ÉCOLE POLYTECHNIQUE
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A Soft Actuator Based on Dielectric Elastomers

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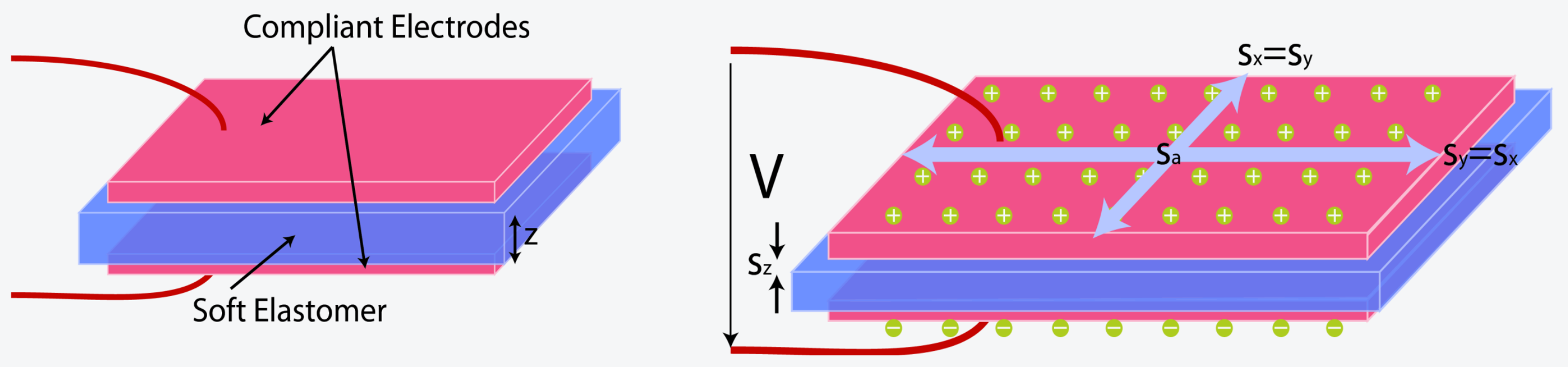
Introduction

We demonstrate here a configuration of soft actuator which has several features such as, being completely soft, simple, thin, foldable, and stretchable while having uni/bidirectional bending actuation. Theoretically the actuation can be extended to multidirectional.

We used Dielectric Elastomer Actuators (DEA) as a base actuation mechanism, and molded PDMS was used as a substrate of the device.

Dielectric elastomer actuators (DEA)

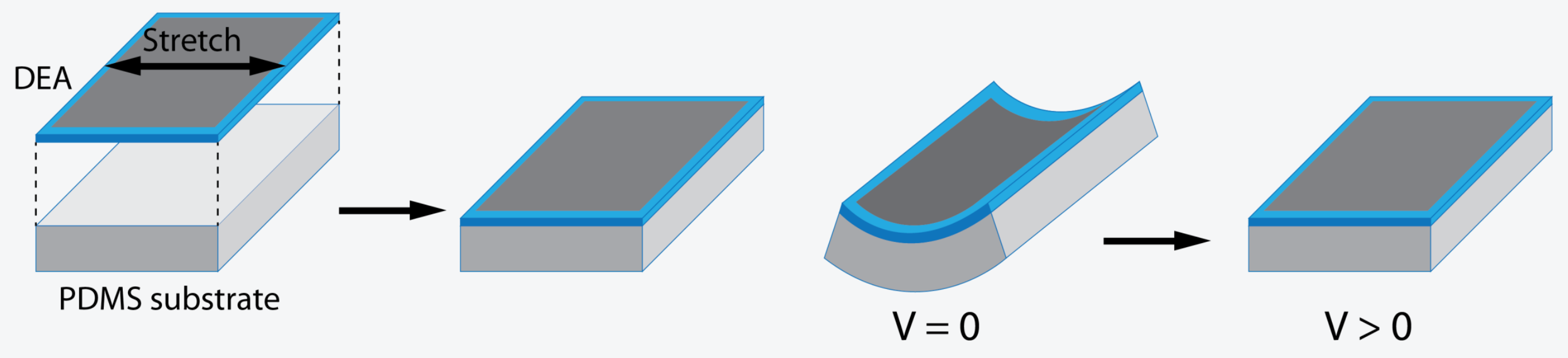
DEA are composed of an elastomer membrane sandwiched between two compliant electrodes. When a voltage is applied to the electrodes, an electrostatic force is generated, compressing the elastomer, which leads to decrease of thickness and expansion of area.



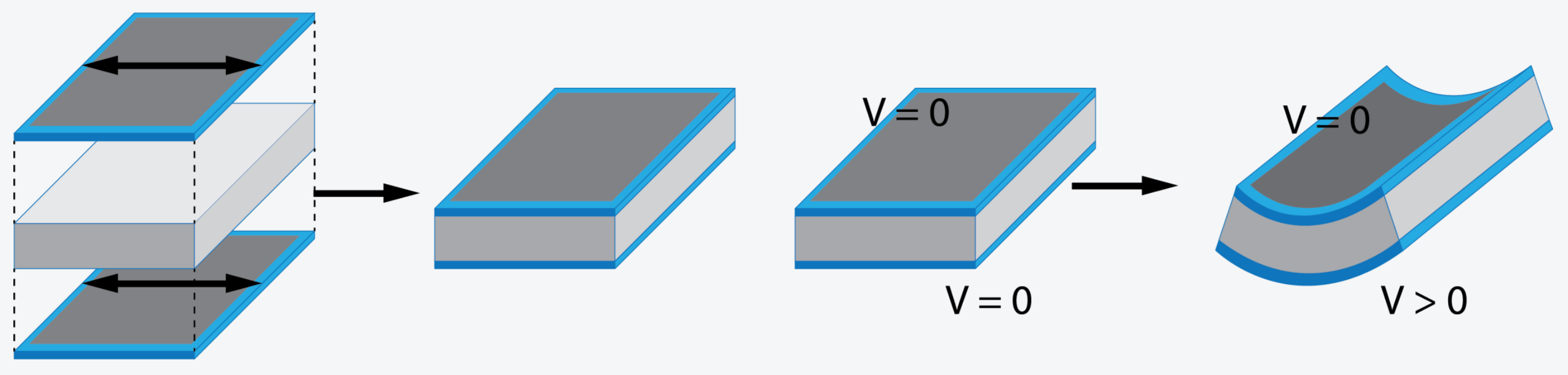
Mechanism

The actuator consists of pre-stretched DEA and a PDMS substrate, which form a curved shape arising from their mechanical properties and the minimization of the strain energy in the DEA and the bending energy of the substrate. Due to its softness and simple structure, improved robustness is expected compared to other flexible DEA.

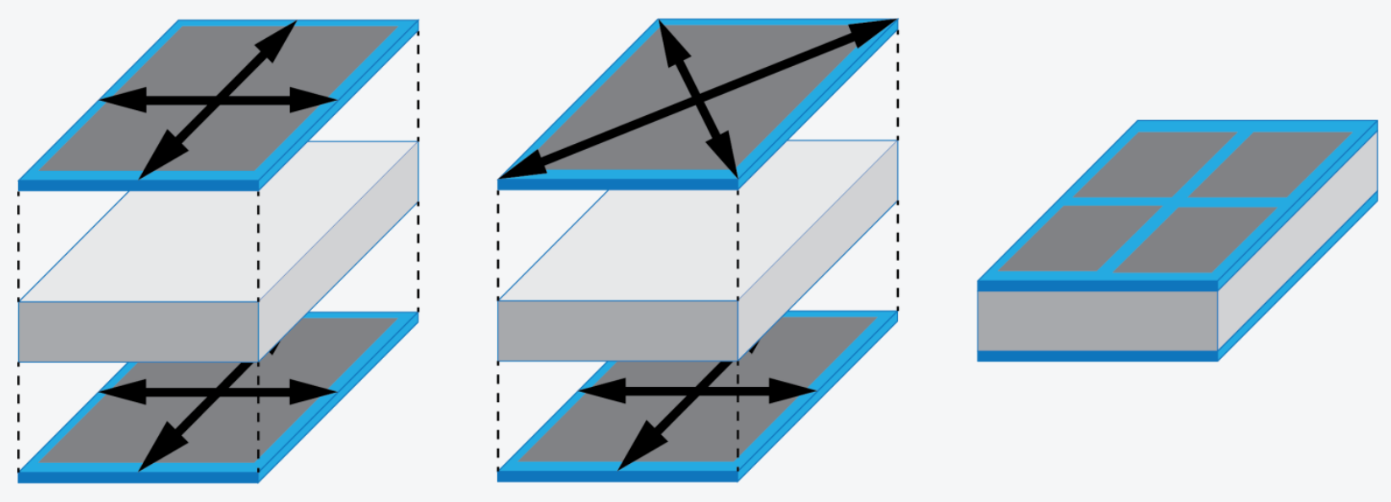
- **Unidirectional actuation mechanism**



- **Bidirectional actuation mechanism**

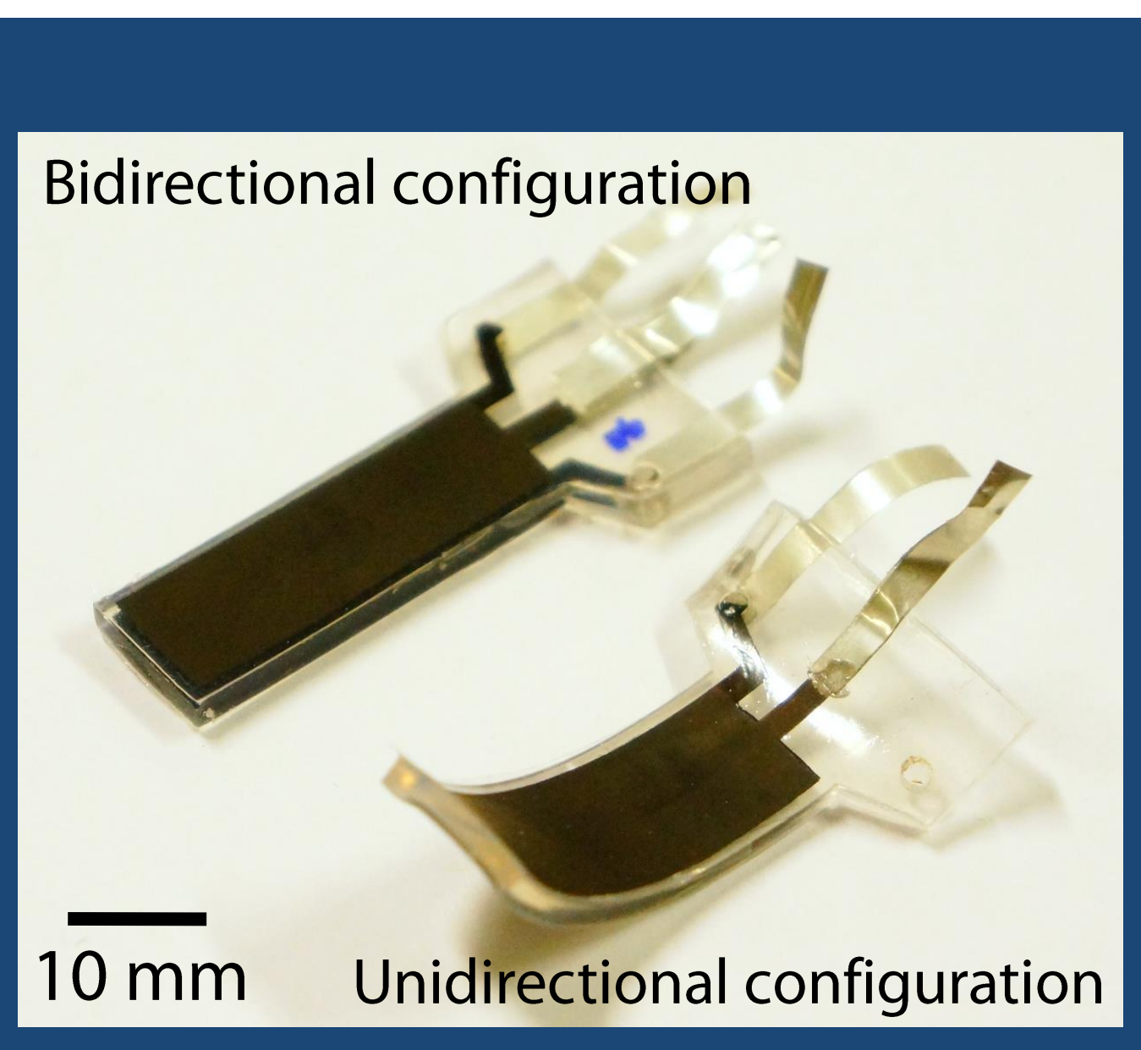


Not only bending actuation but also multidirectional actuation can be expected by changing pre-stretch condition of the DEA and the electrode pattern.

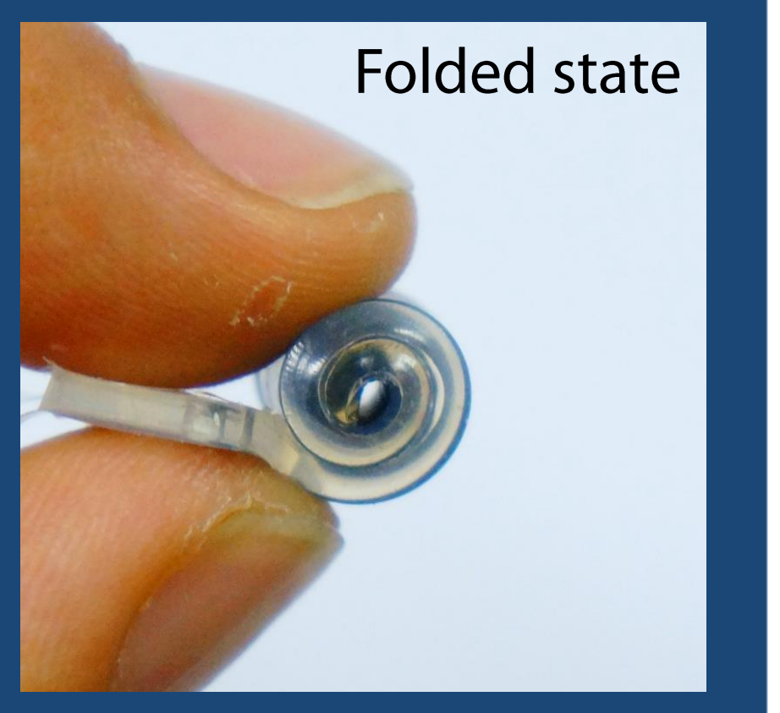


λ_1: Stretch ratio on the length direction
λ_2: Stretch ratio on the width direction
λ_3: Stretch ratio on the thickness direction
l_0: Length of the actuator
l_{D0}: Initial length of the DEA
l_D: Length of the DEA
w: Width of the actuator
θ: Deflection angle of the actuator
t_P: Thickness of the PDMS substrate
t_{D0}: Initial thickness of the DEA
t_D: Thickness of the DEA
μ: Shear modulus of the DEA
E: Young's modulus of the substrate
ε_0: Permittivity of space
ε_r: Relative permittivity of the DEA

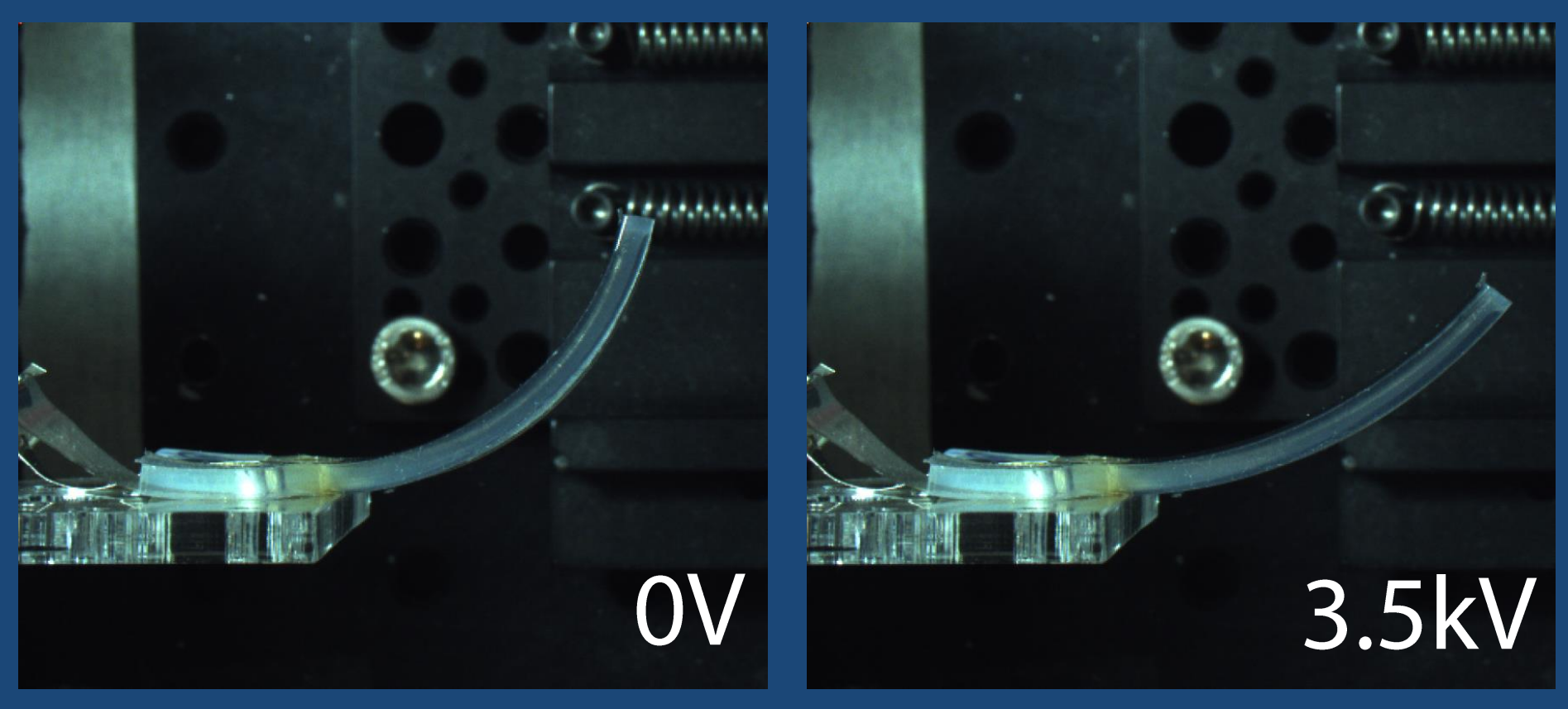
Prototype


Bidirectional configuration
Unidirectional configuration

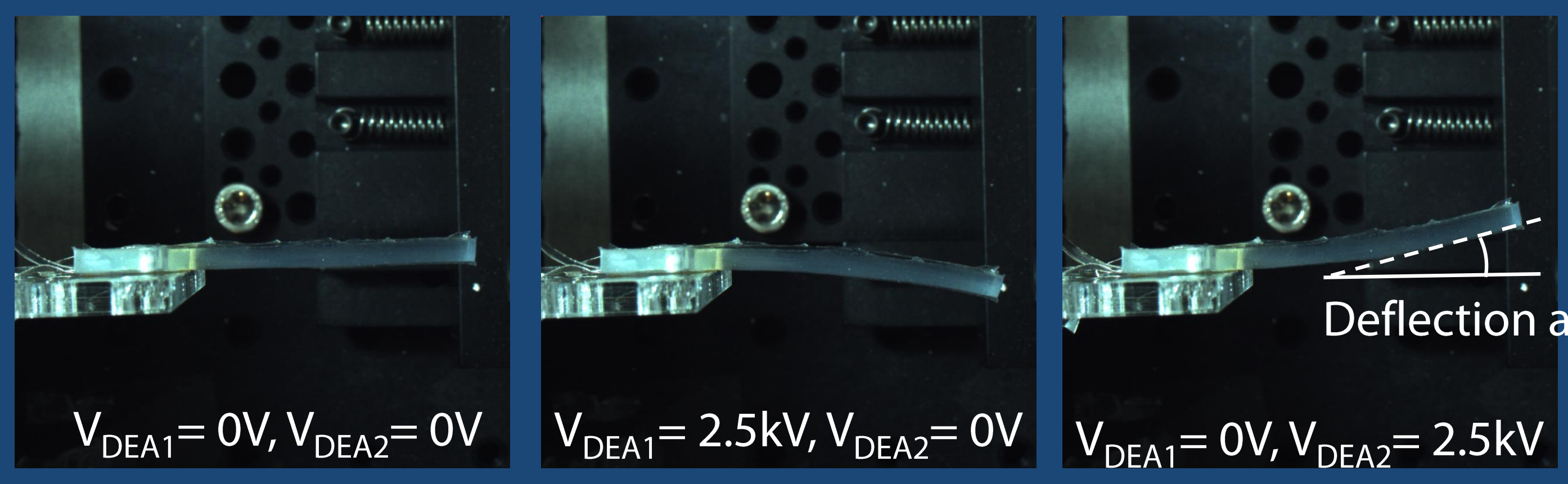

Stretched state


Folded state

Actuator dimension (active part): 12 mm x 32 mm
DEA pre-stretch ratio: 1.25
DEA thickness: ~50 um
Substrate thickness: 2 mm
Material: silicone and carbon black

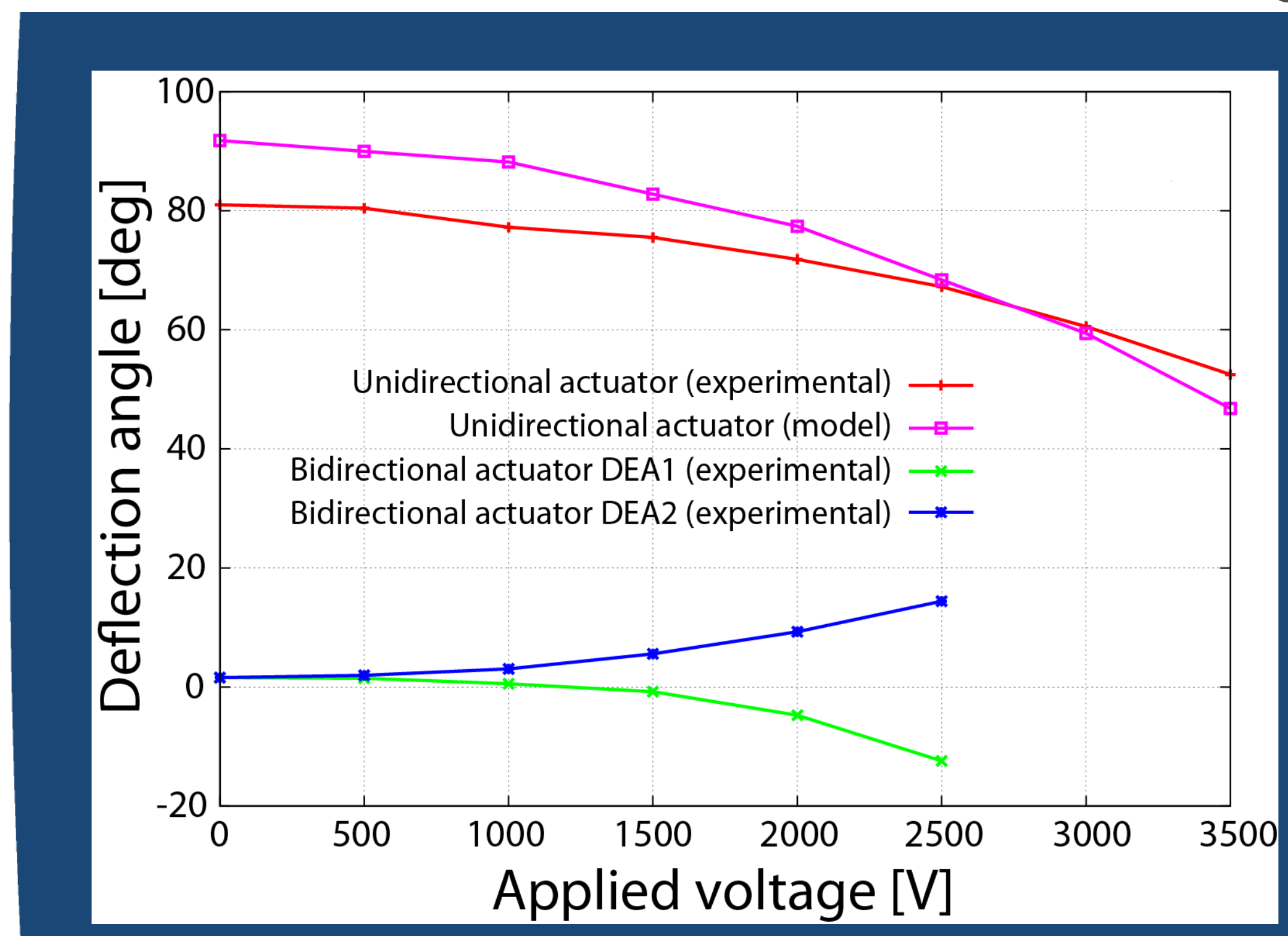


Actuation of unidirectional actuator

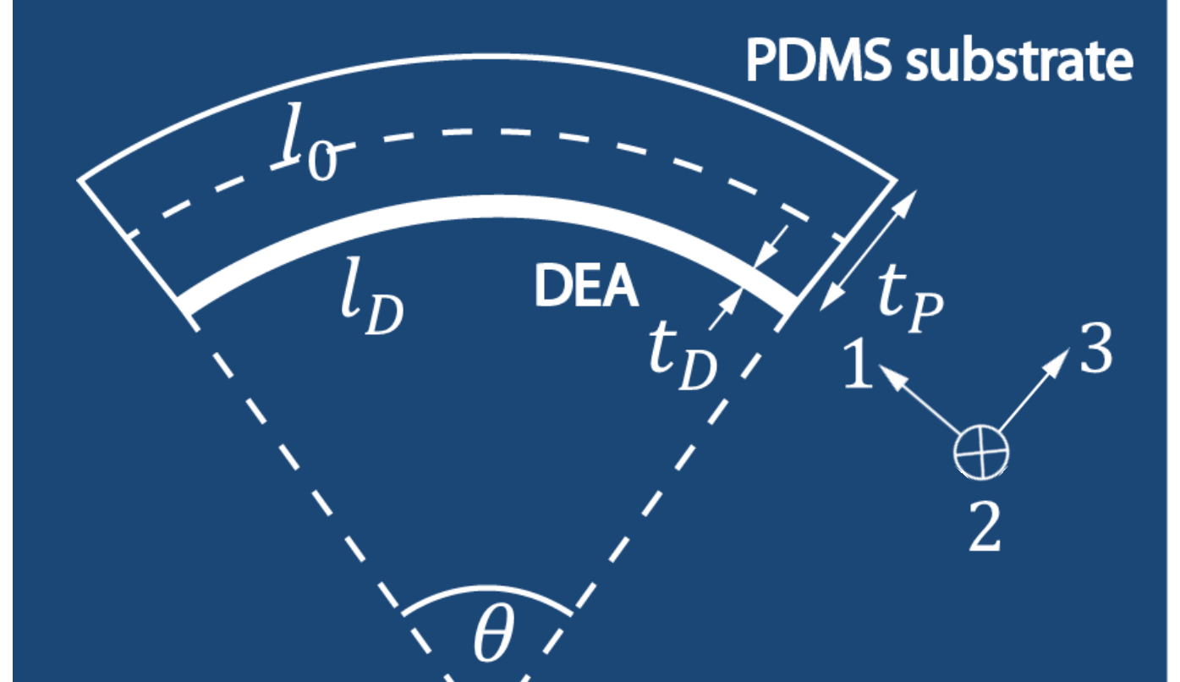


Actuation of bidirectional actuator

Voltage vs. actuation stroke



Actuator model



$\lambda_1\lambda_2\lambda_3 = 1$ (incompressible)

$$\lambda_1 = \frac{l_0 - t_0\theta/2}{l_{D0}} \quad \lambda_2 = \lambda_3 = \frac{1}{\sqrt{\lambda_1}}$$

(Uniaxial strain)

Strain energy of the DEA $U_{strain} = l_D w t_D \frac{\mu}{2}(\lambda_1^2 + \lambda_2^2 + \lambda_3^2 - 3)$ (Neo-hookean solid)

Electrical energy of the DEA $U_{DEA} = \varepsilon_0 \varepsilon_r \frac{w l_D}{2 t_D} V^2$

Bending energy of the substrate $U_{PDMS} = \frac{E w t_P^3}{24 l_0}\theta^2$

Total energy in the system

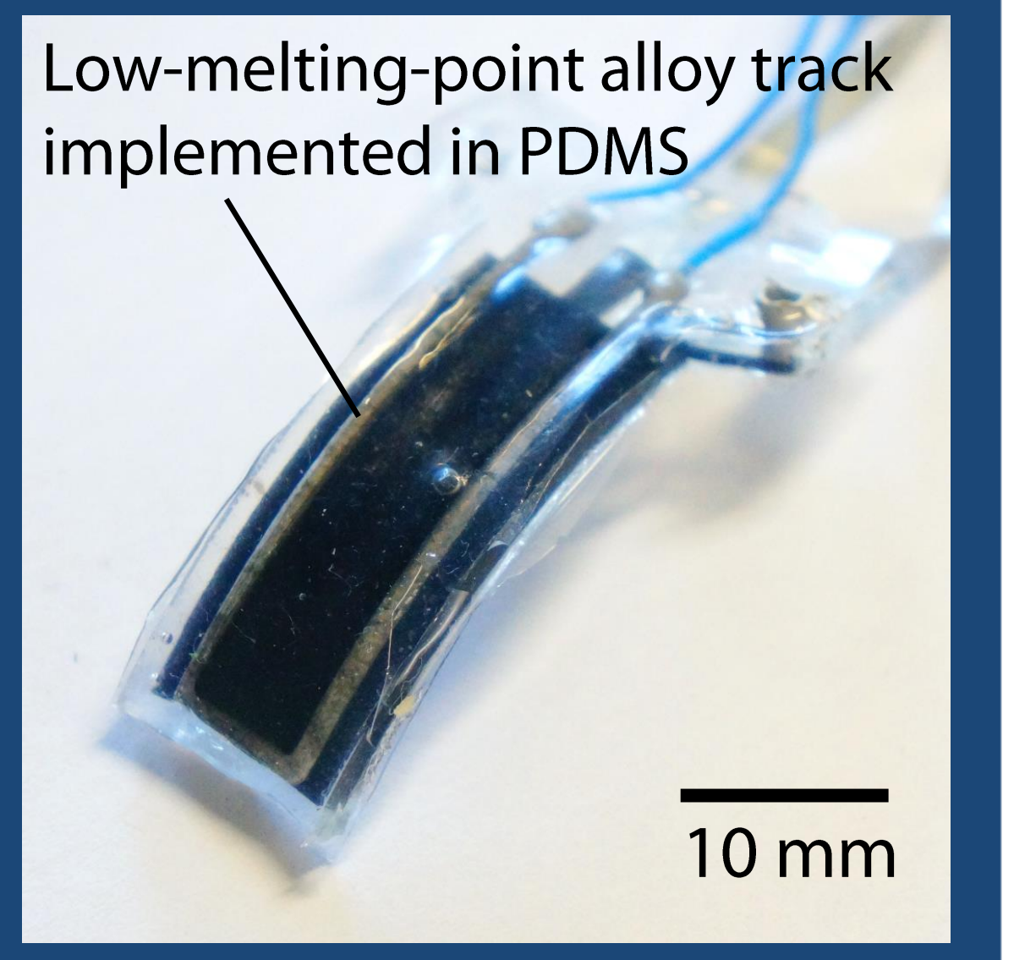
$$U_{total} = U_{DEA} + U_{PDMS} + U_{strain}$$

Deflection angle θ_m at applied voltage V is derived by local minimum of the total energy.

$$\frac{\partial}{\partial\theta} U_{total}(\theta_m, V) = 0$$

Future work

Further characterization of actuation behavior (initial shape, actuation stroke…) is required for obtaining design parameters. Implementation of sensing and variable stiffness material is important for creation of soft robotic devices. Currently variable stiffness actuators are being developed.


Low-melting-point alloy track implemented in PDMS

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