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Short Communication

Smart Soft Actuation System

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We have demonstrated the fabrication of cantilever shaped soft material actuator, by integrating soft silicon material with Ti-Ni shape memory alloy (SMA) wires with the diameter of 250 micrometer. A 3D stereo-lithographic printer was used to pattern a polymeric solid mold that had metal notches to fix SMA wires which were integrated in Ecoflex 30 polymer that was dispensed into this mold to pattern cantilever structures. After curing process of Ecoflex 30, the entire soft actuator device was removed from the mold. SMA wires in soft cantilevers were electrically heated to reach their phase transition temperature that extends the length of SMA wires. Because of residual stress of silicone material and extension of SMA wires, and also remarkable SMA wire deflection because of the initial martensite phase, the Ecoflex 30 based cantilever was deflected. The angle of cantilever deflection as function of applied potential difference (or voltage) was investigated.

Recently, soft materials such as Polydimethylsiloxane (PDMS) have become very attractive in fabrication of various devices like Lab-on-Chip [1], liquid metal based devices [2-5], and Resonators [6]. These soft materials were also applied for actuators and robotics structures because of flexible material characteristics [7]. Pneumatic actuators were commonly used in soft robotics fields by applying air pressure into microfluidic channels that deform soft material shapes [8,9]. Although there were some soft actuators and robotics, no SMA has been integrated with soft material for such actuation and robotics application. In this paper, we have fabricated a soft cantilever actuation structure by integrating soft material with SMA wires and investigated the actuation motion of soft cantilevers by video imaging. This approach will potentially be paradigm shift in robotics and the field of actuators, because the actuation system will be closed to the biological system like micro-tubule based muscle. More flexible work and motion like human will be expected to be achieved by this approach in robotics field.

The mold for smart material was designed by using Solid-works software at first and then was printed by the Stereo-lithographic 3D printer. Because these molds are reusable, the fabrication process for soft material actuators can be economical in compare with those of solid material actuator such as silicon MEMS actuators. After 3D printing process, the residue liquid photopolymer is removed from the printed mold by using IPA and UV light curing process hardens the mold. As a final process, the mold was thermally cured in the oven at the temperature of 65^{O}C for at least 24 hour.

Ti-Ni SMA wire was fixed in the mold via column and anchors. The uncured Ecoflex 30 solution was dispended in the mold and kept at the room temperature for four hours for curing Ecoflex 30. The integrated Ecoflex 30 cantilever with SMA wires in the mold is shown in the Figure 1a. Then, Ecoflex30 cantilevers were removed from the mold. The dimensions for these cantilevers were 10mm in length, 6mm in width and 2 mm in thickness as shown in Figure 1b.

Joule heating induces the phase transition of SMA, as a result, SMA wires can recover their apparent permanent strain by transiting phases from martensite to austenite [10]. This phase transition process expands the length of SMA wire that produces the local tensile stress in PDMS substrate that causes the deflection of PDMS cantilevers because of the constant length of PDMS cantilever. Ni-Ti SMA wires used in this research have two different electrical resistivities for austenite and martensite phases. The detailed electrical characteristics of Ni-Ti SMA wire has been published previously [11].

Based on Six electrical potential conditions for Joule heating in the range between 0.5 V to 3 V with the step increment of 0.5 V were investigated. For the first three voltages (0.5V, 1V, 1.5V) there was no deflection of cantilever observed as shown in Figure 1c, while for the higher voltages (2V, 2.5V, 3V), the deflection of the cantilever was observed as shown in Figure 1d and e. The graph of deflection angle as function of applied potential difference (or voltage applied) is shown

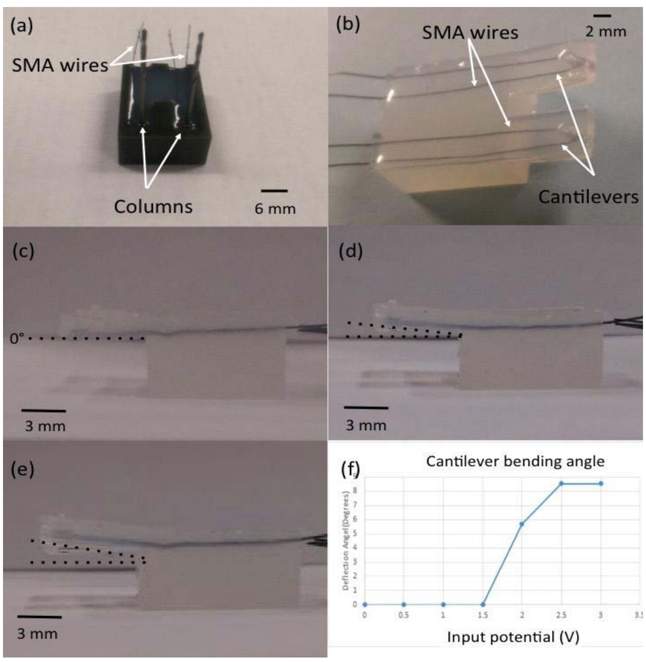

Figure 1: Images for smart cantilever shaped actuation material: (a) Photo-image for the 3D printed mold contained Ecoflex 30 and SMA wires. The pins as wire anchors are depicted in the picture. (b) photo-image of smart cantilever extracted from the mold. Photo-image of cantilever deflection with (c) 0, 0.5, 1, 1.5, (d) 2.0 and (e) 2.5, 3 volts application. (f) The graph for cantilever deflection angle as function of applied potential.

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in Figure 1f. Based on this graph, the maximum deflection angle of Ecoflex 30 cantilever was found to be 8.5 degree at 2.5V and 3V. This deflection angle of cantilever was also the function of cantilever dimensions, Young modulus, wire positions and the diameter of SMA wire.

Conclusion

We have demonstrated the integration of Ti-Ni SMA wire with soft material to produce new smart actuation material. The standard molding process with embedded SMA wire has realized the fabrication of soft cantilever actuators. The actuation performance of the soft cantilever was characterized, and the maximum deflection angle of cantilever 8.5 degree was observed. By optimizing the deflection mechanism by adjusting the dimensions of cantilever based on mechanical simulations, this defection angle is expected to increase significantly. Because of flexibility of material and easy molding capability for any arbitrary shapes, soft actuation material may cause paradigm shift in the field of solid robotics, actuators in the future. In addition, this method will significantly improve the bio-inspired robotics and actuators because of the bio-like actuation dynamics.

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