Laser Cutter Fabrication of Repulsive-Force Electrostatic Actuators

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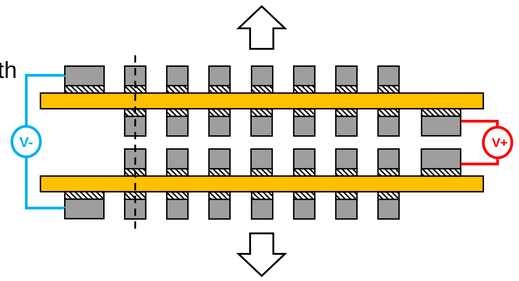
Abstract In recent years, a new class of planar, repulsive-force electrostatic actuators have been designed in the millimeter to centimeter scale. These actuators consist of layers with two conductive electrodes separated by an insulating film. By stacking multiple layers and charging to high voltages (1000-5000 V), these layers produce a repulsive force and separate. Previous fabrication methods use a relatively expensive and time consuming flex-PCB manufacturing process, which entails etching copper-coated plastics into the desired electrode patterns[1]. This research aims to create the same actuators using the faster, easier, and more cost-effective process for assembling the layers: laser cutting the electrodes from a metallized plastic film or metal sheet and laminating them onto an insulating film substrate. Fabricated actuators successfully generated >4 mN of force at 1000 V, and are then used to power a centimeter-sized mobile robot.

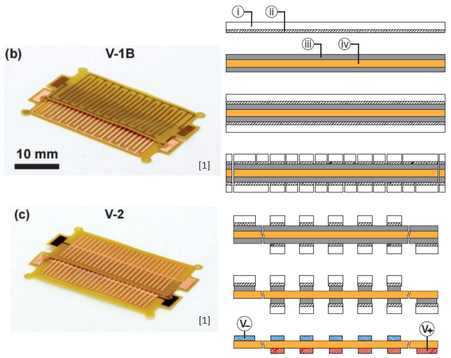
Introduction / Background

Design/Operation

- Actuator layers consist of:
  - 2 conductive films with desired electrode patterns
  - 1 insulating dielectric film substrate
- By stacking multiple layers and charging to 1000-5000 V, the layers produce a repulsive force



Prior Process Flex Circuit Manufacturing Process etches electrode design onto copper foil using ferric chloride ($FeCl_3$)

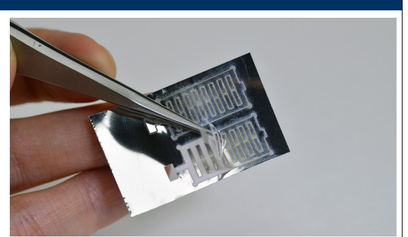


Goals

- Create a faster, cheaper process for manufacturing the actuators
- Good for prototyping
- Useful for low-force actuation, sensing, and applications in mobile robots

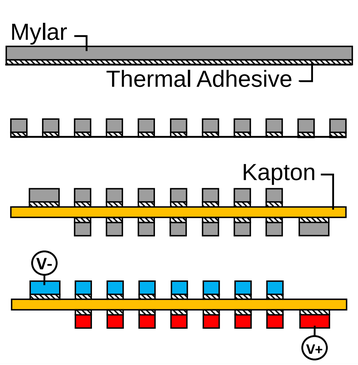
Methods

25 µm Kapton film



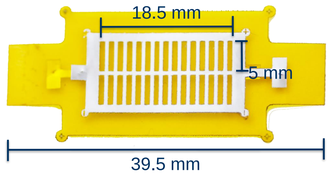
25 µm metalized Mylar w/ Thermal Adhesive

1. Laminate thermal adhesive onto Al-coated Mylar (25 µm thick) or Stainless Steel (12 µm) sheet
2. Laser cut electrode pattern in Al-coated Mylar or Stainless Steel
3. Peel, align, and place electrodes on both sides of insulating Kapton
4. Laminate the stack and attach power lines

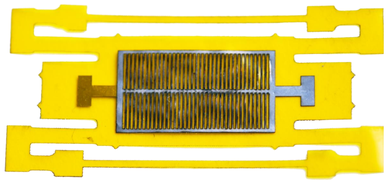


Resistance Testing

Final Actuators

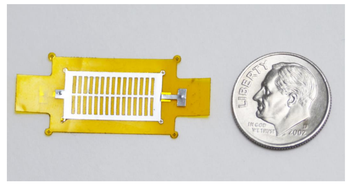


Al-Coated Mylar Actuator



Stainless Steel Actuator

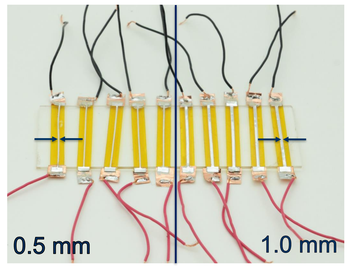
Al-Coated Mylar Actuator layer compared to a dime



Mylar Resistance Testing

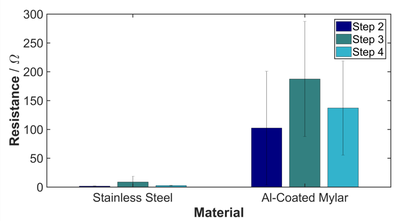
25 µm metalized Mylar

- 0/5 of the 0.5 mm bars were conductive (breaks in wire)
- 3/5 of the 1.0 mm bars were conductive (1200 Ω average)
- Aluminum coated Mylar is very susceptible to scratches and breaks that reduce conductivity

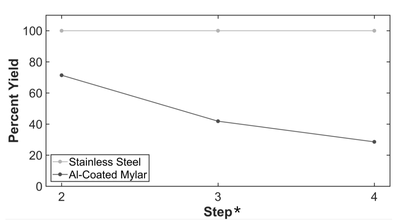


Actuator Resistance Testing

Resistance Measurements



Resistance Yield

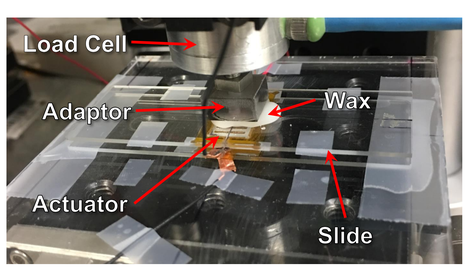


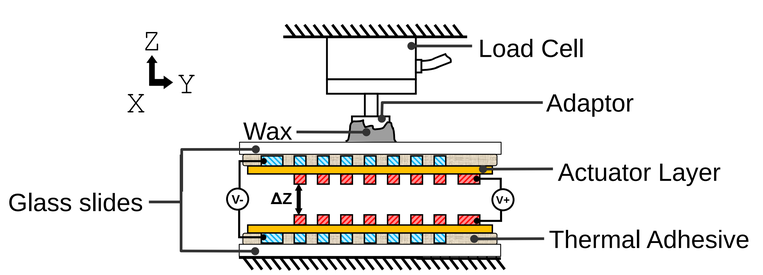
Stainless Steel actuators have superior conductivity and yield to Al-coated Mylar actuators. (* Steps are referred to in "Methods" section)

Force Testing

Force Testing

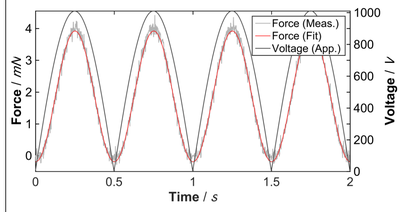
Testing setup for blocked force characterization, with photo (top) and mechanical diagram (bottom)



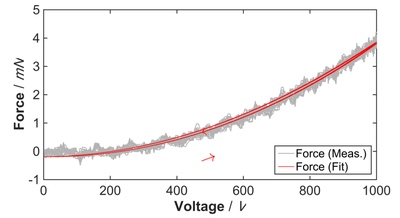


Force Testing Results

Force & Applied Voltage vs. Time
(measured and sinusoidal fit)

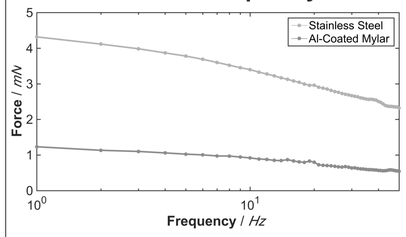


Force vs. Voltage
(measured and sinusoidal fit)
Unfiltered, periodic peaks are 60 *Hz* noise



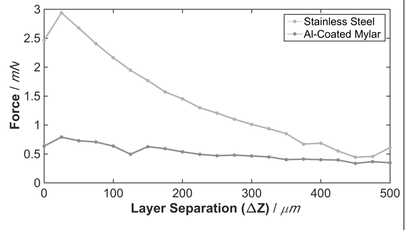
- Force correlates quadratically with voltage; the greater the voltage, the greater the repulsive force.
- Voltage and force peaks occur at the same time
- Maximum repulsive force (4 mN) is generated by the two layers with a separation of ΔZ = 50 µm and charged to 1000 V

Force vs. Frequency



As frequency increases, the force decreases by approximately 50%.

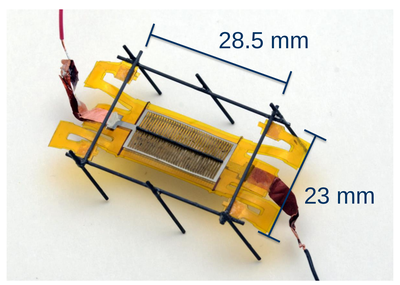
Force vs. Z-Axis Offsets

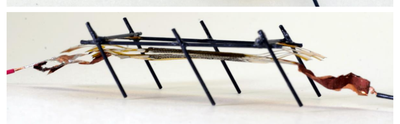


Square-root of sinusoid inputs at 2 Hz / 1000 V peak-to-peak

Application

- A low-cost, easy to assemble robot powered by a flexible repulsive force electrostatic actuator
- Robot frame assembled from 0.67 mm diameter carbon fiber rods aligned in a 3D-printed jig
- Actuator suspension adhered to robot frame
- Actuator powered by off-board high voltage power supply





Future Work

- Create a lighter robot using thinner carbon fiber rods and wires

References

[1] E. W. Schaler, T. I. Zohdi, and R. S. Fearing, "Thin Film Repulsive Electrostatic Actuators", *In Review*.

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