ICCM23

FIBER-REINFORCED LIQUID CRYSTALLINE ELASTOMER COMPOSITES: MULTI-STIMULUS RESPONSIVE ACTUATORS WITH MULTIDIRECTIONAL MORPHING CAPABILITIES

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1. Research background

- Liquid crystalline elastomer concept and applications

2. Experimental section

- Liquid crystalline elastomer composite fabrication

3. Results and discussion

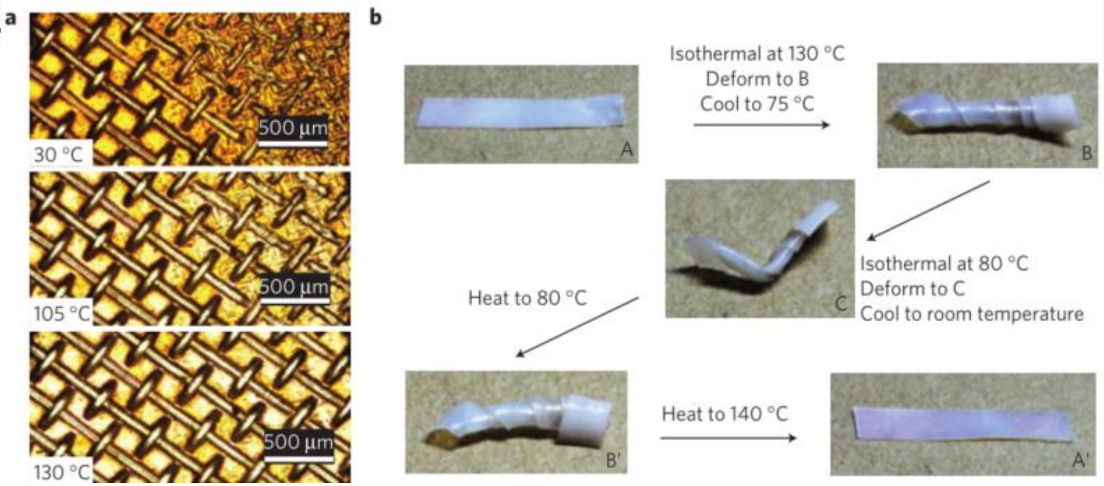
- Morphology characterization
- Thermal and mechanic behavior analysis
- Reversible transformation behavior analysis

4. Discussion

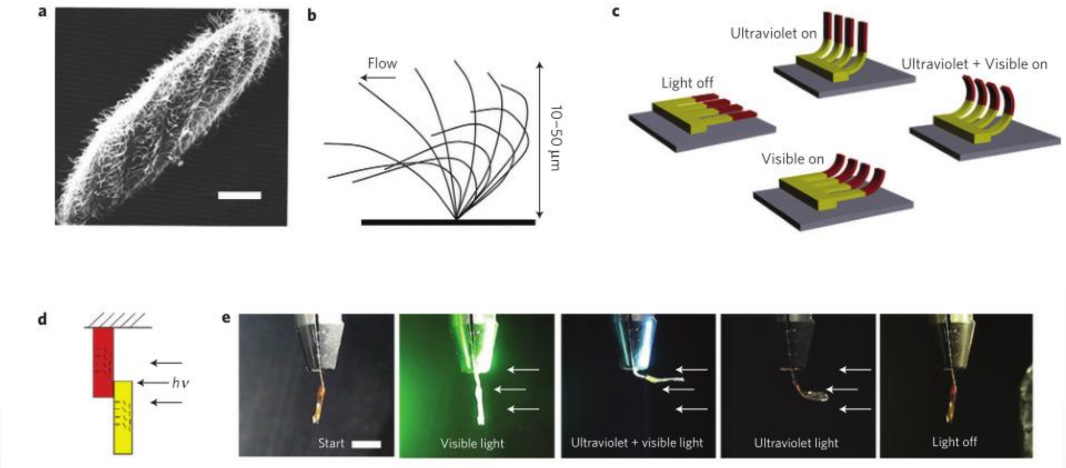
Research background

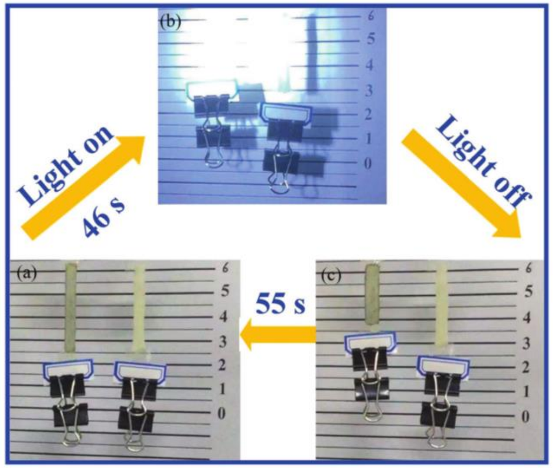
--Concept of liquid crystalline elastomer

Liquid crystalline elastomer (LCE) is a polymeric smart material characterized by its ability to undergo deformation when subjected to heat, and subsequently recover its original shape upon cooling.

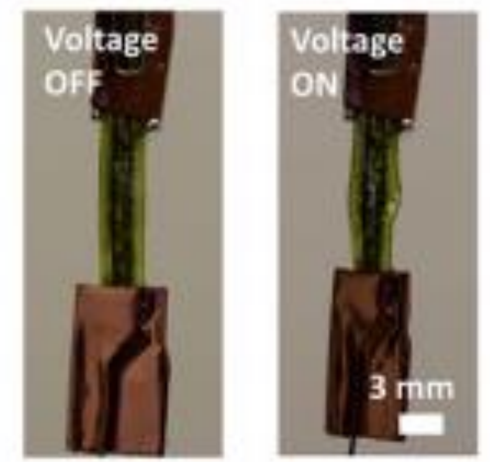


LCE transformation induced by thermal stimulation.





LCE transformation induced by light stimulation.



LCE transformation induced by electric stimulation.

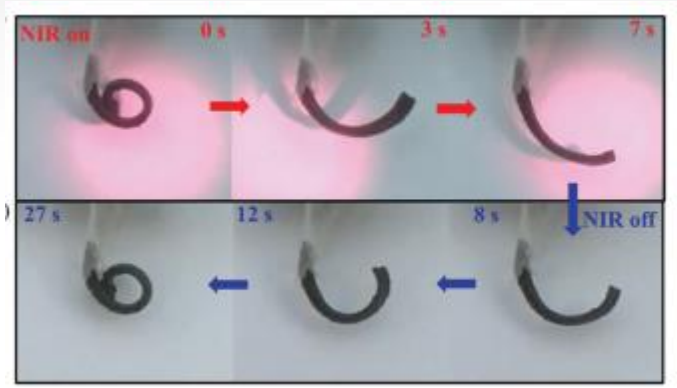
Nature Materials, 2009, 8(8): 677–682.； Nature materials, 2014, 13(1): 36–41.； Soft Matter 2019, 15(30): 6116–6126.

Research background

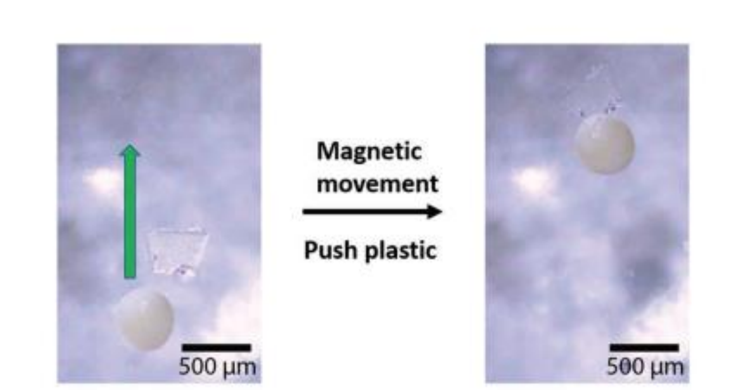
--Liquid crystalline elastomer composites

Prominent composite fillers encompass:

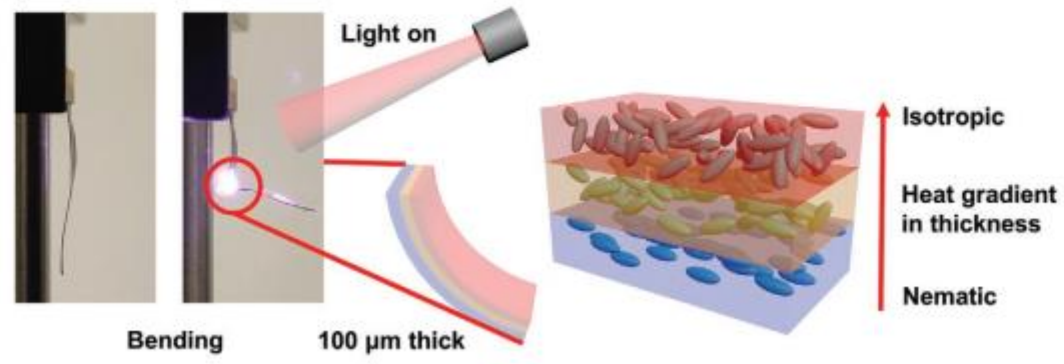
- **Carbon nanotubes**
- **Gold nanoparticles**
- **Magnetic particless**



LCE incorporated with carbon nanotubes exhibits actuation when subjected to near-infrared (NIR) light.



LCE embedded with Fe3O4 nanoparticles controlled by magnetic guidance.



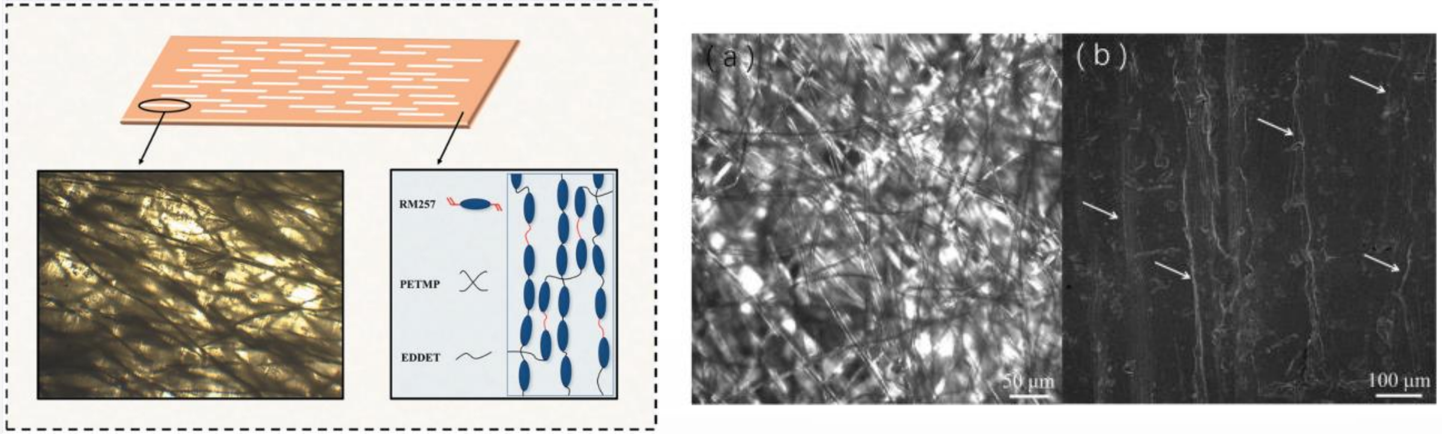
LCE integrated with gold nanoparticles demonstrates light-responsive actuation.

New Journal of Chemistry, 2020, 44(26): 10902-10910.; Advanced Functional Materials, 2019, 29(29): 1902454.; Advanced Materials, 2020, 32(46): 2004270.

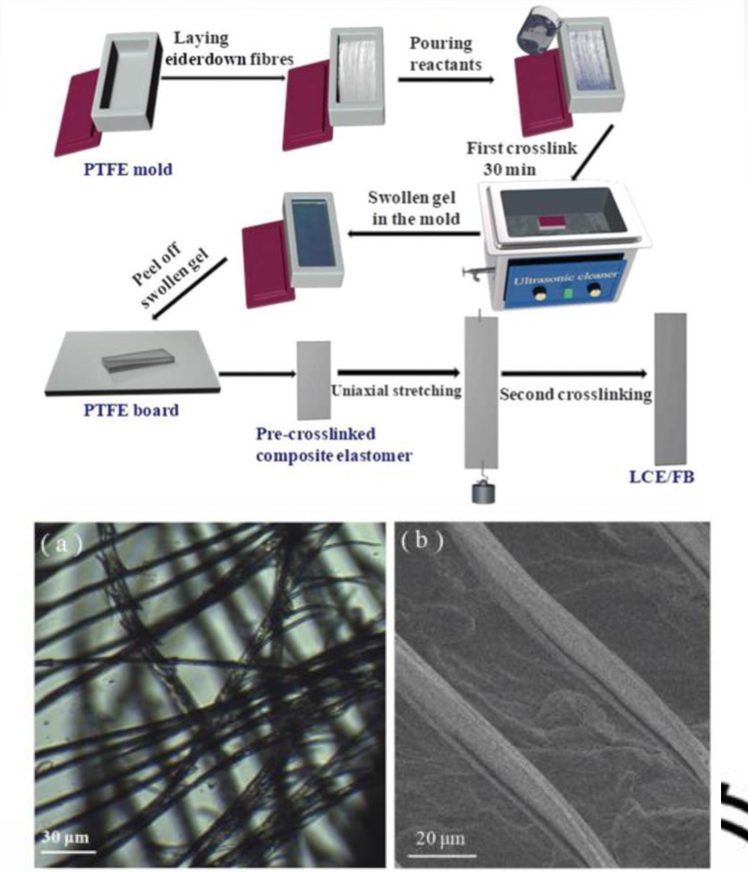
Research background

--Continuous fiber reinforced liquid crystalline elastomer composites

- **In prior studies, the integration of chopped fibers or soft fibers into the matrix of the LCE was implemented to enhance the material's toughness.**



Catkin fibers reinforced LCE



Eiderdown fibers reinforced LCE

Experimental section

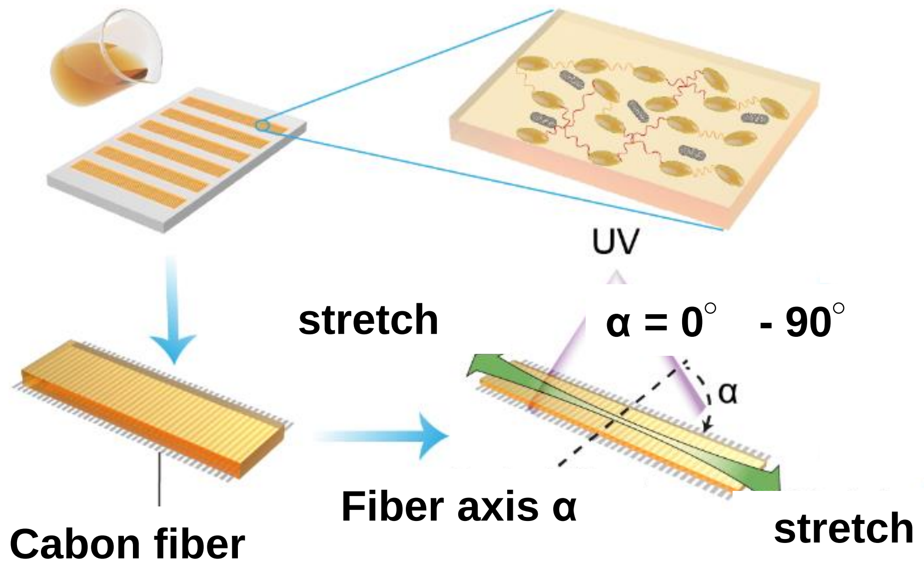
--Fabrication of LCE composites

Step 1:
The reaction between the liquid crystal monomer and the corresponding crosslinker.

Step 2:
The curing process of the sample and subsequent vacuum evaporation.

Step 3:
The shape fixation of the material through the application of UV radiation under unidirectional stress.

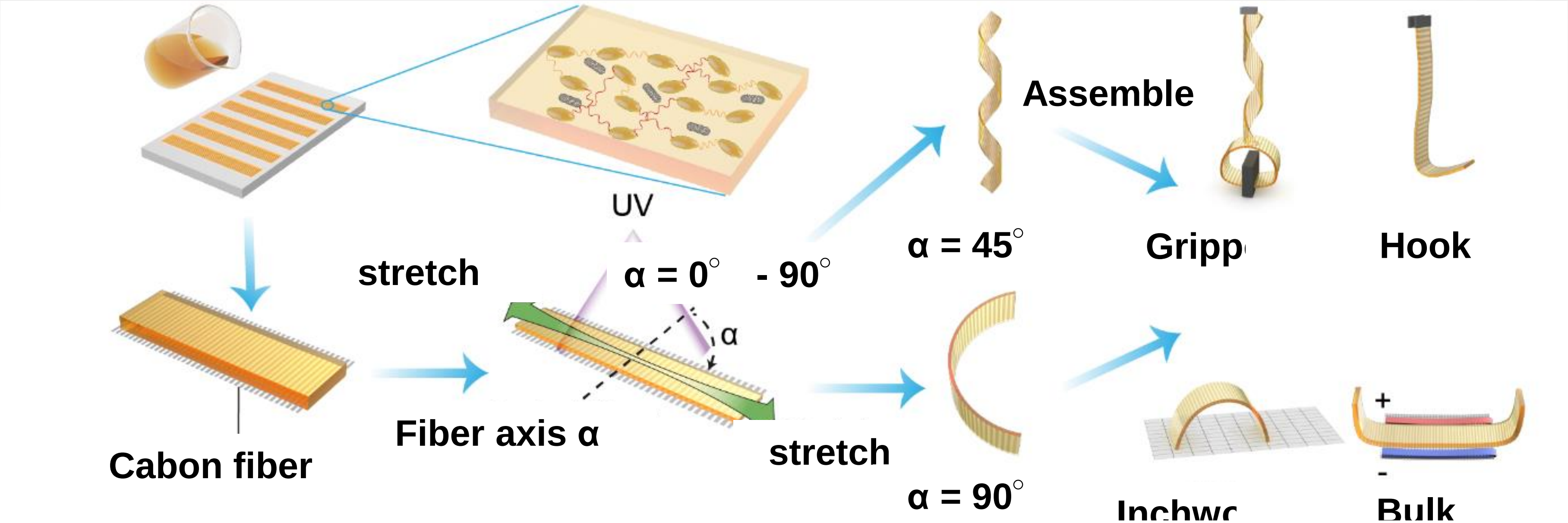
- **The LCE membrane is comprised of RM 82 liquid crystal monomer, which exhibits phase transition characteristics when subjected to heat.**
- **Within the framework of the LCE, a continuous carbon fiber is consistently affixed to a single side, as opposed to being symmetrically applied to both surfaces.**



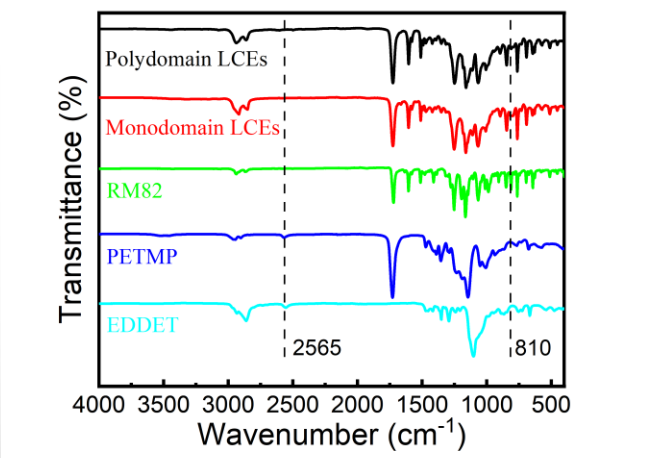
The process of synthesizing LCE composite membranes

Results and discussion

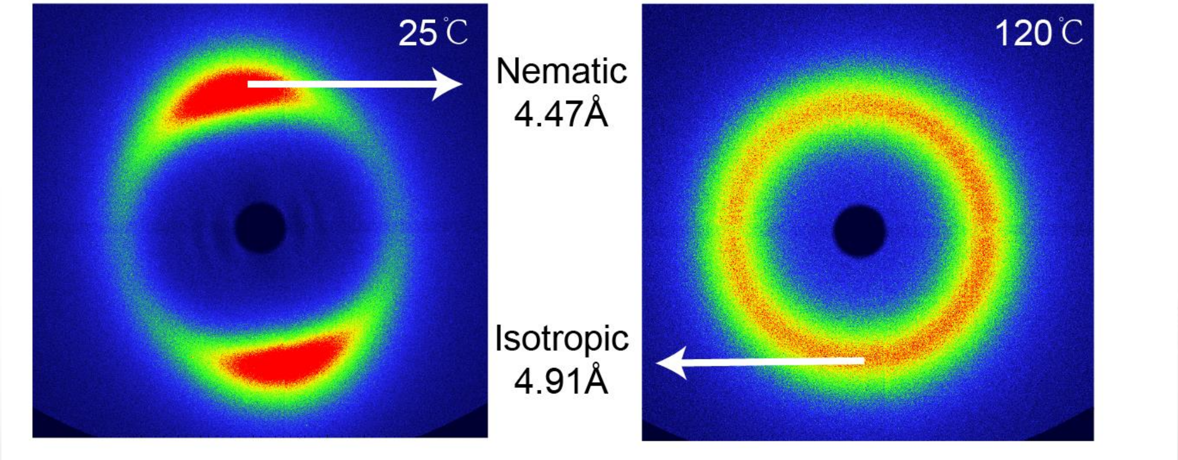
--Molecular structure and mechanic property analysis



The process of synthesizing LCE composite actuators with different α



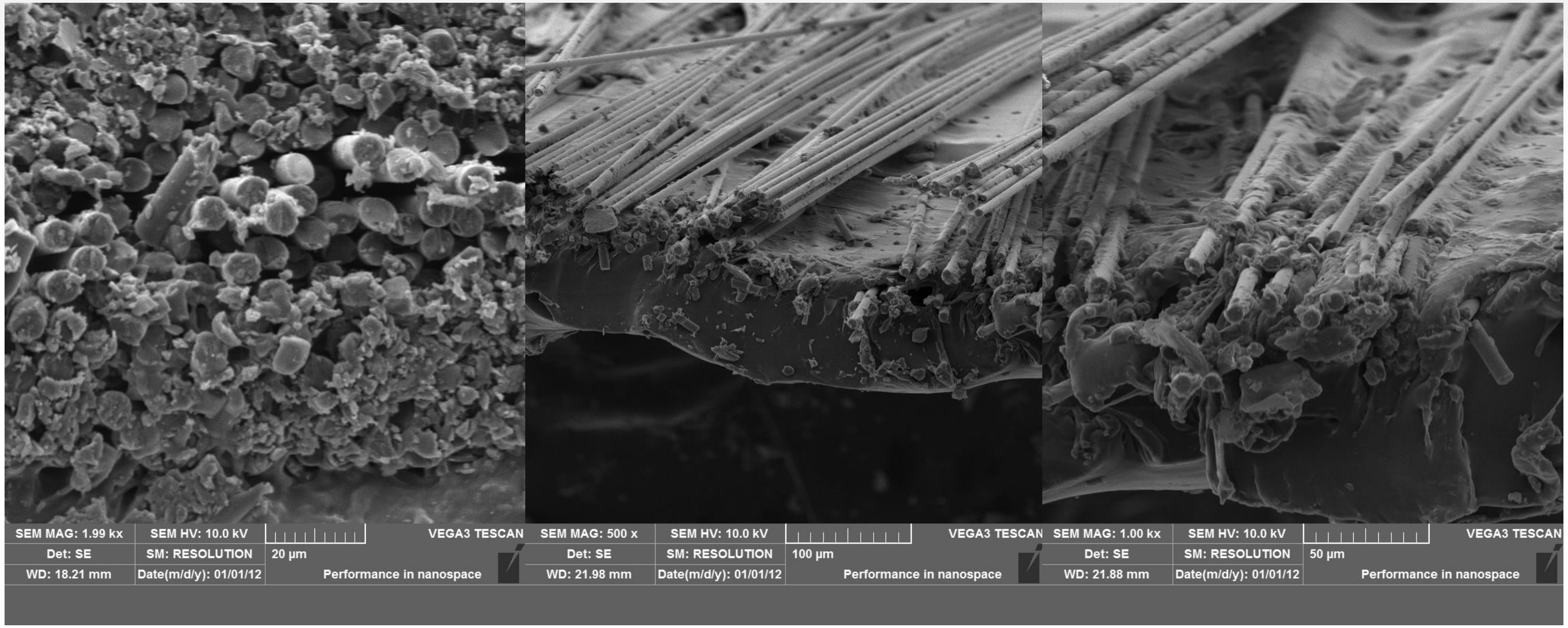
FTIR result



2D-XRD result

Results and discussion

--Micro structure characterization and analysis



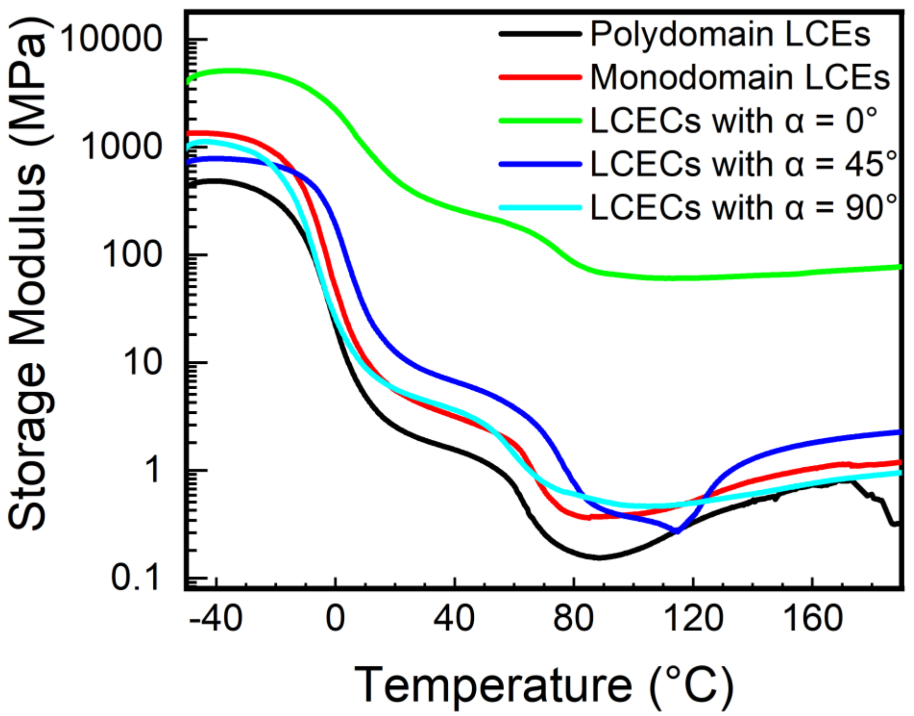
SEM images of LCE composites

Features:

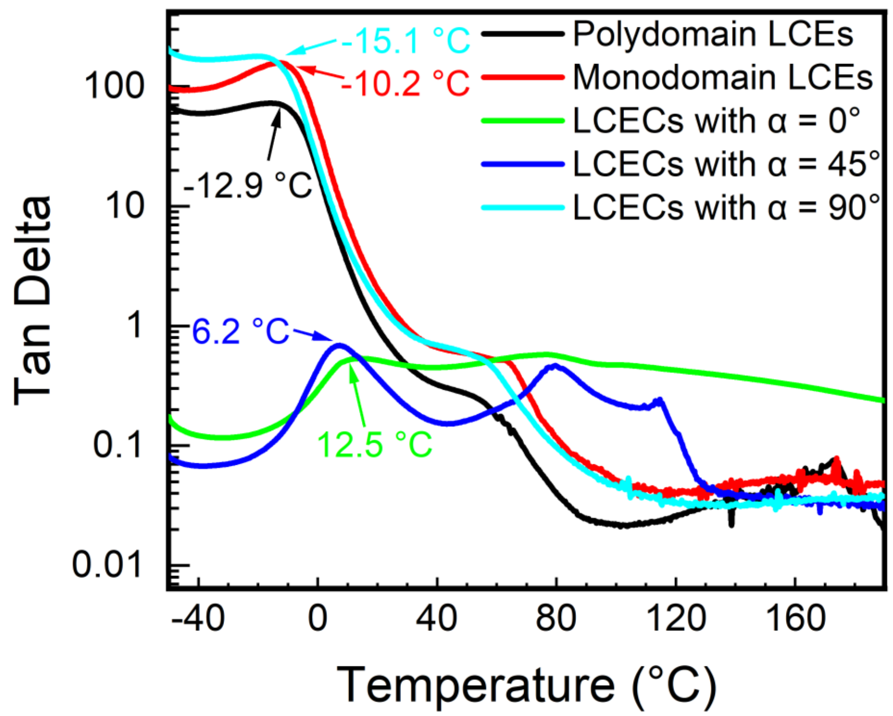
- **Unilateral distribution**
- **An irregularity is apparent within the fiber bundle.**

Results and discussion

--Mechanical property analysis



Storage modulus of LCE composites

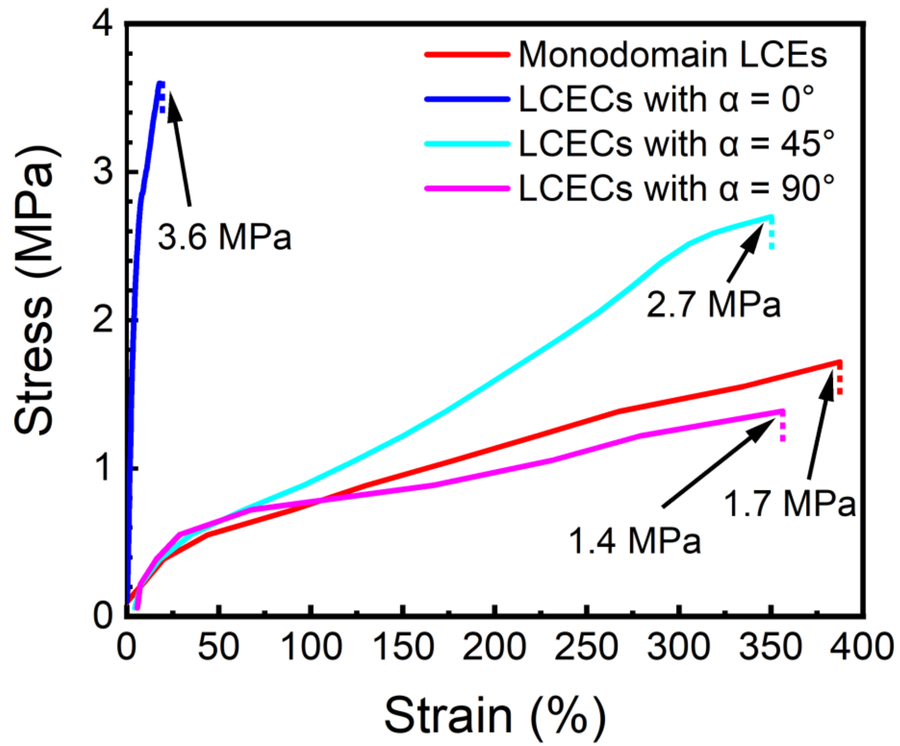


Loss factor of LCE composites

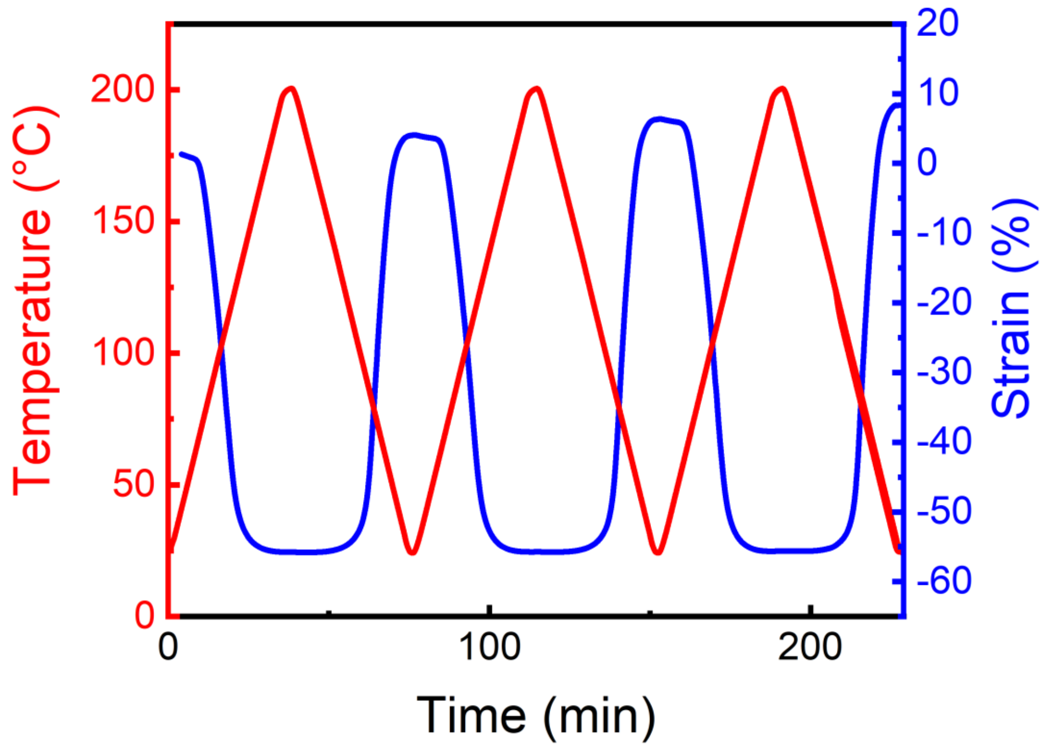
- **The glass transition temperature of LCE composites with angles of α = 90°, α = 45°, α = 0° was found to be -15.1°C, 6.2°C, and 12.5°C, respectively.**
- **A broader peak width indicates a robust interface binding strength between the two, and the motion of chain segments necessitates higher energy input.**

Results and discussion

--Mechanical property analysis



Tensile test of LCE composites

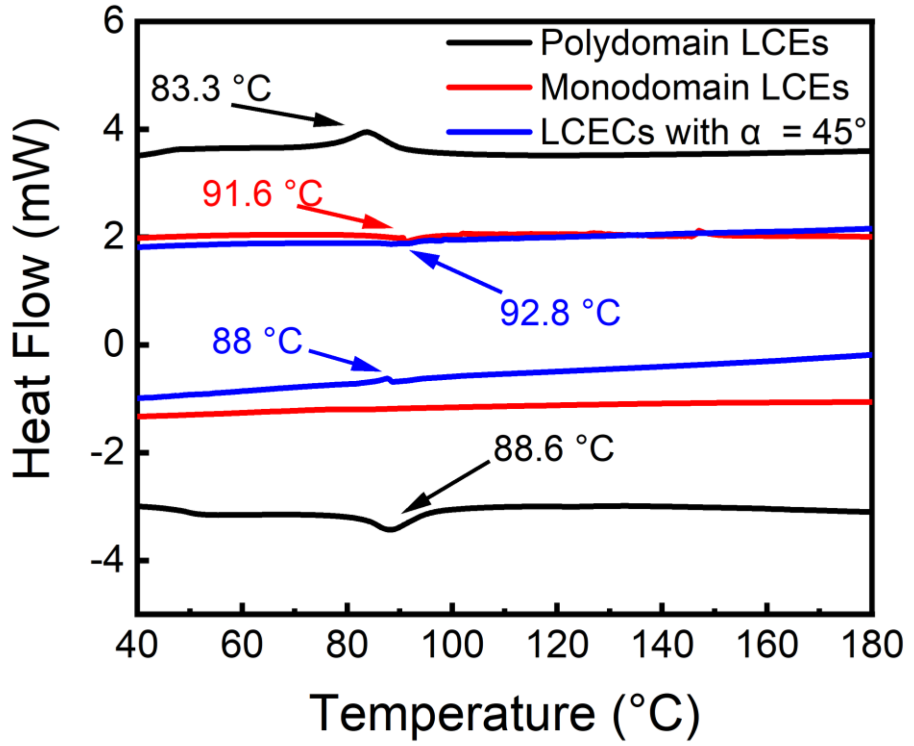


Reversible transformation test

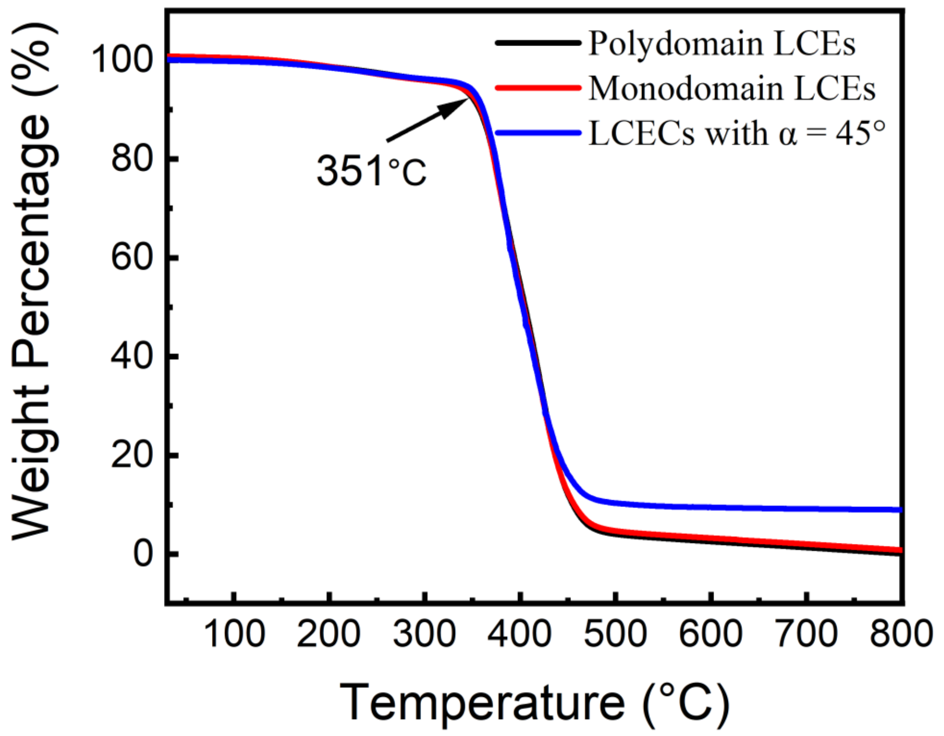
- **The sample displayed a strain up to 350.1 % of 2.7 MPa without broken when α = 45°**
- **A reversible elongation of 57.1% at a stress of 0.2 MPa achieved at 200 °C**

Results and discussion

--Thermo property analysis



Differential scanning calorimeter (DSC) results

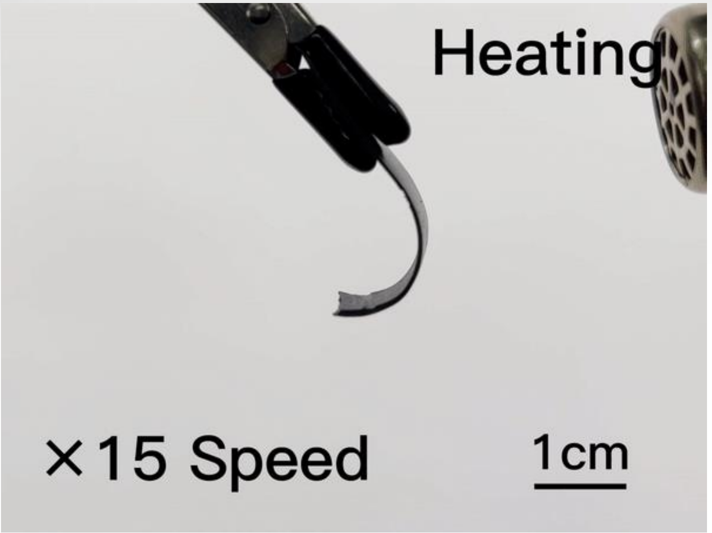


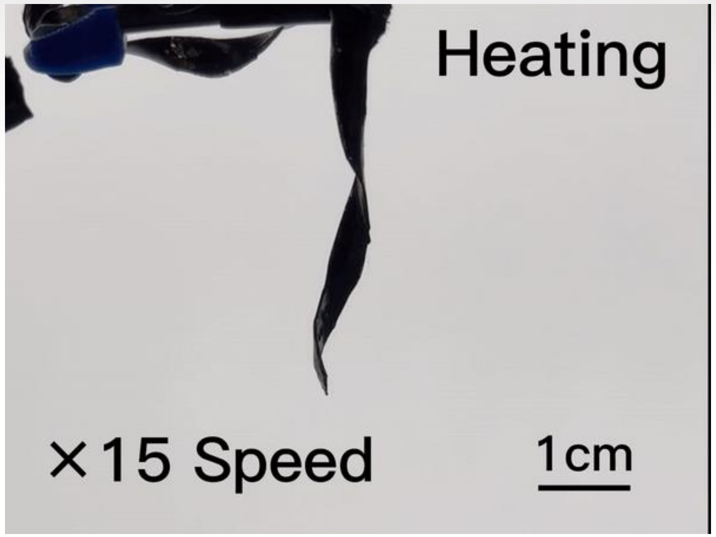
Thermogravimetric analysis (TGA) results

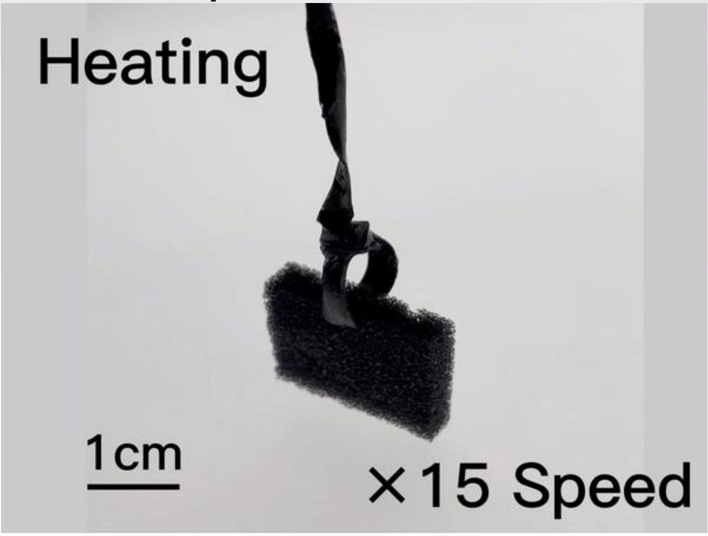
- **The monodomain LCEs owns nemactic-isotropic transition temperature at 91.6°C**
- **The degradation temperature of LCE composites was 351.1 °C**

Results and discussion

--Reversible deformation performance







Bending deformation of LCE composite with α = 90°

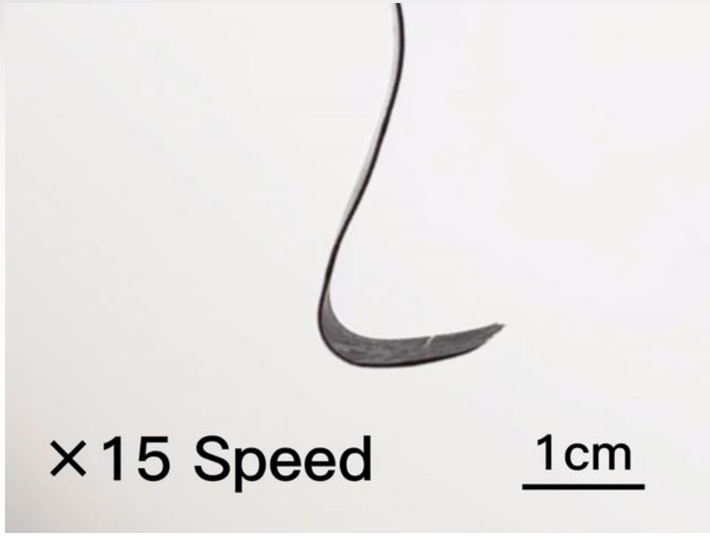
Twisting deformation of LCE composite with α = 45°

Transformation of LCE composite gripper with α = 90° and 45°

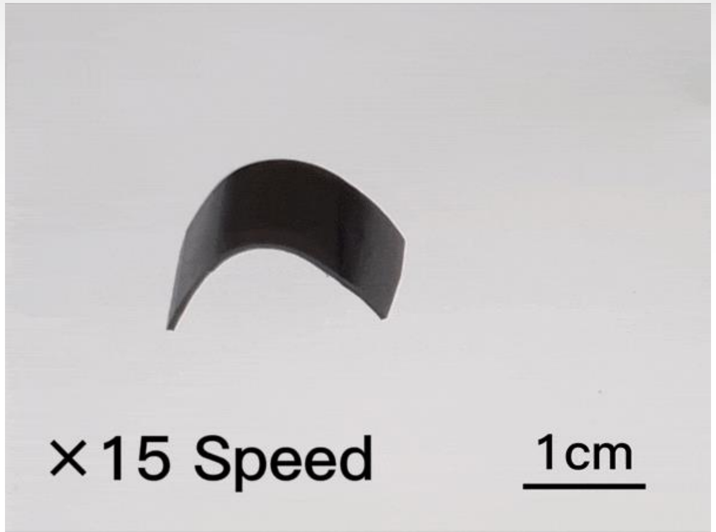
- **The heating process involved the application of a heat gun for 15 seconds at a temperature of 120°C, followed by a cooling period of 20 seconds.**
- **The experiment showcased bending and twisting transformations based on various α angles.**
- **The gripper demonstrated the ability to expand, contract, capture, and release a foam sample weighing 201mg.**

Results and discussion

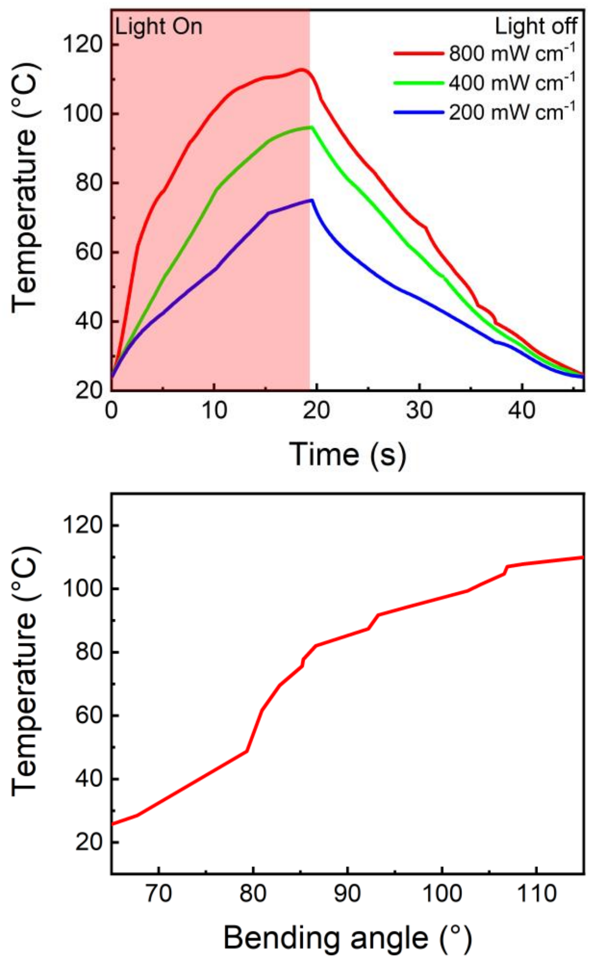
--Reversible deformation performance



Transformation of LCE composite actuator under light



The light-induced inchworm crawling motion of the LCE composite actuator

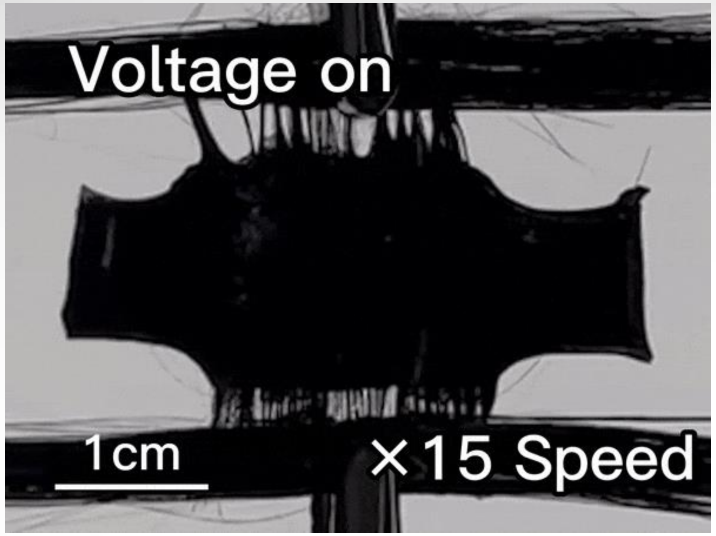


The correlation between temperature, bending angle, and light intensity.

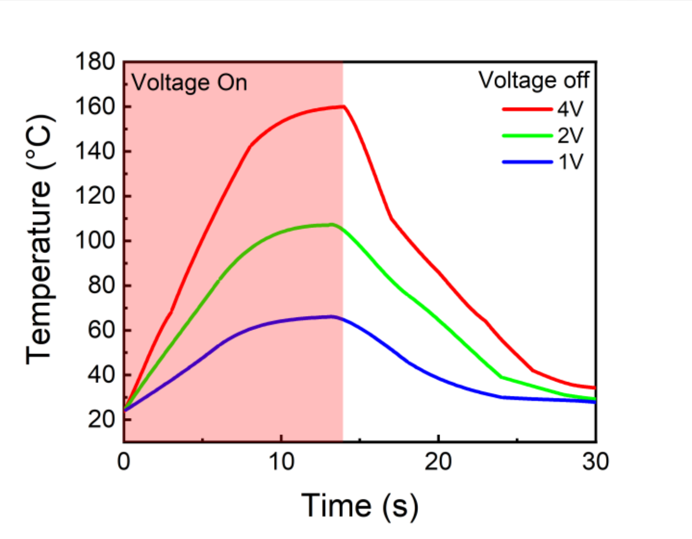
- **Carbon nanotubes have been incorporated into the composite material to facilitate light absorption.**
- **During the aforementioned process, the bending actuator exhibited efficient heat distribution, reaching a temperature of 113.4°C in a span of 21 seconds, and subsequently recovered within 31 seconds.**

Results and discussion

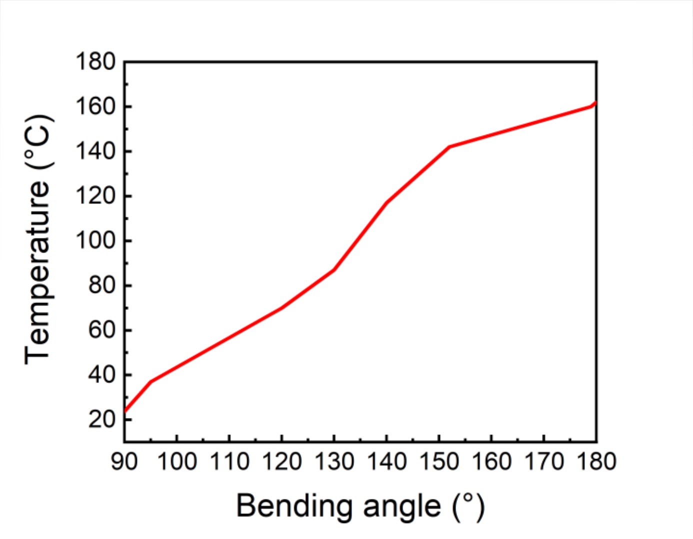
--Reversible deformation performance



Transformation of LCE composite under electricity



Temperature under different voltage

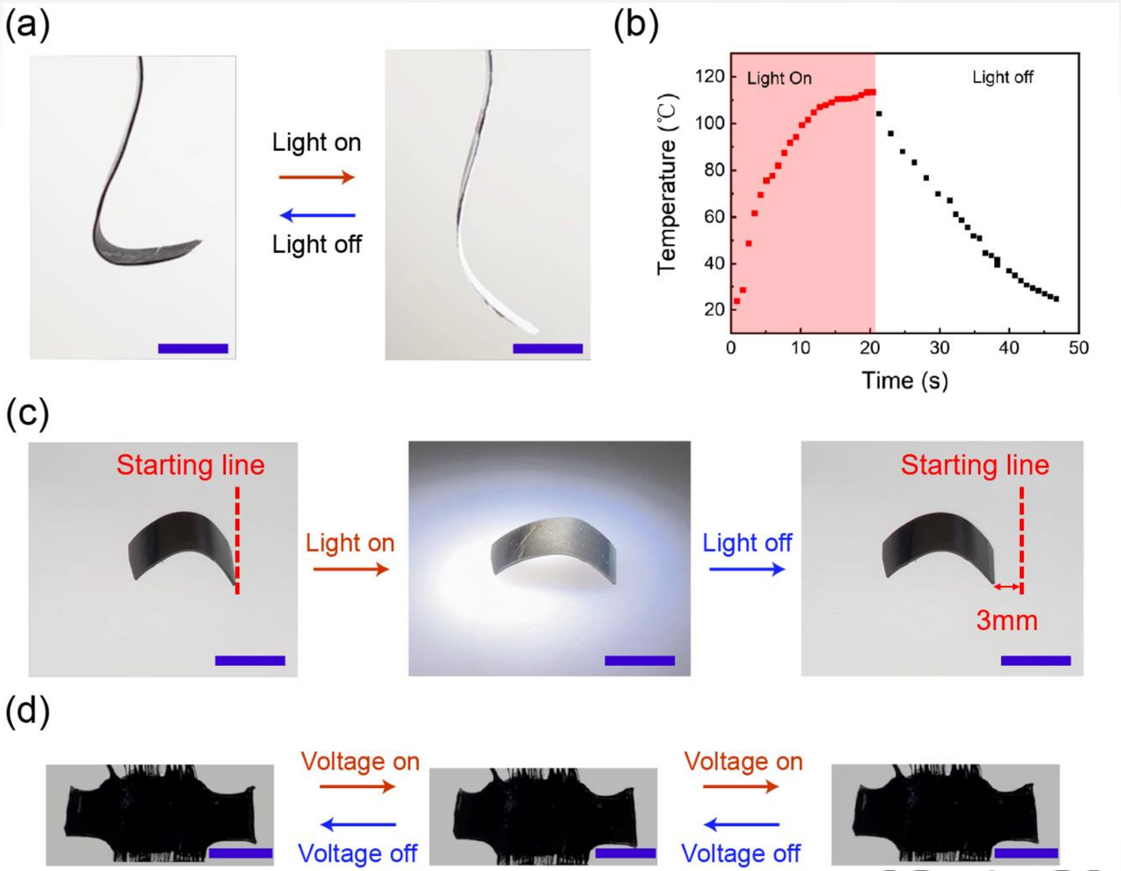


Bending angle under different temperature

- **Continuous carbon fiber has been utilized in the composite material to confer electrical conductivity.**
- **The clamps positioned at both ends of the sample impose limitations on the permissible range of the sample's driving angle.**

Discussion

- LCE composites with varying α angles have been fabricated.
- Upon heating, the LCE composite exhibited bending behavior (at α = 90°) and twisting behavior (at α = 45°).
- To showcase the transformation behavior of the LCE composite, heat, light, and electricity were employed.
- The microscopic mechanism underlying these transformations has been thoroughly examined and discussed.



This work has been published on Composites Part B: Engineering, 2023, 256: 110640

Thanks for your attention!

The center for smart materials and structures, Harbin Institute of Technology, Jun 23, 2018

Questions&Answers?