

Thermoplastic Sheets that Produce Gaussian Curvature from Light

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Abstract

Stimuli-responsive materials that transform planar sheets to three-dimensional (3D) geometries find use in a variety of technical fields ranging from robotic surgery to aerospace engineering. Being able to control accurately the shape change from planar sheets to complex 3D structures is crucial in generating functional devices. Polymers represent ideal materials for stimuli-responsive devices based on their fast actuation times, responsiveness to a variety of stimuli, and economic feasibility. We use planar, polystyrene sheets (0.3 mm thick) that are pre-strained to shrink in-plane by ~55% when heated uniformly above its glass transition temperature (~103°C). These polymer sheets are patterned with black ink from an inkjet printer and exposed to either an IR or LED light. The patterned portions of the polymer sheet preferentially absorb external light, resulting in localized heating in the patterned regions, where they produce localized strain gradient through the thickness of the material. This strain gradient generates out-of-plane deformation, which can be controlled by dictating the ink distribution across the polymer surface. Finite element analysis was used to predict the resulting out-of-plane deformation based upon the ink pattern. This fast and controllable conversion from initially 2D materials into 3D geometries represents a desirable platform to develop functional applications.

Initially, we employed this self-folding system to generate sharp folds for geometric structures such as cubes or pyramids. In this talk we will focus on generating and controlling Gaussian curvature to produce more complex structures, such as spheres or gripping devices. We use an indirect and direct method of heating to study the final curvature of the polymer sheet. We form spherical structures by utilizing IR- and LED-triggered actuation mechanisms, in conjunction with spatial placement of ink on the specimen, showing that exposure to IR light leads to structures with higher fidelity. We developed and applied a simple geometric model to explain the formation of a curved shape for each actuation light source yielding excellent visual agreement with experimental results. Figure 1 demonstrates the shape change from planar to spherical structures.

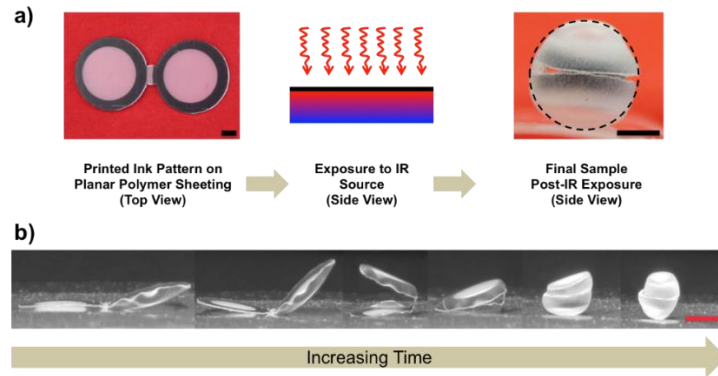


Figure 1: (a) Stimuli-responsive planar, polymer sheets are patterned with ink from an inkjet printer and exposed to an IR light to initiate Gaussian curvature. The red to blue color scale indicates regions of higher and lower temperature, respectively. (b) A time lapse depicting the shape change of the polymer sheets with a total time of < 10 seconds. The scale bars represent 2.5 mm (a) and 5.0 mm (b).

In addition to generating Gaussian structures, we have demonstrated the ability to combine both folding and curvature into a single device. This combination allows for a new level of functionality, previously unattainable with either folding or curvature alone. Gripping devices are produced with a wide range of ink patterns and geometries, resulting in the ability to grasp and hold objects > 24,000 times the mass of the individual polymer samples. Figure 2 demonstrates the ability of the grippers to pick up an object. Being able to produce controllable curvature from planar starting materials for these types of functional devices will lead to many new applications.

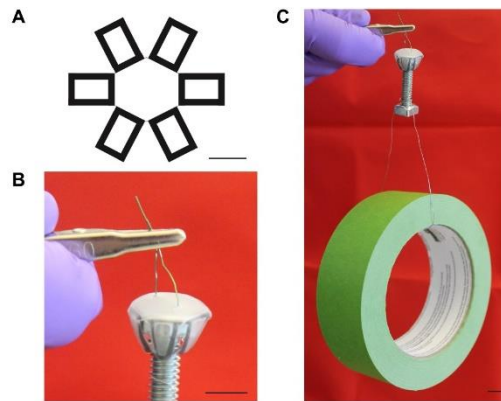


Figure 2: (a) A six-panelled, rectangular geometry produces viable gripping devices. A close up (b) and full view (c) of the gripper attached around the head of a bolt and withstanding the weight of a roll of tape with no visible deformation to the gripper. The scale bars represent 10 mm.