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Danish Polymer Center
DPC
DTU Chemical Engineering

Silicone dielectric elastomer fiber actuator

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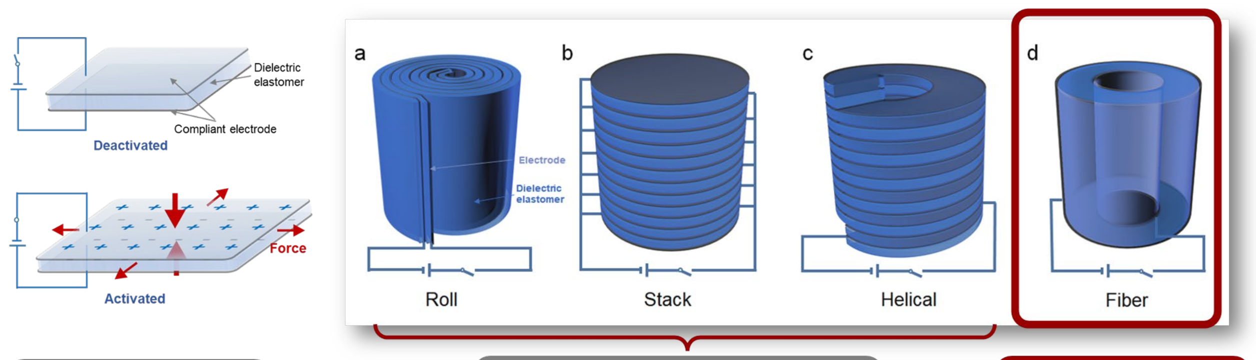
Abstract

Due to the linear response to an external electrical stimulus, dielectric elastomers show great potential as artificial muscles. In this work, we demonstrate a continuous preparation of polydimethylsiloxane (PDMS) hollow fibers through a coaxial spinning method utilizing a rapid thiol-ene photocuring reaction. The developed PDMS fiber, with an external diameter of ~460 µm and uniform wall thickness of ~80 µm, shows a significantly increased tensile strain of ~600 % and strength of 0.62 MPa compared to those of the planar film (86 % tensile strain and 0.14 MPa strength). To assemble the fiber actuator, an ionic liquid core electrode is injected and coated with ionogel or carbon grease as the outer electrode. The fiber actuator with ionogel possesses a high transparency of ~90 % in the visible light spectrum. The fiber actuator exhibits a sizeable linear strain of 9 % and repeatable and stable linear actuation strain over 1000 cycles. Moreover, the fiber actuator is employed in weight-lifting systems constructed using Lego models. The loading weight and displacement are regulated using suitable fiber lengths and bundles. Additionally, when actuated in an ionic liquid electrolyte, the PDMS fiber actuator exhibits remarkable actuation strain (10 %) and fast response (0.1 s). Furthermore, the PDMS fiber actuator can also serve as a microfluidic pump, displaying remarkable pumping capabilities.

Introduction

Planar transducer — **Other transducer configurations**



- Area strain
- Scalability
- Adaptability

- Complicated manufacturing
- Hard to be scaled

- Simple
- Bundle
- Applied in textiles

Fig.1 Configurations of dielectric elastomer actuators.

Experimental

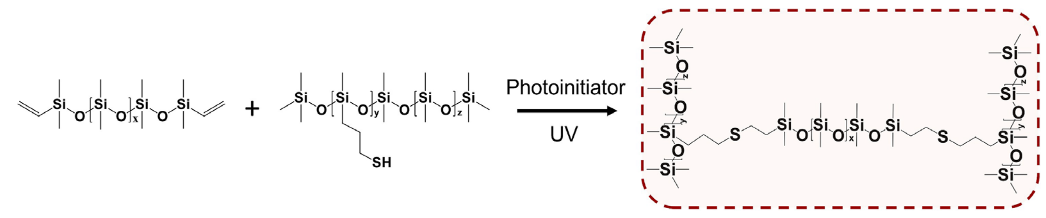


Fig.2 Photocuring of silicone via thiol-ene reaction.

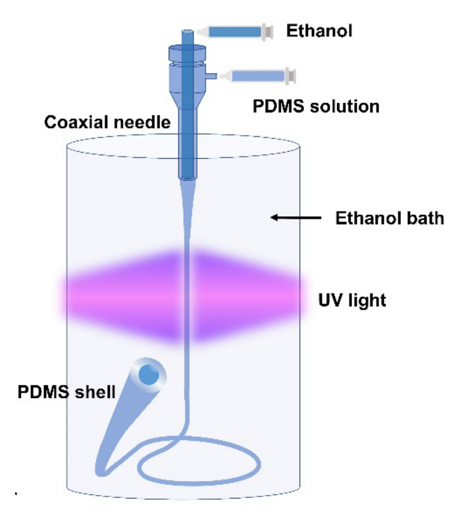


Fig.3 Preparation of PDMS fibers by the wet spinning method.

Fig.4 PDMS fiber by the meter.

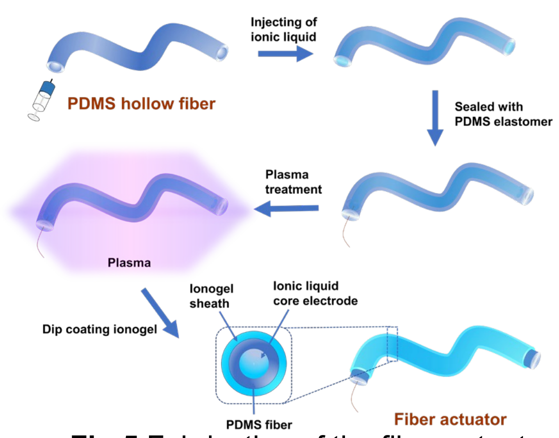


Fig.5 Fabrication of the fiber actuator.

Results

▪ Mechanical properties and morphologies

Preparation of **PDMS fibers with different dimensions** by changing the volume flow rate ratio of inner solvent (**Q_{inner}**) and outer PDMS solution (**Q_{outer}**).

Table 1 Mechanical properties of PDMS film and fibers.

Sample	Q_{inner}/Q_{outer}	Wall thickness (µm)	Y@ (10-20% strain) (MPa)	Strain (%)	Strength (MPa)
Film	-	-	0.2±0.01	83±3	0.14±0.02
Fiber a	0	-	0.21±0.01	625±78	0.67±0.09
Fiber b	0.5	108±4	0.21±0.03	592±38	0.62±0.05
Fiber c	**1**	**78±3**	**0.22±0.02**	**596±30**	**0.64±0.02**
Fiber d	1.5	62±5	0.15±0.01	457±21	0.37±0.03

- ➢ PDMS fibers: **Higher strain and strength** compared to film
- ➢ Fiber c: **Stable geometry** and **thin wall thickness**

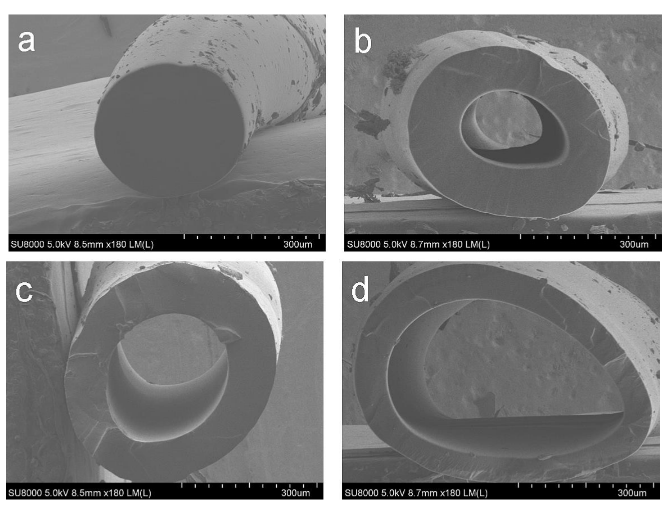


Fig.6 The cross-section images of Fibers a-d.

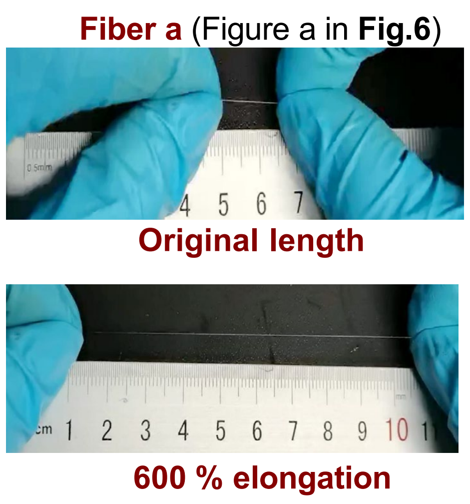


Fig.7 Highly stretchable Fiber a.

▪ Actuation of PDMS fibers actuators

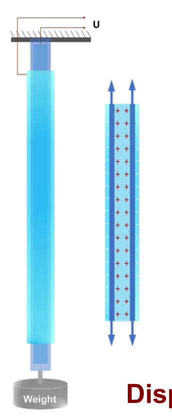


Fig.8 Illustration of linear actuation.

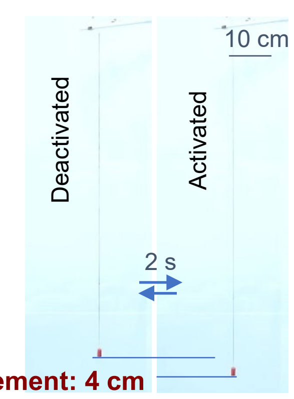


Fig.9 Actuation of a 65 cm fiber (Fiber c).

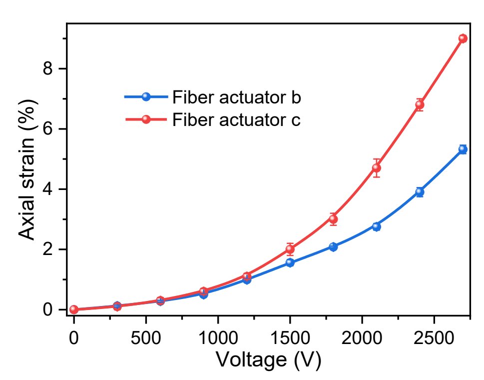


Fig. 10 Axial strain of fiber actuators (Assembled by Fibers b and c).

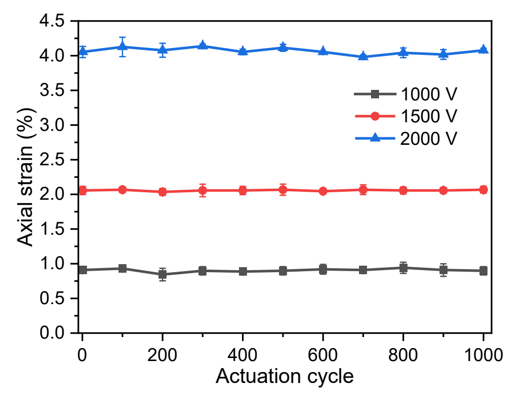


Fig. 11 Cyclic actuation of fiber actuator c at different voltages.

Stable actuation over 1000 cycles

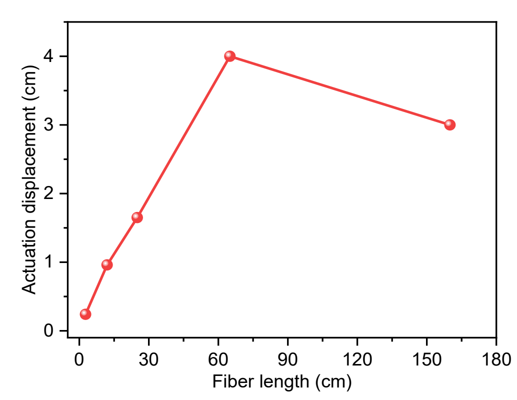


Fig. 12 Actuation displacement of fibers with different length at 2700 V.

Large actuation displacement

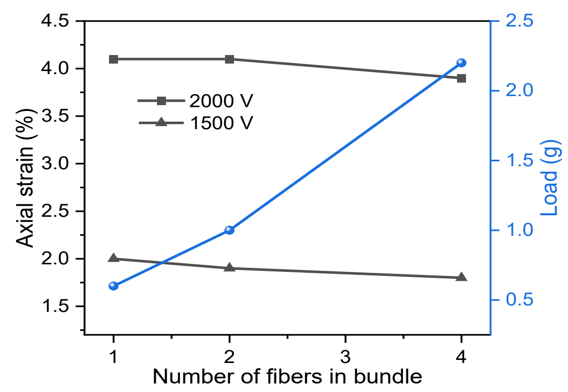


Fig. 13 Axial strain and load of bundle actuators at different voltages.

Increased actuation force

▪ Lifting system

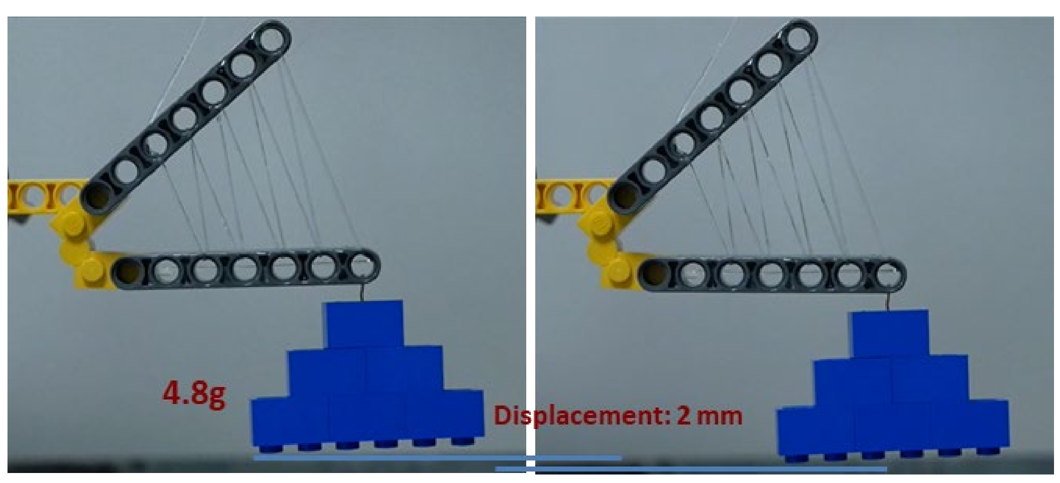


Fig. 14 A lifting system constructed by Lego breaks at 2700 V.

A long fiber with nine actuation segments

▪ Actuation in wet condition

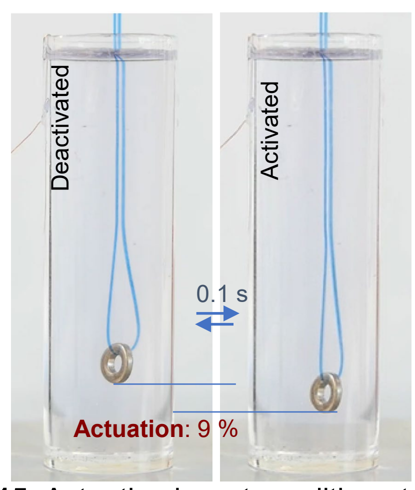


Fig.15 Actuation in wet condition at 3000V.

Fast response

▪ Fiber pump

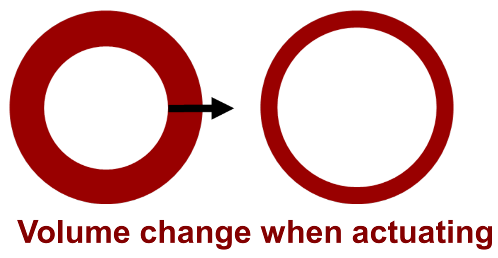


Fig.16 Fiber pumps constructed by fiber actuator.

Conclusions

- The optimized PDMS fiber shows a **7-fold increase in tensile strain** and **a 5-fold increase in tensile strength** compared to the planar film. (**Table 1**)
- The fiber actuator presents a large linear strain of ~10 %, and the linear strain is highly repeatable over 1000 cycles. (**Fig. 10** and **11**)
- Large actuation displacement (4 cm) and weightlifting capabilities (4.8 g) are achieved by increasing the fiber length to 65cm and winding up one fiber into a bundle (9 sub-fibers). (**Fig. 9, 12** and **14**)
- The silicone fiber actuator can also be actuated in wet conditions, where an excellent actuation strain of 10 % and a fast response time of 0.1 s are obtained. (**Fig. 15**)
- The silicone fiber actuator displays remarkable pumping capabilities when set up as a microfluidic pump, and the pumping flow rate is increased by increasing the number of fibers. (**Fig. 16**)

References

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Acknowledgments

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