Microhydraulic Actuation

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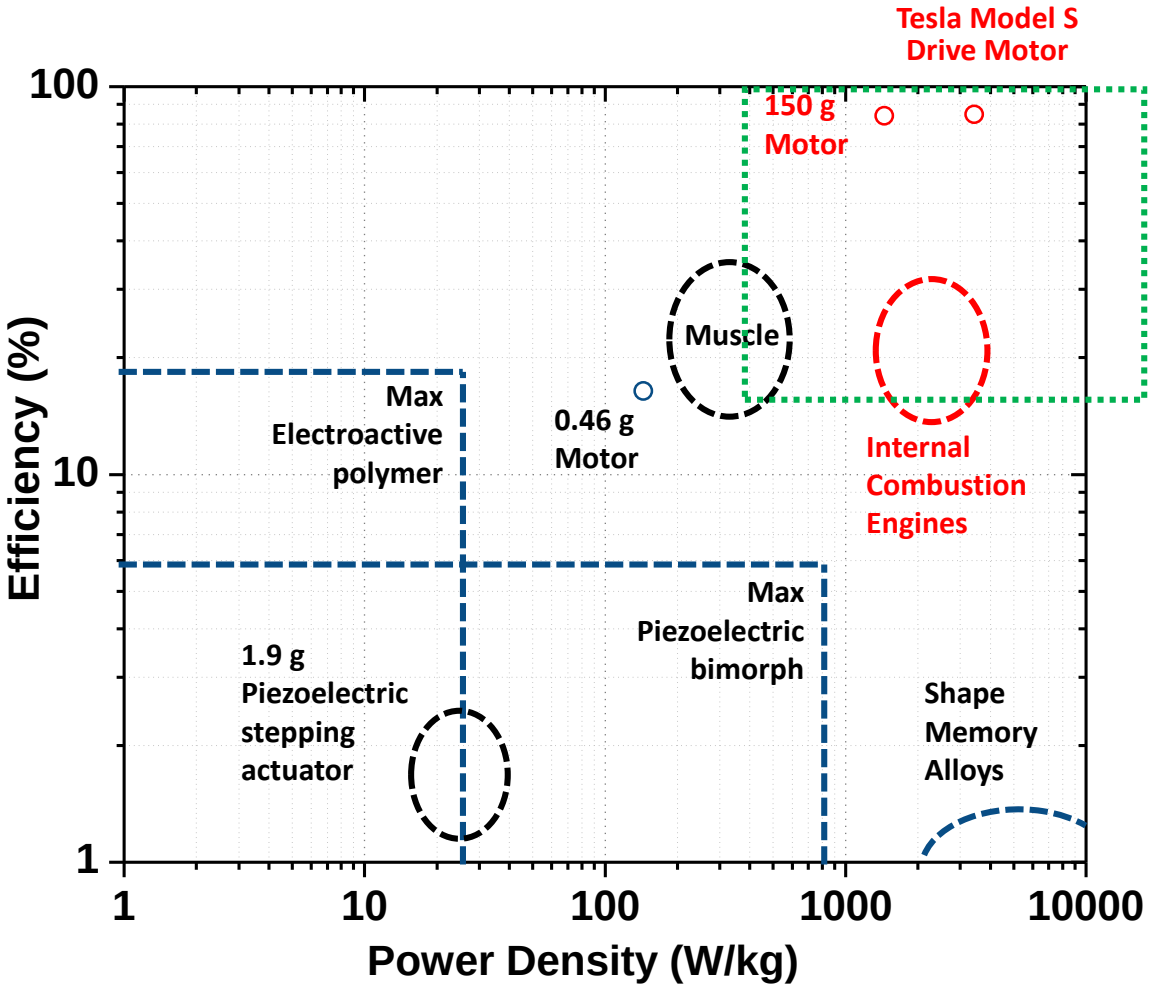
Actuator Landscape

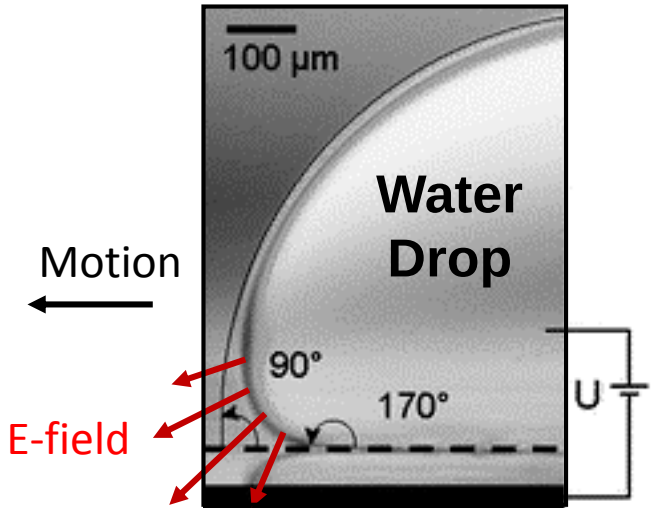
- Power density and efficiency are desired characteristics for all actuators, but no micro-actuators have both
- Our goal: Build an efficient and powerful micro-actuator

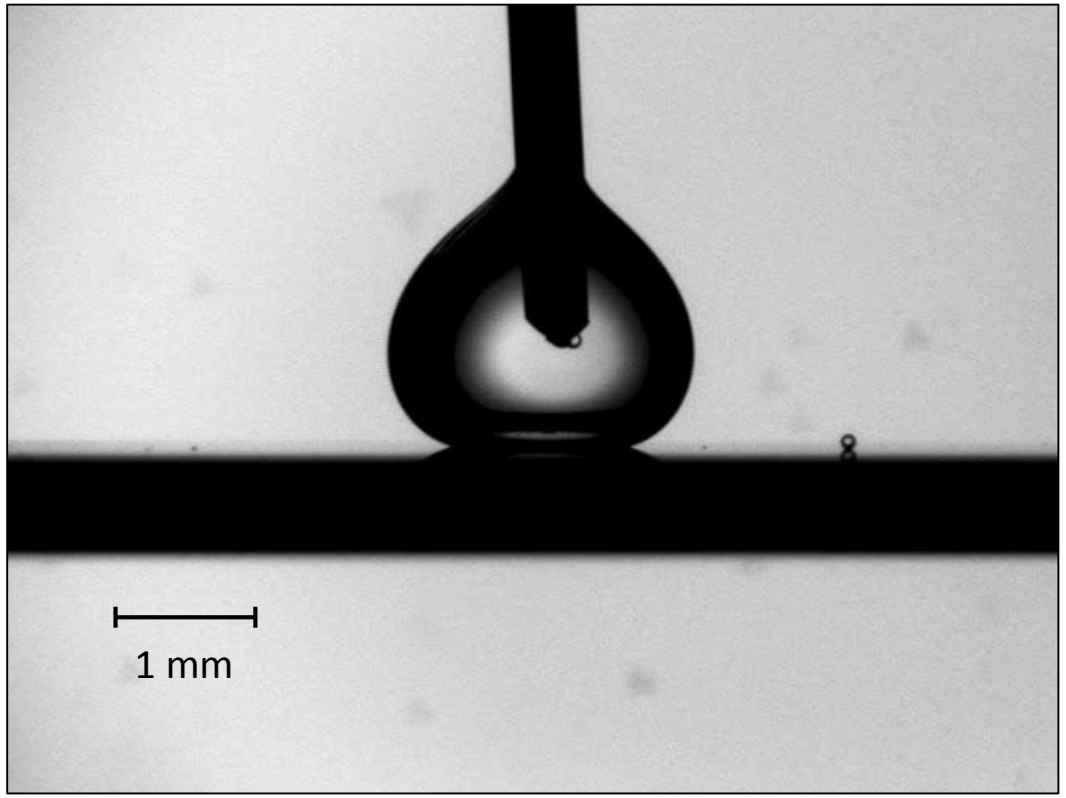


Macro-actuators
Micro-actuators

Physical Basis – Electrowetting

- Surfaces can electrically change from hydrophobic to hydrophilic



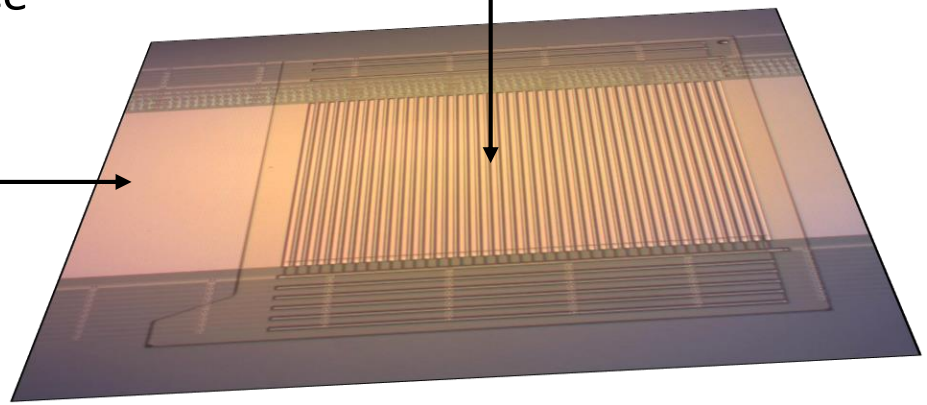


Electrowetting of a water drop in oil

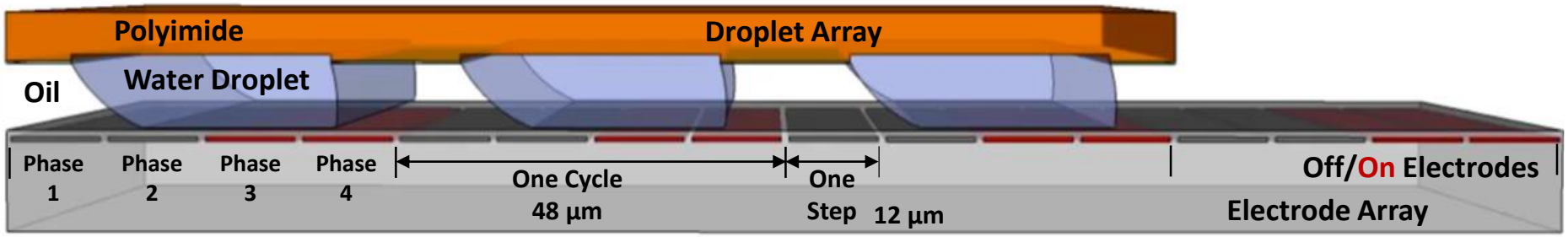
Actuator Structure and Operation

- Actuator consists of a glass electrode array and a polyimide droplet array separated by a droplet layer
- Electrodes can distort droplets to produce a net force moving the droplet array

Droplet Array
Thin (5–10 µm) polyimide
with water droplets attached

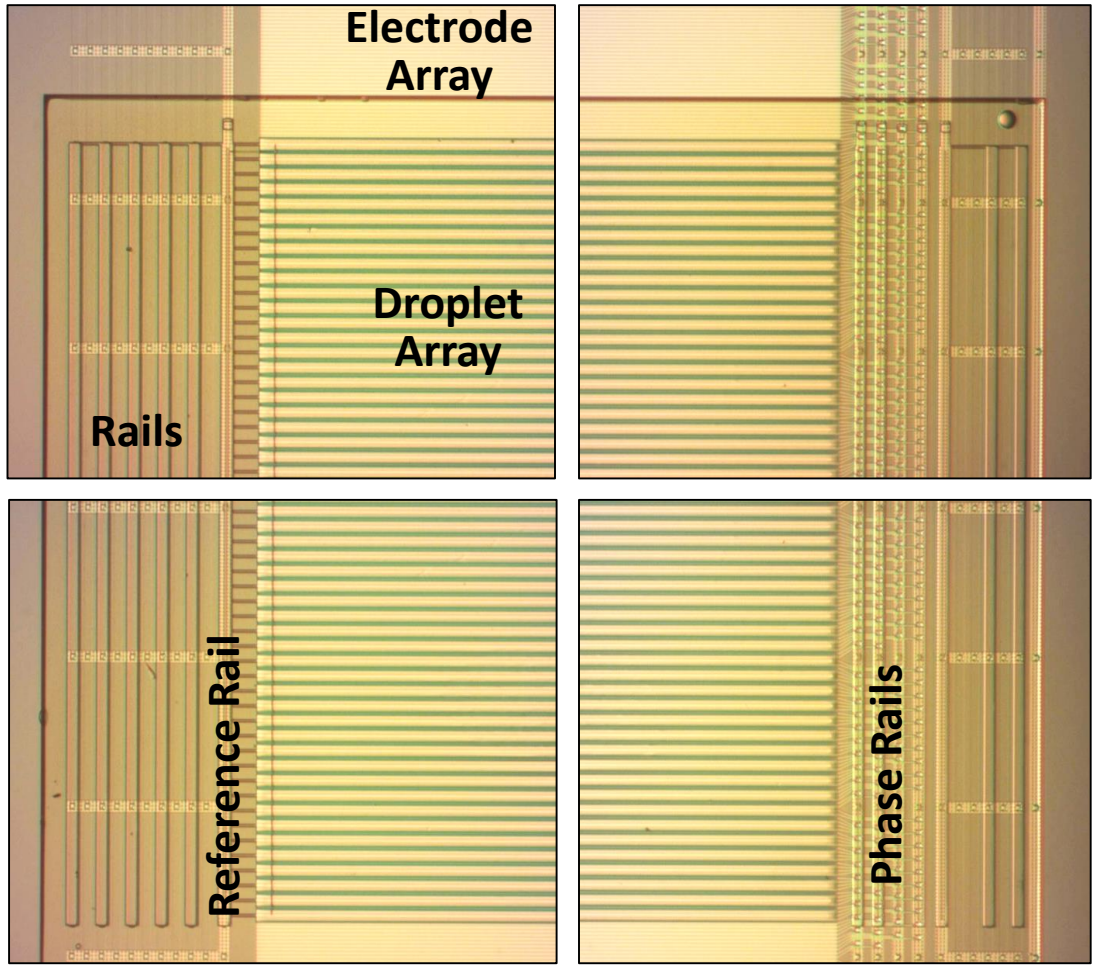


Electrode Array
Multi-phase electrodes with an
electrowetting dielectric



Actuator at Rest

- When brought in contact, droplet array and electrode array snap together and self-align
- Contact fixes the location in two dimensions
  - X position is fixed by rails
  - Z positon is fixed by droplet height
  - Y position is free for translation



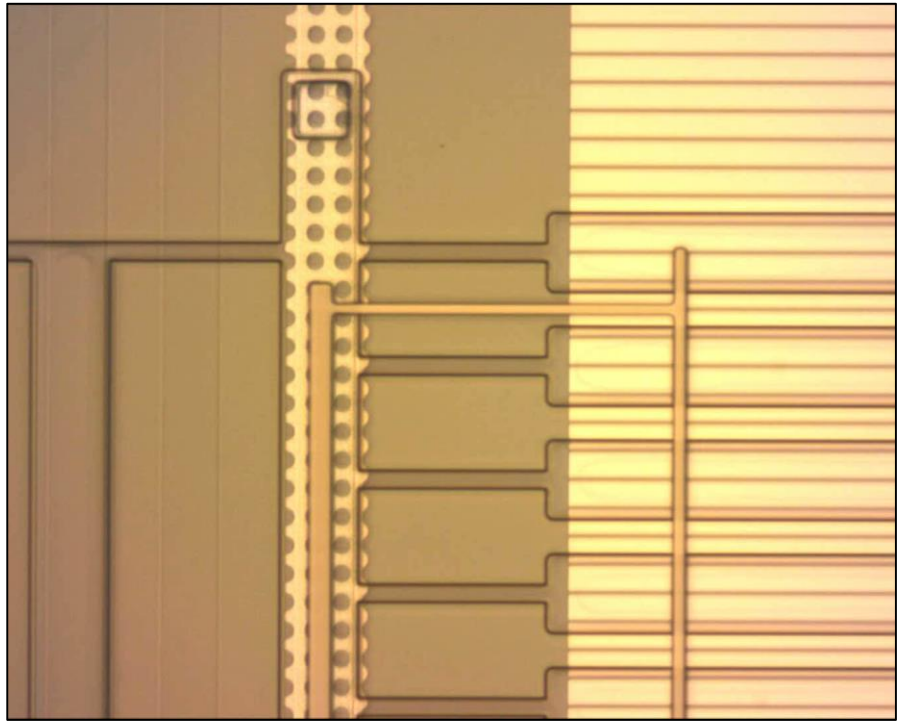
250 µm

Actuator in Motion

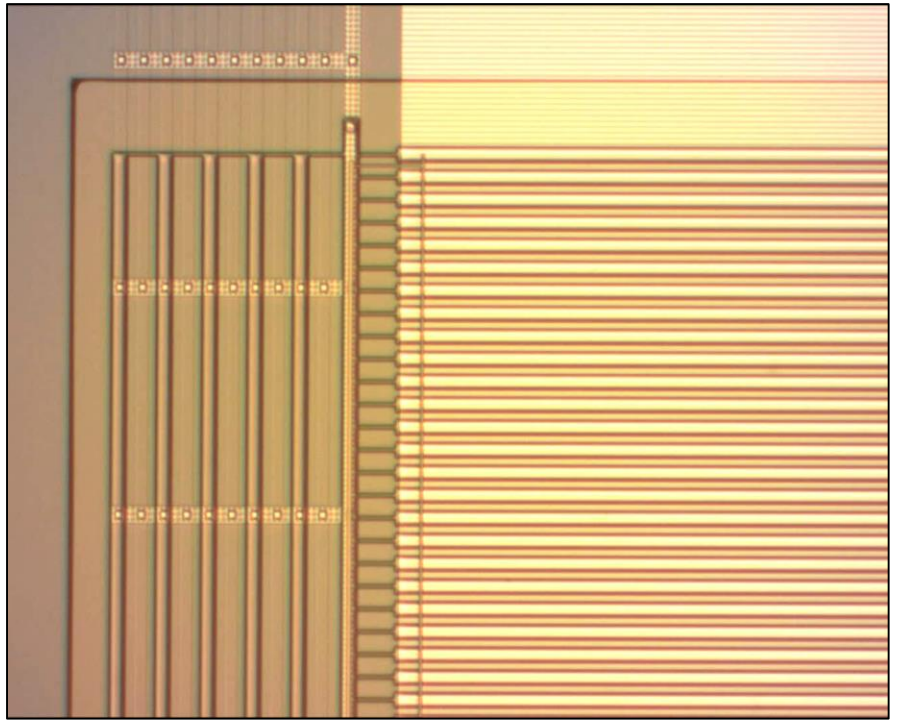
Slow Linear Actuation

Step Frequency 5 Hz

50 µm



Precision	1 µm
Accuracy	12 µm
Max Step Frequency	16000 Hz
Max (unloaded) Velocity	192 mm/s



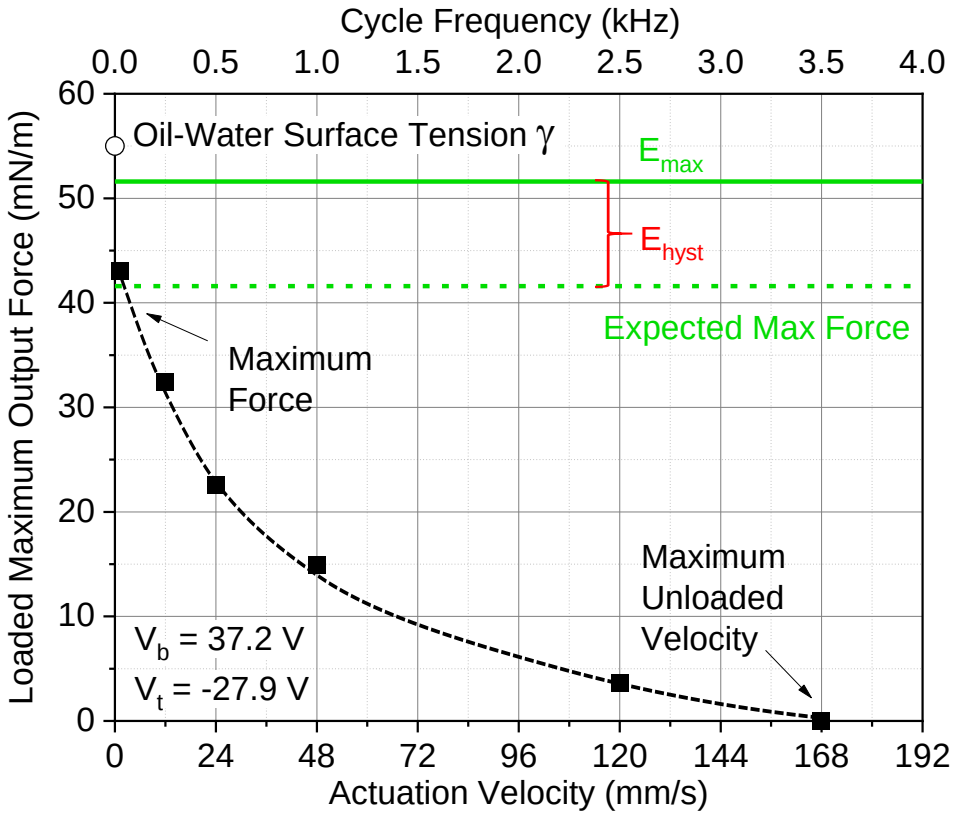
Fast Linear Actuation

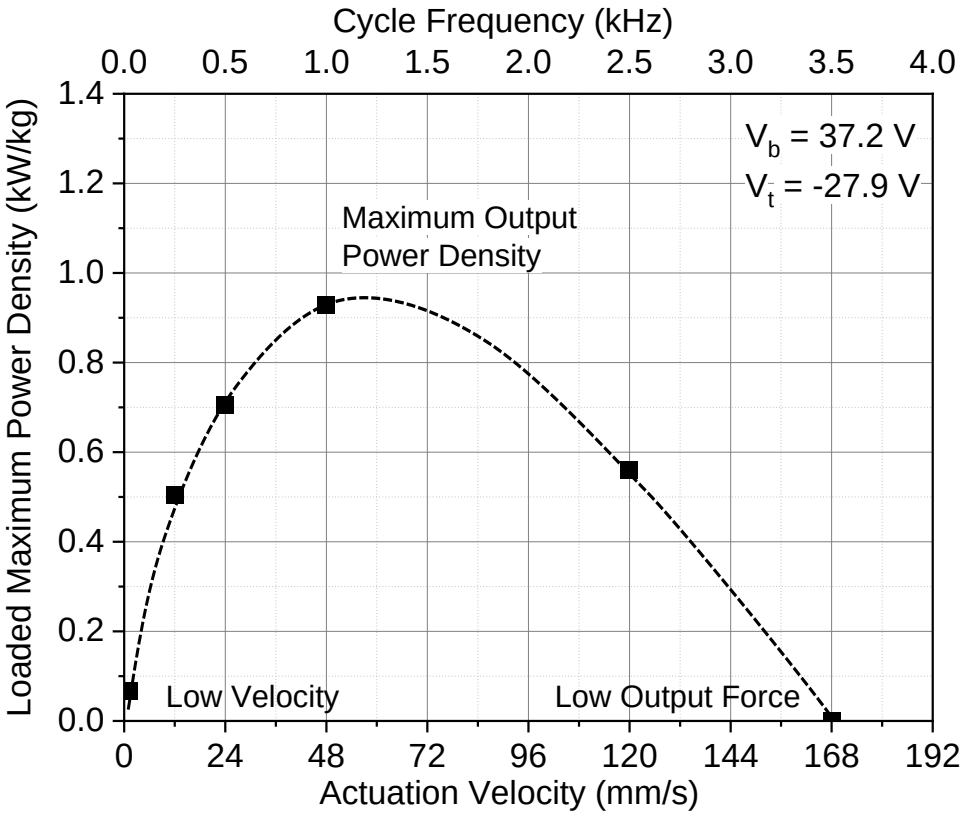
Step Frequency 4000 Hz 20 cyc

250 µm

Acceleration	3.07 km/s^2
Max Force/Weight Ratio	5500
Max Power Density	1 W/g
Efficiency at Max Power	60%

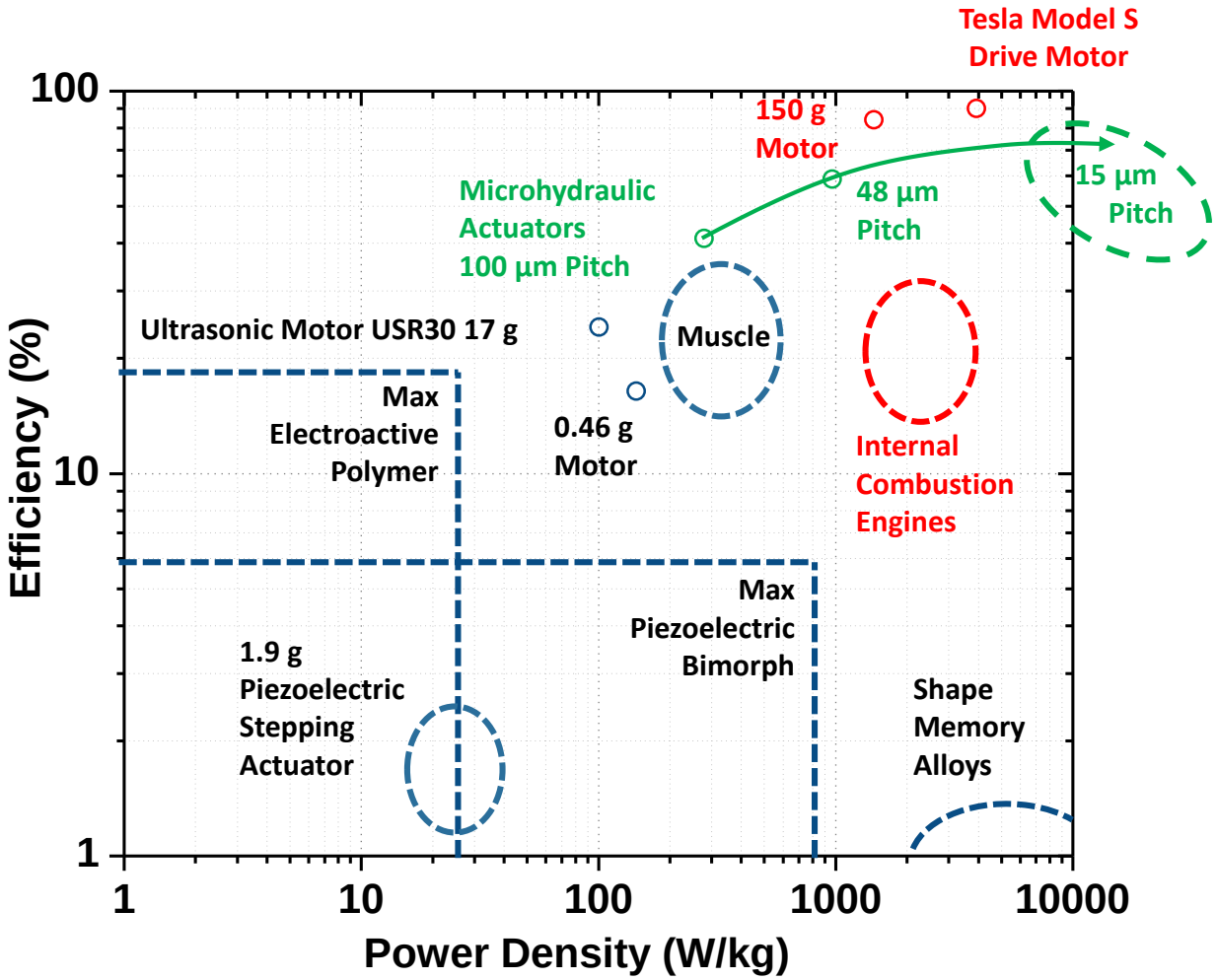
Mechanical Characterization



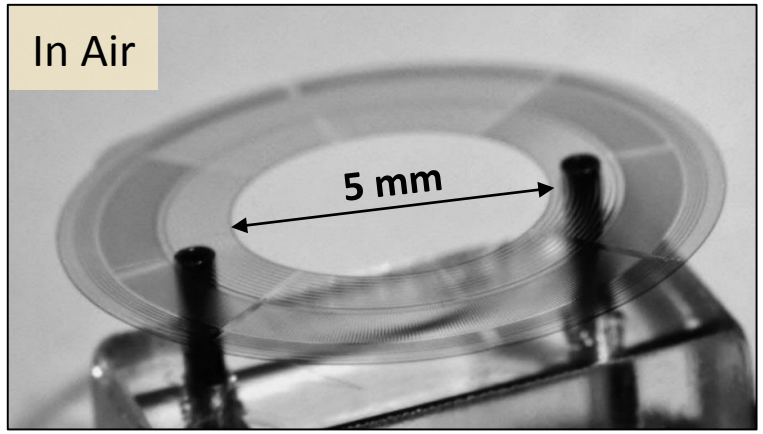


Efficiency and Power Density

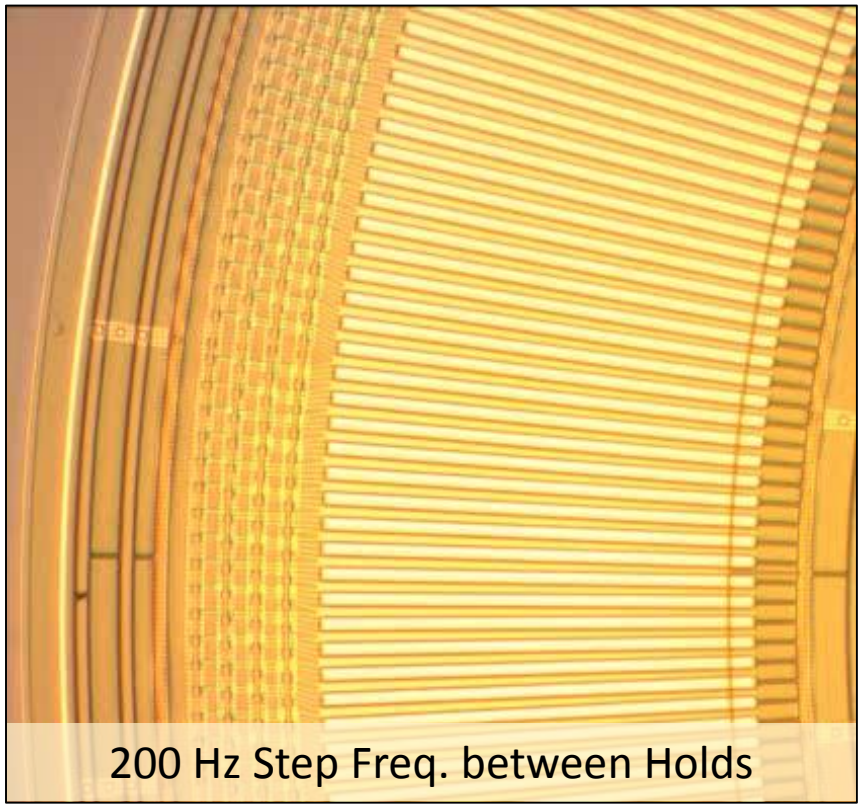
- Power density of the 48 µm pitch design is already comparable to electric motors
- Scaling improves power density at a quadratic rate
  - Projected power density at 15 µm pitch is ~10 W/g

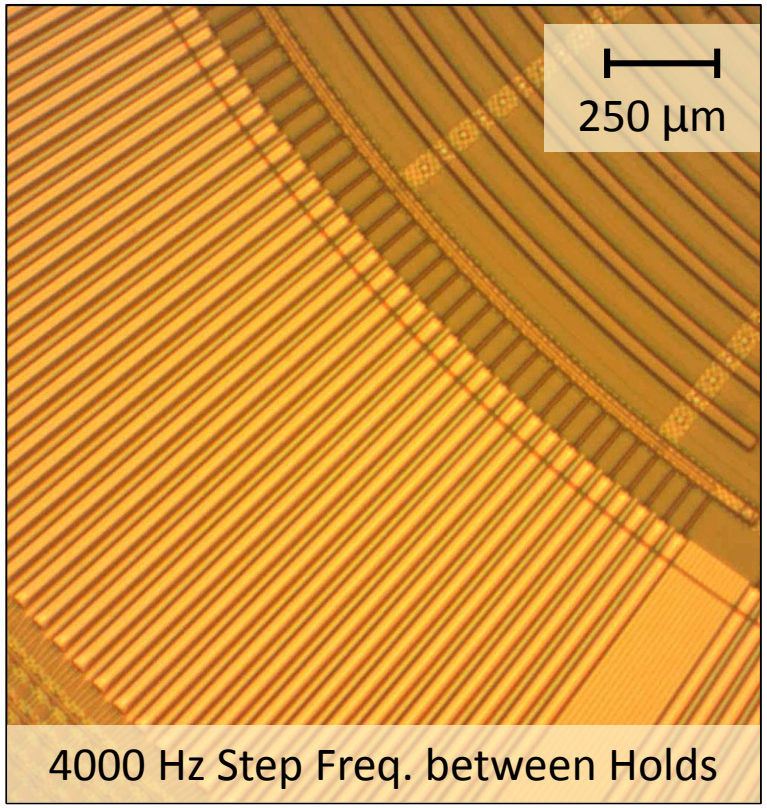


Rotational Actuation



Precision	0.03°
Accuracy	0.17°
Max velocity	2700°/s
Max acceleration	43 M°/s^2
Torque	84 mN-mm

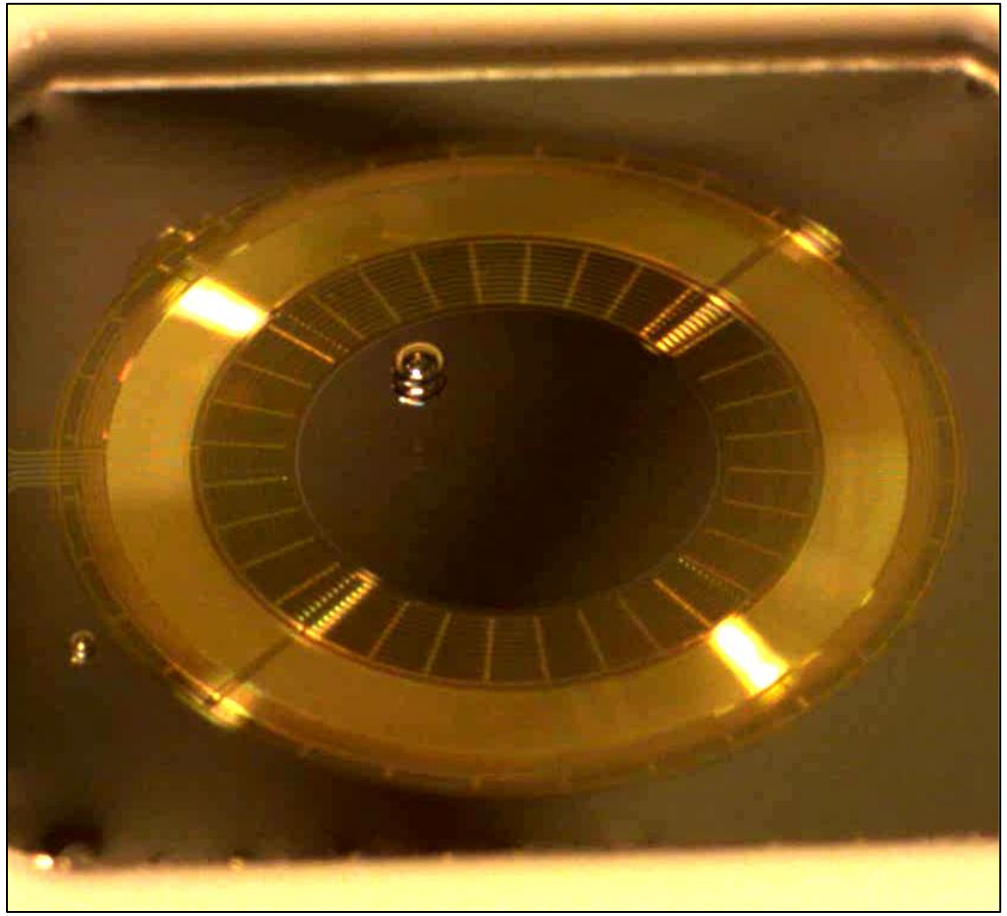


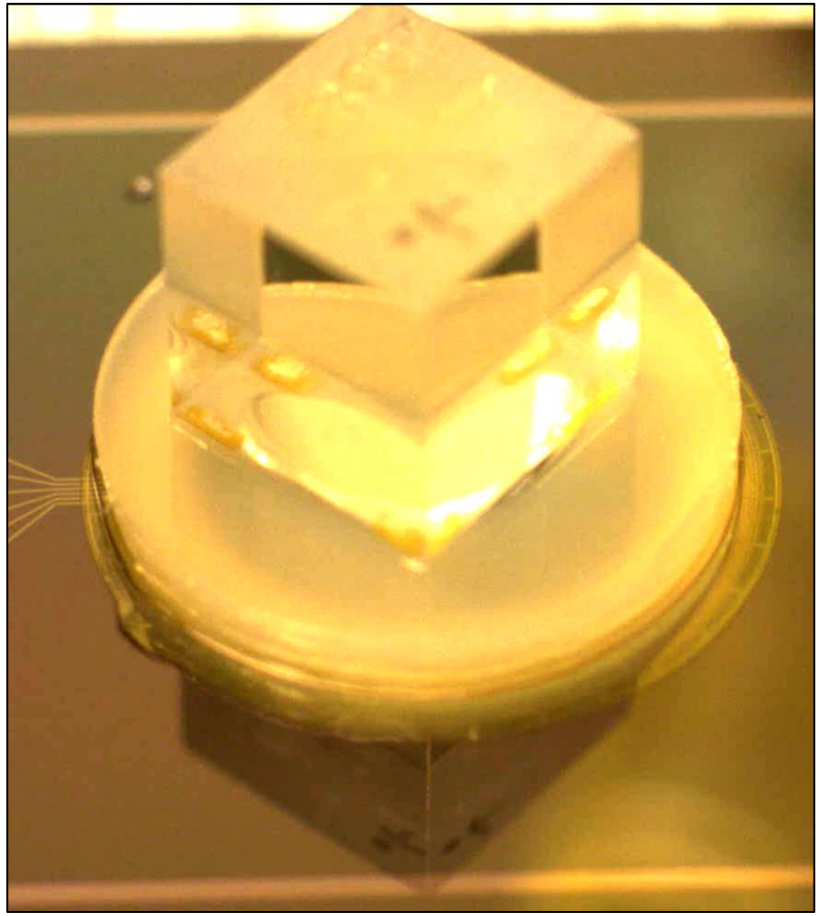


Rotational Actuation – Macroscopic

4000 Hz
Step Freq.

100 cyc
between
Holds





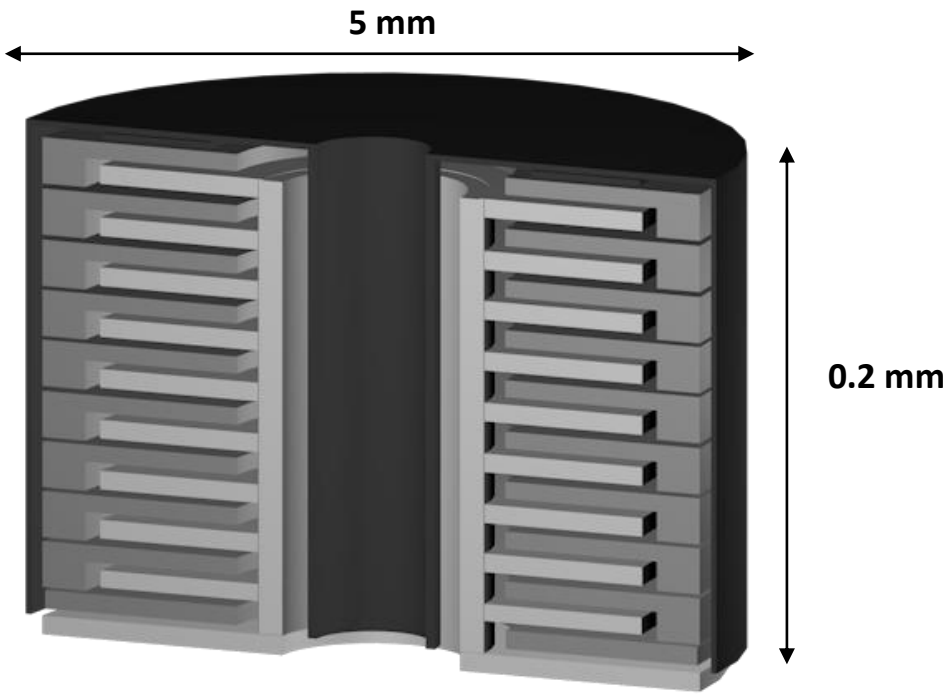
Moving
5 mm
Beam
Splitter
(0.37 g)

1000×
Mass of
Actuator

Applications – Shorter Term

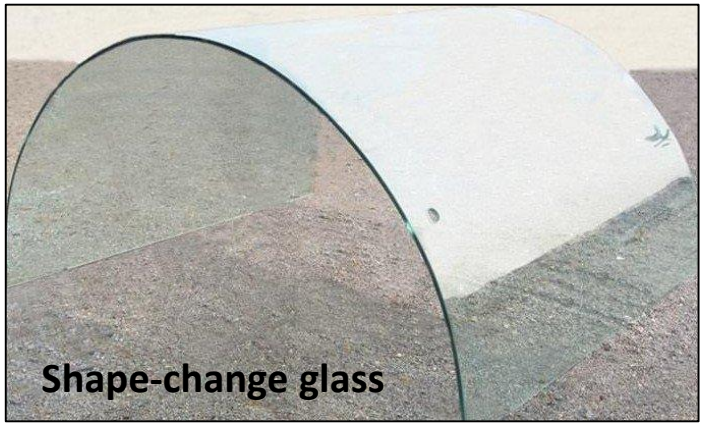
- Building the world's smallest stepper motor (0.1 g) with precise positioning for cameras or laser communication

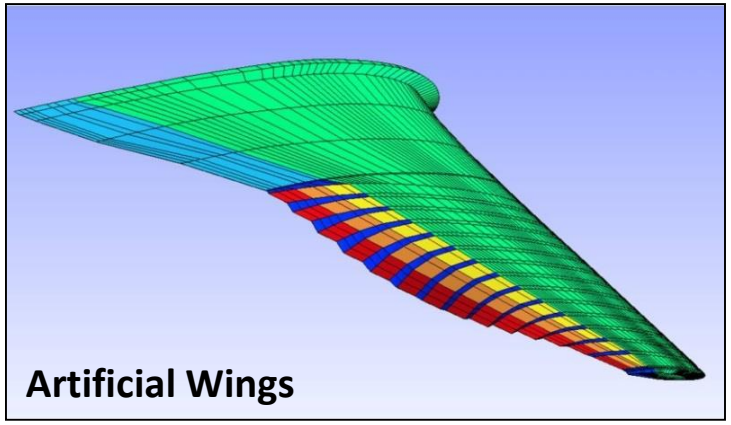
- Building small precise linear actuators with capability to move mirrors or lenses



Applications – Longer Term

- Exoskeleton with artificial muscle
- Shape-change glass and other shape-change materials
- Artificial wings





Conclusion

- Microhydraulic actuation is a new MEMS technology developed at Lincoln Laboratory under the Advanced Devices Line program
  - Allows powerful, efficient, and versatile actuation on a small scale
  - Allows very precise and rapid positioning
  - Excellent metrics even at an early stage of development
  - Many metrics improve with shrinking droplet pitch
- Liquid/solid composition of microhydraulic components offers unique challenges and opportunities

Acknowledgments

- Thanks to the MEL team that made this possible: Joel Maldonado, Hero Chea, Matt Cook, and others
- Thanks to Eric Holihan for help with assembly
- Thanks to the Advanced Device Line for supporting this research