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# Fabrication of Structured Polydimethylsiloxane Using Polymer 3D Printing Mold

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**Abstract**

Fused deposition modeling (FDM), stereolithography (SLA) and Powder Bed Fusion (PBF) are the three common 3D printing (3DP) techniques. Some structured polymers or molds often formed using SLA and PBF techniques by researchers are much more expensive and a complicated post-processing. Here, we use FDM 3DP technique, which is simple, cheap and time-saving, to manufacture the polymer master mold for multi-use cycling casting polydimethylsiloxane (PDMS) with various structures such as waves and cones. The cast structured PDMS can be applied as a triboelectric layer for the Al-PDMS triboelectric nanogenerator (TENG) to harvest mechanical energy. The more effective contact area the structured PDMS has, the better electrical output performance is. The mechanical-to-electric conversion energy using the Al-PDMS TENG fabricated by the polymer FDM 3DP and casting is the potential sustainable energy for the self-powered device application in the future.

Keywords: Polymer; 3D Printing; Casting; Polydimethylsiloxane; Structure; Triboelectricity; TENG

## Introduction

3D printing technique has arisen as a multifaceted technology platform for computer-assisted design (CAD), and it's a cost-effective additive manufacturing that has been developed since 1980s. It plays an indispensable role in various industrial fields, even in high-tech era nowadays, therefore 3D printing technique becomes one of the critical techniques for Industry 4.0 and digital fabrication [1-2]. The main feature of 3D printing technique is that it enables us to design complex three-dimensional geometries. There are three common 3D printing techniques, which are fused deposition modeling (FDM), stereolithography (SLA) and Powder Bed Fusion (PBF) [3-4]. Table 1 lists the comparison of 3D printing techniques with some of their relevant features. So far, 3D printing technique is used to various fields such as medical applications [5], sustainable energy [6], and so on. Here, we report on fabricating a PDMS film cast by polymer FDM 3D printed mold. We select the FDM technique because the fabrication is cheaper, simpler, and more time-saving. As the fact mentioned above, by using 3D printing technique, a macro-scale structured PDMS film is fabricated. Through applying the structured PDMS film to TENG, self-powered ability of the device has been tested. The structured PDMS for Al-PDMS TENG can light up LEDs in series and efficiently charge different capacitors, so that it is capable of providing sustainable electrical energy for practical applications in the future [7-8].

**Table 1:** The comparison of polymer 3D printing techniques.

| | FDM | SLA | PBF |
|---|---|---|---|
| Printing duration | Short | Long | Long |
| Cost | Cheap | Expensive | Very expensive |
| Dimension(desktop) | (200*200*300 mm$^3$) | (145*145*175 mm$^3$) | (165*165*320 mm$^3$) |
| Resolution | Low | High | High |
| Surface quality | Smooth | Very smooth | Very rough |
| Ease of use | Convenient | Convenient | complicated |
| Material choice | Standard thermoplastics | Resin | Metal, Engineering thermoplastics |

## Discussion

### Material Selection

Table 2 lists the properties of polymer materials (Polylactic acid(PLA), PolyMideTM(CoPA) and Copolyester plus (CPE+)) with a focus on glass transition point, melting point, heat resistance, surface quality and dimension accuracy. In this work, we select PLA because of its good surface quality, which is important to be a casting mold; and we also choose CoPA due to its high melting point and heat resistance, which could cut down the curing time and accelerate the process. Polymer materials all have their own merit. According to the demand of various applications, each polymer materials will be utilized effectively.

**Table 2:** The material properties of PLA, CoPA and CPE+.

| | PLA (Polylactic acid) | CoPA (PolyMide™) | CPE+ (Copolyester plus) |
|---|---|---|---|
| Glass transition point | 60 °C | 67 °C | 100 °C |
| Melting point | 155 °C | 190 °C | >160 °C |
| Heat resistance | 50 °C | 180 °C | 94 °C |
| Surface quality | smooth | average | rough |
| Dimension accuracy | great | great | average |

### Fabrication of structured PDMS

The schematic process flow and assembly of structured PDMS film is shown in Figure 1. A computer-aided design tool of Autodesk Inventor software is used to design the master mold for casting to form structured PDMS. The PLA, CoPA (Ultimaker) polymer molds are printed by 3D printer (Ultimaker 3, Ultimaker). The PDMS solution is prepared by the well-mixed elastomer (Sylgard 184, Dow corning) and curing agent (10:1 in weight). The degassed solution was poured into the master mold. Then cure the PDMS in the oven about 55-65°C depending on the material of master molds for about 2h and cool down for peeling off the structured PDMS. The structured-PDMS film and aluminum (Al) are assembled into a TENG, and used as triboelectric layers, respectively, and the other Al attached to the backside of PDMS also as an electrode.

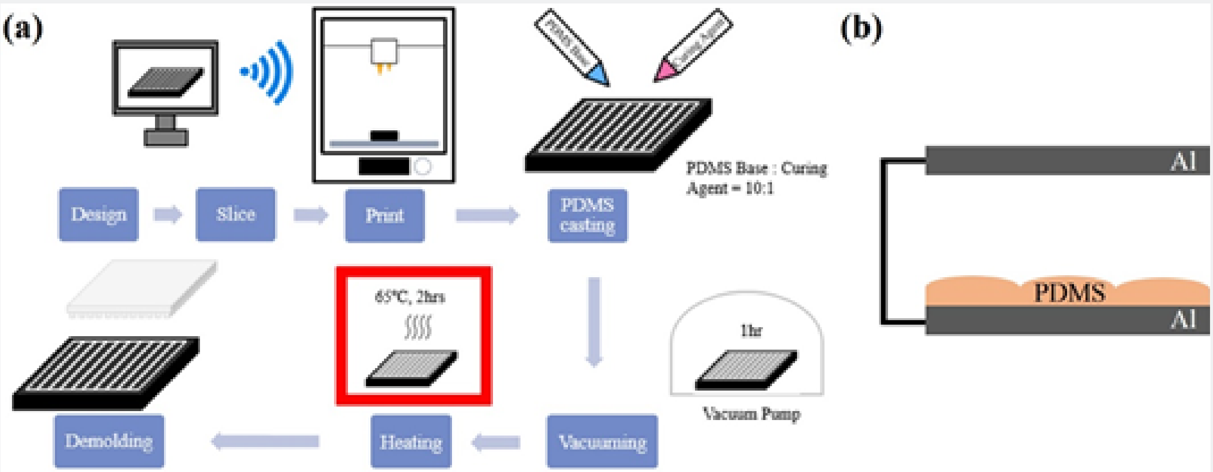


**Figure 1:** (a) Schematic structured PDMS fabrication using polymer 3D printing as a master mold and followed by PDMS casting to form various structures (b) the assembly of the structured-TENG.

### Output performance and applications of Al/PDMS Structured-TENG

Through 3D printing technology, we can design the mold with various creative structures, such as waves and cones, for casting the PDMS film, as shown in Figure 2. A structured-TENG is produced by combining with 3D printing and PDMS casting. The output performance of structured-TENG (wave) is measured that the maximum open-circuit voltage ($V_{oc}$) and short circuit current ($I_{sc}$) is 21.8 V and 12.75 μA, respectively. The stable $V_{oc}$ has been measured during the durable test for 10000 cycles, as shown in Figure 3(a). We can examine that the device is reusable and has great durability. The structured-TENG can also be applied to charge different capacitors efficiently, which can light up 30 green LEDs, as shown in Figure 3(b).


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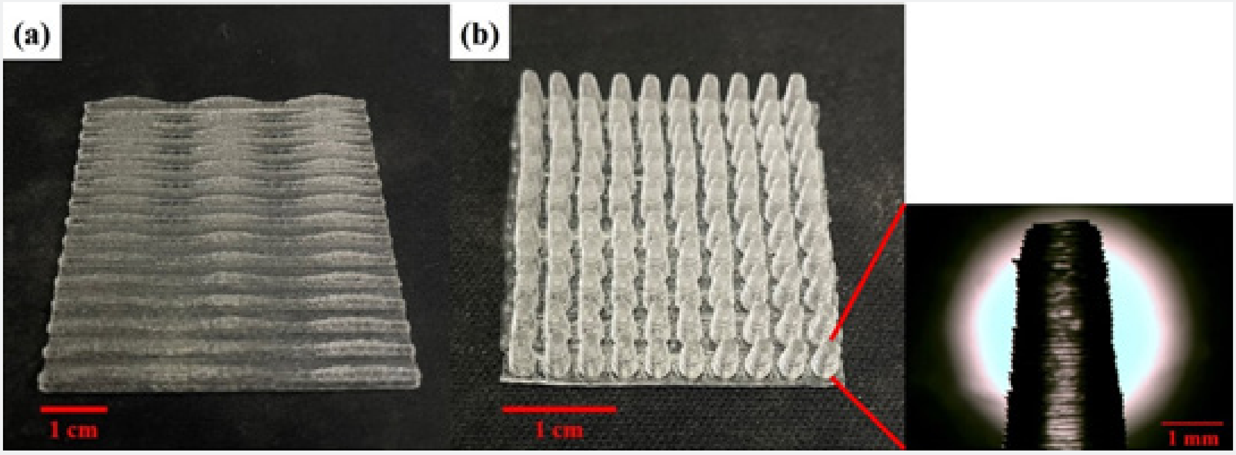


**Figure 2:** The various structured triboelectric PDMS layer: (a) waves and (b) cones.

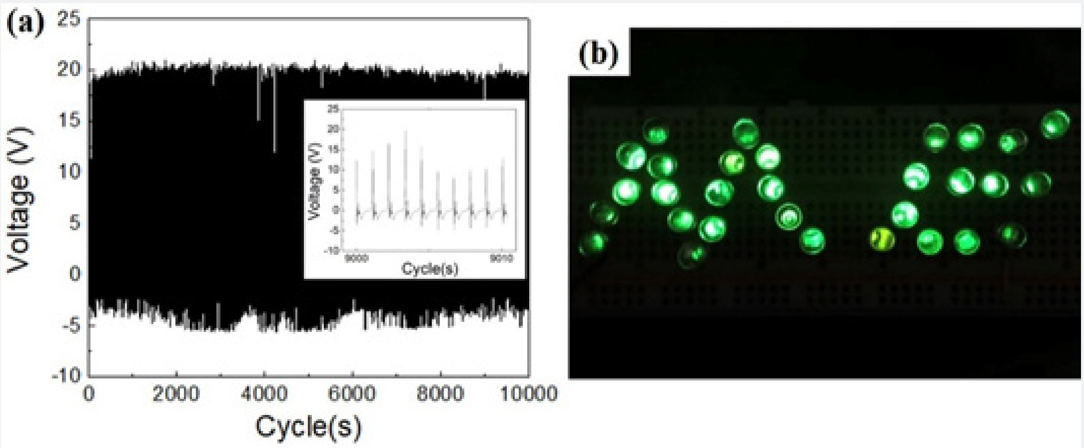


**Figure 3:** The output performance of the structured-TENG: (a) the open-circuit voltage for 10000 cycles and (b) the image of lighting up 30 LEDs.

## Conclusion

We demonstrate that using FDM 3D printing technology is able to manufacture a reusable master mold, for casting PDMS triboelectric layers with macro-scale structure quickly. Through 3D printing technology, complex and creative structures could be designed and applied to TENGs. In terms of applications, it is proved that the Al-PDMS structured-TENG can charge electronic devices to achieve self-powered function through capacitor charging tests. In the future, it can also extend its application to self-powered pressure sensors and human-machine interfaces.

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