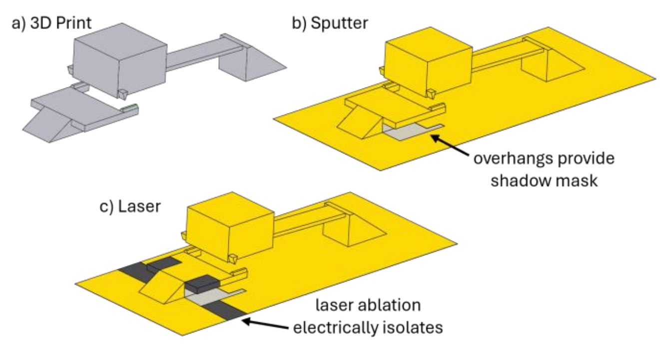

Figure 2. Rapid three-step fabrication process. a) Structures are 3D printed using two-photon polymerization b) Chromium and gold are sputtered on the sample. Overhangs directly incorporated on the structures provide masking during the sputtering process. c) In the last step, metal is laser ablated away to enable electrical isolation.

After the substrate is prepared, the standard protocol for dip in laser lithography (DiLL) from Nanoscribe was followed. Post-development, the structures undergo sputter coating with a 10 nm chromium adhesion layer, followed by a 200 nm gold layer. The thick gold layer ensures sufficient metallization under the switch contacts. Figure 1 and Figure 2 illustrate the inclusion of overhangs in the design, which serve to electrically isolate the individual components of the assembly [4]. After the sputtering process, laser ablation of the gold layer is performed with an LPKF U4 laser. The laser ablation, in conjunction with the pre-designed overhangs, ensures the electrical isolation of the structures (see Figure 2). This three-step process enables the rapid development and testing of MEMS devices within hours—a significant improvement over the days or weeks required by traditional microfabrication techniques. Furthermore, the adoption of 3D printing technology facilitates the creation of complex structures beyond the capabilities of conventional microfabrication methods.

For the integration of the printed components with larger systems, pads are formed during the laser ablation phase. Z-axis conductive-anisotropic tape (3M 9703) is then applied to these gold pads, and a breakout board is connected to the tape, simplifying integration and allowing ease of integration with external devices. This approach substantially enhances the efficiency of testing for rapidly developed MEMS devices.

Experimental Setup

The g-switch's mechanical response was tested using a Femtotools FT-S1000 force sensing probe and control system. The contact was observed on a Keyence VHX-1000 digital microscope (Figure 3). The probe was lowered until contact was observed through real time force measurement. A digital multimeter was connected on each side of the switch to measure the contact resistance and observe when an electrical connection was made. Using the Femtotools software and probe, the proof mass was displaced, and both displacement and force was recorded. This process was repeated for five runs to record the mechanical response of the switch. To test the point of electrical contact the probe was manually displaced until continuity was observed on the multimeter.

RESULTS

The results from the mechanical response test can be seen in Figure 4. The green shaded section shows the response without contact and the red shaded region shows the force response after mechanical contact was made with the pads. The resistance of a continuous gold trace with the anisotropic tape was measured at 20 Ω. With electrical contact the circuit exhibited 27 Ω, resulting in a contact resistance of 7 Ω.

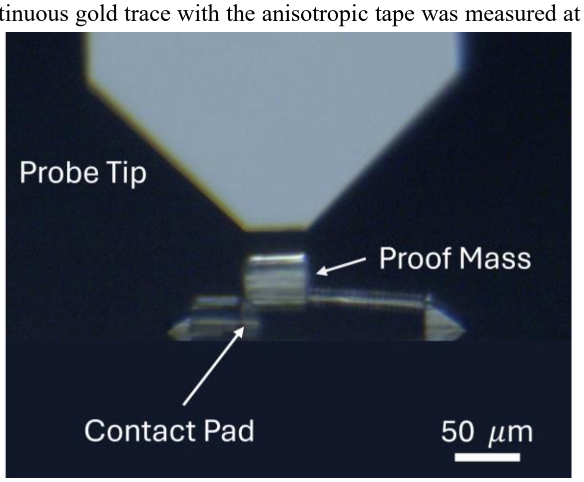

Figure 3. A 1000 μN FemtoTools probe is used to actuate the g-switch sensor.

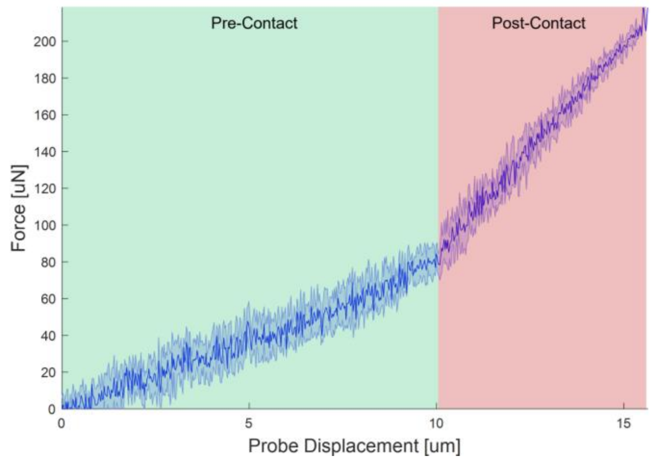

Figure 4. Plot of force vs displacement of g-switch. The green section of the plot shows the response before proof mass contacts the pad. The red section shows the response after mechanical contact has been made up to the point of electrical contact.

CONCLUSION

This device and fabrication process show a rapid, simple, and elegant approach to fabricate conductive and mechanically complex microdevices. The demonstration of a zero-power g-switch has utility in wide sector of technologies where powered accelerometers are not practical. The hybrid 3D printing process can be adapted to create devices where complex, electrically functional sensors and actuators with arbitrary directionality are needed.

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