Three-dimensional structures from electrically-activated self-folding of polymer sheets

James D. Turner and Dr. Yong Zhu

Department of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, NC

Motivation

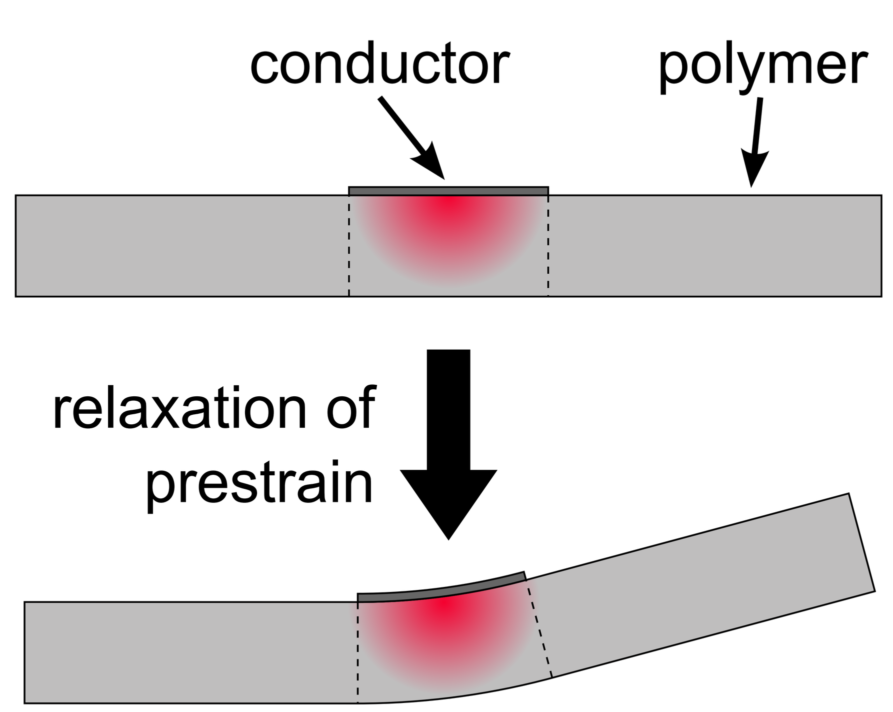
- Some current applications of folding include vehicle airbags, heart stents, portable kayaks, and solar panels for rocket-launched probes and satellites
- *Self-folding* in response to an external stimulus is particularly useful in remote areas or on a small scale
- Current approaches for self-folding are complex and expensive or limited in their versatility
  - Localized light absorption for thermal activation
  - Separate actuators for stiff plates with flexible joints
  - Photoactive and electroactive polymers

Objective

- Develop a method for simple, autonomous, electrically-activated folding of polymer sheets.

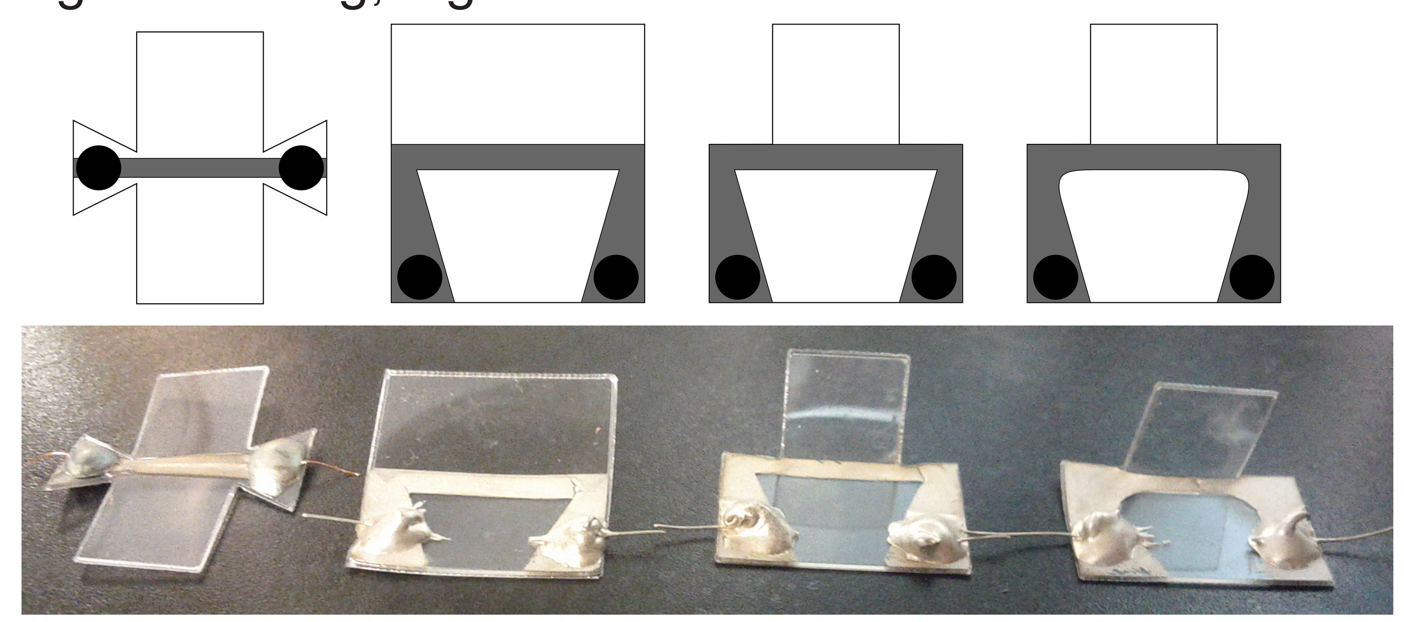
Approach

- A polymer sheet is heated above its glass transition temperature T_g and stretched in-plane, then cooled back to room temperature while still in a strained state
- If completely heated above T_g, the polymer sheet would shrink to its original size
- A silver nanowire conductive film functions as a flexible resistive heater on one side of a desired crease line
- Heating results in a temperature gradient through the sheet such that one side exceeds T_g
- Relaxation of the region above T_g results in folding



Results

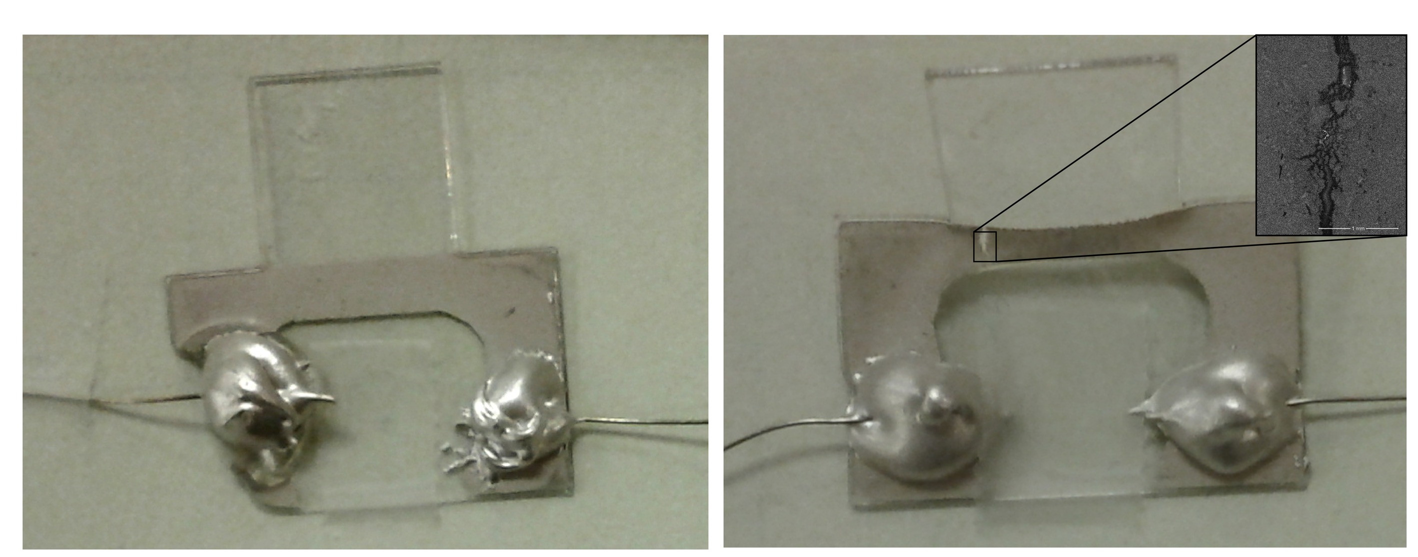
- Evaluated many alternative patterns for reliability and angle of folding, e.g.:



- Also varied thickness of nanowire conductor, nanowire solvents, environmental temperature during folding, and rate of increase of applied current
- Most failures occurred at the interface between the electrical contacts and nanowire conductor
- Failures in the nanowire conductor itself most frequently occurred near sharp changes in geometry
- Most reliable design works ⅔ of the time, often achieves folding angles as large as 90°

Failure Mechanisms

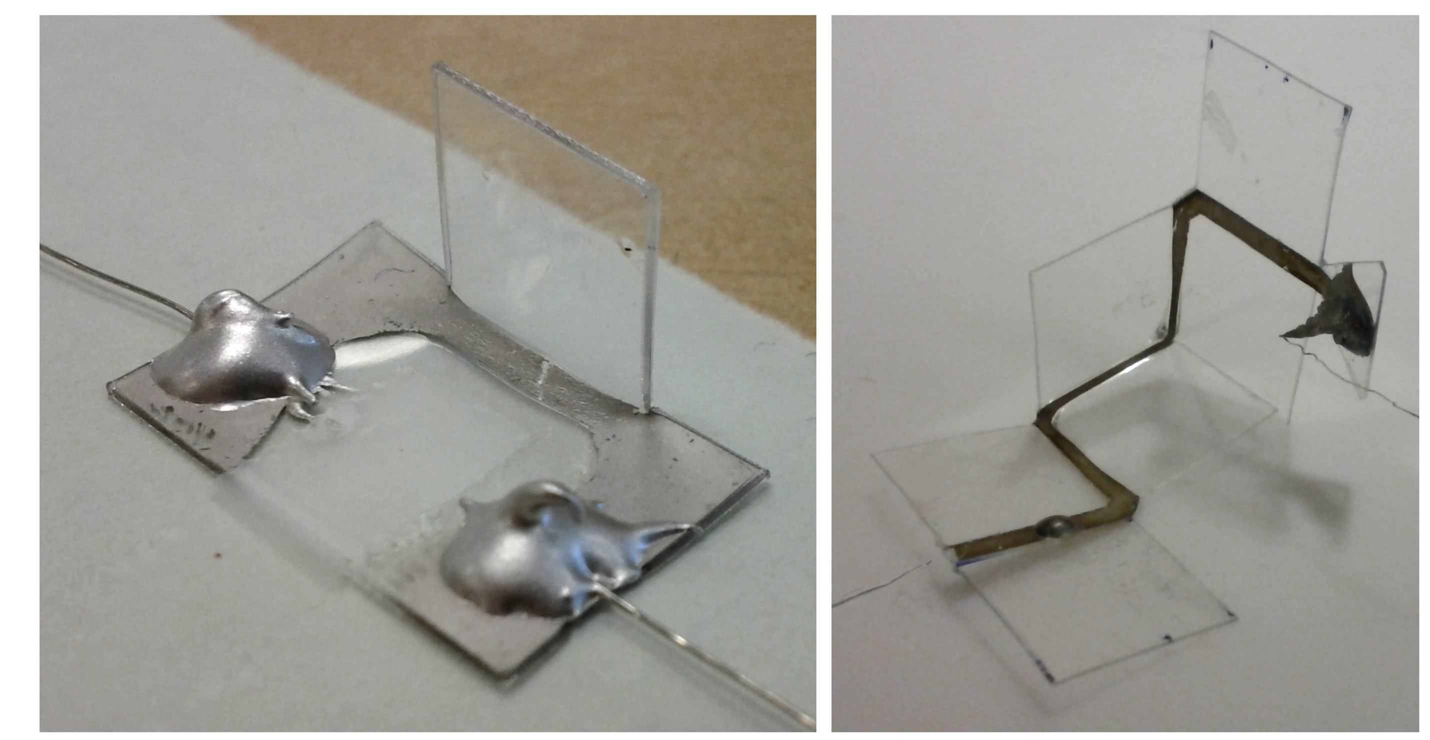
- Failure occurs when the electrical heating circuit is broken, which can be caused by the following:
  - Overheating at the interfaces between electrical contacts and the nanowire conductor
  - Mechanical failures in the nanowire conductor
  - Fuse-like failures in the nanowire conductor



Failure at contact interface (left) and fuse-like failure (right)

Conclusions

- This simple approach allows for automatic creation of complex 3-D structures from 2-D sheets
- Reliability is the most significant issue, improved by:
  - Rounding out sharp corners
  - Accounting for nonuniform temperature distribution in the nanowire conductor
  - Placing stiff electrical contacts away from creases



Two successful samples; the one on the right is a partially-folded cube

Future Work

- More complex folding patterns and shapes
- Investigate the folding angle and the resistance of the conductor as a function of time during folding
- Measure the temperature distribution in the conductor
- Improve resilience of the nanowire conductor by adding a viscous matrix for support
- Integrate a secondary electrical circuit for a light, sensor, etc., that continues to work after folding

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