

# Responsive Liquid Crystal Micro Actuators for Microrobotic Applications

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Program: 2019 Cornell NanoScale Science & Technology Facility Research Experience for Undergraduates (CNF REU) Program

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Primary Source of 2019 CNF REU Funding: National Science Foundation via the National Nanotechnology Coordinated Infrastructure (NNCI) Grant No. NNCI-1542081

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Primary CNF Tools Used: ABM contact aligner, MVD 100, Oxford 81, Unaxis 770 deep Si etcher, Heidelberg mask writer - DWL2000

## Abstract:

Multifunctional micro-sized soft robotics are poised to revolutionize drug delivery, surgical operation and many other biomedical applications. However, building such microrobots with a variety of functionalities is challenging due to the lack of fabrication technologies for responsive materials at the microscale. In this research, we developed a scalable microfabrication technology to build light and thermal activated microrobots using liquid crystal (LC) polymers which are known for their facile response to relatively weak stimuli. First, an ultraviolet light curable precursor containing LC oligomers was developed, allowing for patterning of the LC microrobots via photolithography. Second, fluoroctyl-trichlorosilane-coated silicon microgrooves were used to establish unidirectional alignment in LC microactuators. Finally, heat was applied to confirm the LC microactuators could properly contract along the alignment direction as expected when experiencing a phase transition from the LC to its isotropic phase. These LC microactuators could further bend as hinges if an athermal photoresist was patterned on top, allowing 2D patterned films to fold into 3D objects. Fabricating these LC-based responsive microrobots in a scalable way will provide a powerful platform for dynamically reconfigurable micro-sized origami-robots.

## Summary of Research:

The field of microrobotics presents a promising future for advancements in sensing, surgery, and drug delivery. However, current microrobots are only capable of performing simple functions, such as self-propulsion or particle encapsulation [1]. In order to evolve into multifunctional, controllable devices, it is necessary to develop a new actuation system. In this work, we propose to use of photopatternable responsive liquid crystal (LC) polymer to fabricate micro-scale devices from.

The initial challenge of this project was to develop an ultraviolet (UV) curable LC precursor compatible with photolithography technology. The precursor contained a photoinitiator, a 3:1 molar ratio of LC diacrylate to butylamine, and chloroform as the solvent. To test precursor performance, the substance was spin coated at 1000 rpm, yielding a thickness of 2.5  $\mu\text{m}$ . Exposure to UV light in the ABM contact aligner excited the photoinitiator and a postbake at 90°C released free radicals to complete polymerization [2]. From

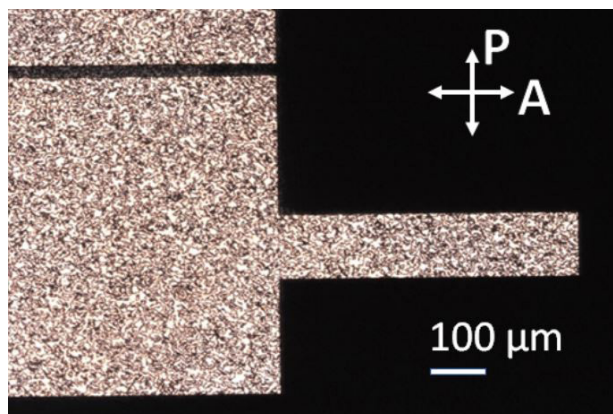


Figure 1: A well-developed LC pattern viewed between crossed polarizers (A and P).

successful samples, features 50  $\mu\text{m}$  and smaller can be observed. However, photopatterning the LC polymer with no initial alignment results in a speckled image when viewed through crossed polarizers (Figure 1).

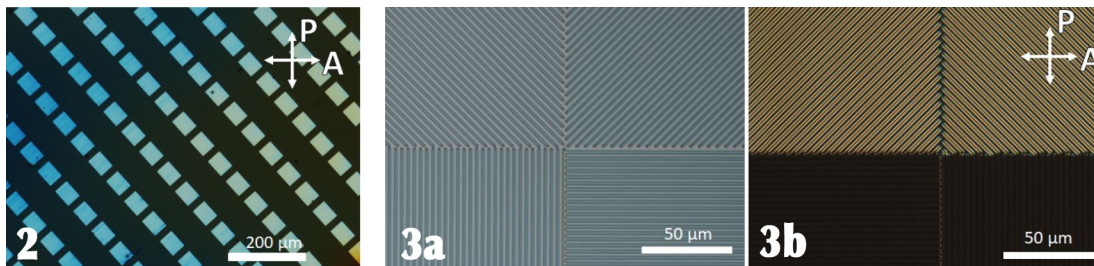


Figure 2, left: Well aligned LC patterns oriented  $45^\circ$  relative to the polarizers. Figure 3, right: (a)  $1.5 \mu\text{m}$  wide and  $1.4 \mu\text{m}$  deep Si grooves with four orientations. (b) Aligned LC on top of etched Si grooves. Birefringent materials appear brightest when aligned  $45^\circ$  relative to the polarizer and darkest when  $0^\circ$  or  $90^\circ$  relative to the polarizer. The black lower half of the image suggests near perfect alignment.

Given no set direction to follow, the LC mesogens align themselves in random orientations.

For an LC polymer actuator to work, it is crucial that the mesogens display predesigned alignment. LC polymers will expand along the direction of average molecular alignment and contract in the perpendicular when transitioning from isotropic to LC phase. Altering the surface architecture was accomplished through two methods. In the first, the substrate was spin-coated with polyimide PI-2555 and physically rubbed with a velvet cloth after a 30-minute-long bake at  $170^\circ\text{C}$ . The LC polymer achieved planar anchoring and aligned along the rubbing orientation. This method proved to be a reliable technique and resulted in few defects (Figure 2). While suitable for aligning simple patterns, such as cantilever beams, it is unable to align the LC polymer in differing orientations. Fabricating a micro robot which can actuate hinges in various directions requires a more versatile micropatterning technique. In the second method, fluorooctyl-trichlorosilane-coated silicon microgrooves,  $1.5 \mu\text{m}$  wide and  $1.4 \mu\text{m}$  deep, were etched to establish an arbitrary alignment (Figure 3a). The LC once again can be aligned planarly along the groove geometry, as visible in Figure 3b.

The final challenge of this work was inducing actuation of the aligned LC polymer in response to heat. Patterned cantilevers were released from the substrate during development in IPA and exposed to  $90^\circ\text{C}$  while still submerged in the solution. LC can only expand and contract in the 2D plane when experiencing a phase transition. However, the combination of a thermal polymer PI-2555 and LC coating proved to be an efficient bimorph, allowing the 2D patterned films to fold into 3D shapes (Figure 4a,b) in response to the elevated temperature. Successful actuations thus far (Figure 4c) have a measured radius of curvature of  $25 \mu\text{m}$ . To further improve the quality of the LC-patterned films, an oxygen plasma etch was required to remove fringes of excess polymer before IPA development. This is to prevent a chain of adhering cantilevers (Figure 4d). Continued work will focus on doping the LC precursor with a photoresponsive dye to induce actuation via light exposure.

The use of responsive LC films is a promising platform for microrobotic actuation. Not only has this work shown it is possible to fabricate LC films with available nanofabrication technology, but it is possible to align the polymers through patternable microgrooves as well. Future development of these actuators may lead to new fields of reconfigurable origami-based microrobots.

#### Acknowledgements:

I would like to thank Professor Itai Cohen, Qingkun Liu, and the CNF staff for their support this summer. This work was carried out as part of the 2019 CNF REU Program and supported by the National Science Foundation (Grant No. NNCI-1542081).

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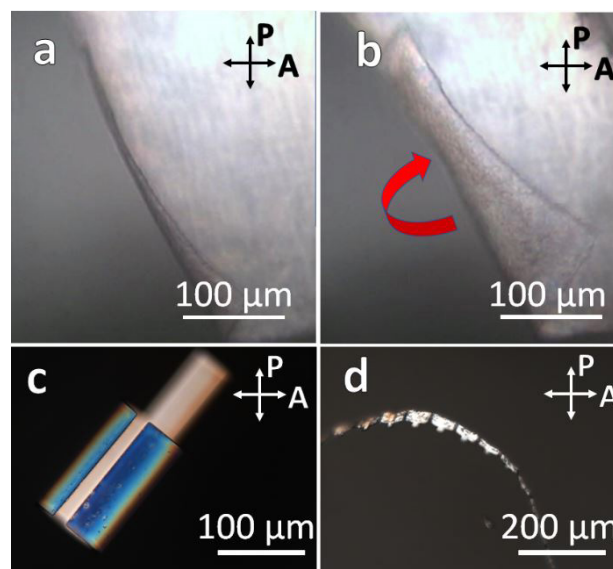


Figure 4: (a) Cantilever edge at  $60^\circ\text{C}$ . (b) Cantilever edge at  $90^\circ\text{C}$ . (c) A curled cantilever pattern. (d) A connected chain of released cantilevers.