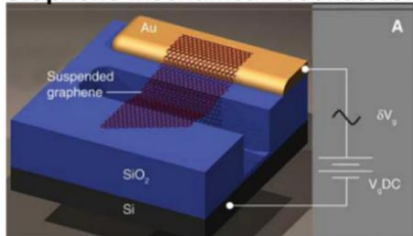


Finite Element Modeling of MEMS Chevron Thermal Actuators for Strain Engineering of Graphene

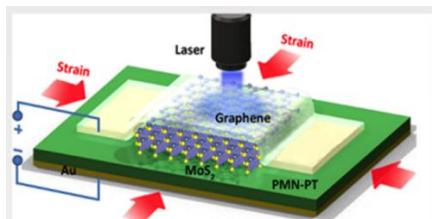
Mounika Vutukuru, Jason Christopher, David Bishop, Bennett Goldberg, Anna Swan
Optical Characterization and Nanophotonics Laboratory

Strain Engineering of 2D Materials: Motivation

Graphene mechanical resonators:

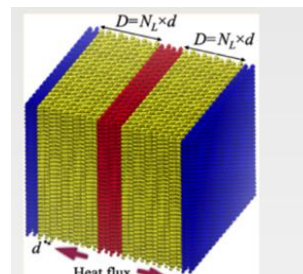


Bunch et al. *Science* **315**, 490 (2007)



Strain - modified band gap
Transistors, Photodetectors, LEDs

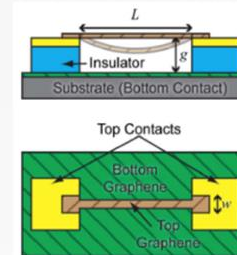
Y.Y. Hui et al., *ACS Nano*, **7**, 7126 (2013)



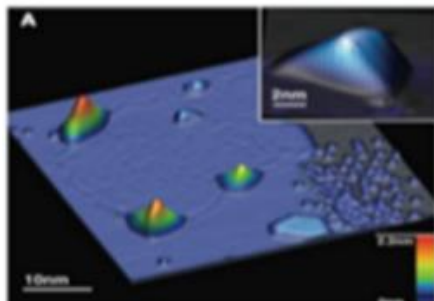
Strain - modified
thermal conductivity
Thermal management CPU's

J. Chen et al., *Nano Lett.*, **14**, 819 (2014)

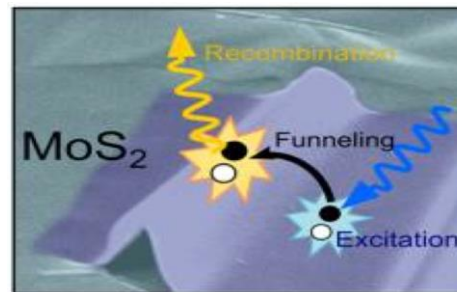
Graphene mechanical switch:



Milaninia et al. *APL* **95**, 183105 (2009)

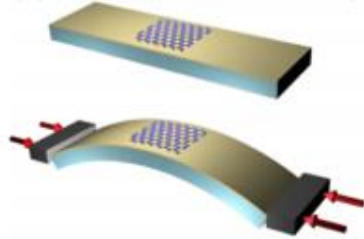


N. Levy et al., *Science*, **329**, 544 (2010)



A.C. Gomez et al., *Nano Lett.*, **13**, 5361 (2013)

Current Straining Techniques



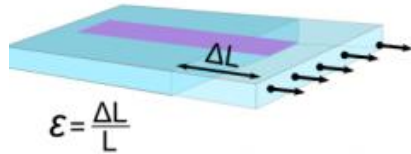
Straining technique	Type of strain	
	Uniaxial	Homogeneous
Bending of a flexible substrate	Uniaxial	Homogeneous
Elongating the substrate	Uniaxial	Homogeneous
Piezoelectric stretching	Biaxial	Homogeneous
Exploiting the thermal expansion mismatch	Biaxial	Homogeneous

Mohiuddin, T. et al., Phys. Rev. B 79, 205433 (2009)

A 2D material is deposited on the center of an elastic substrate



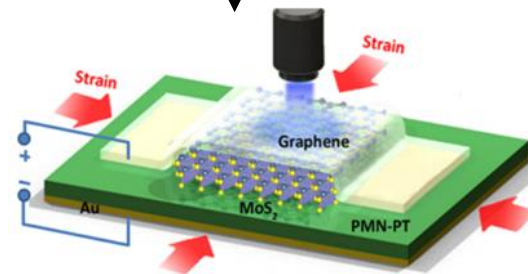
The substrate is elongated



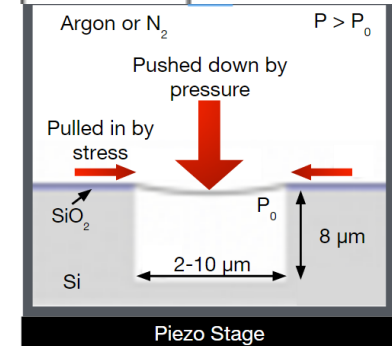
$$\epsilon = \frac{\Delta L}{L}$$

Wang, Y et al., Nano Res (2015)

Roldan, R., et al Journal of Physics: Condensed Matter, 27 (2015)



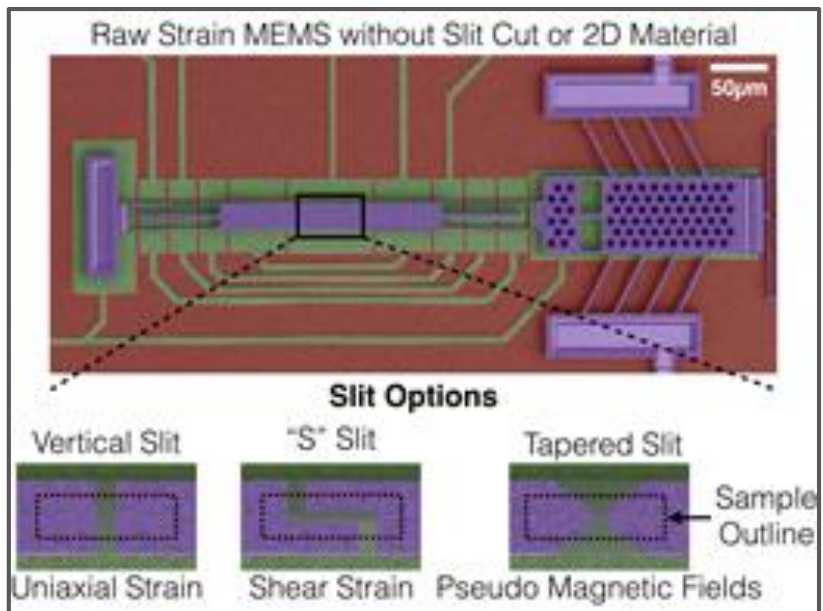
Y.Y. Hui et al., ACS Nano, 7, 7126 (2013)



Kitt, A. L. et al., Nano Letters, 13(6), 2605–2610 (2013)

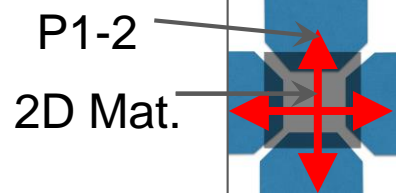
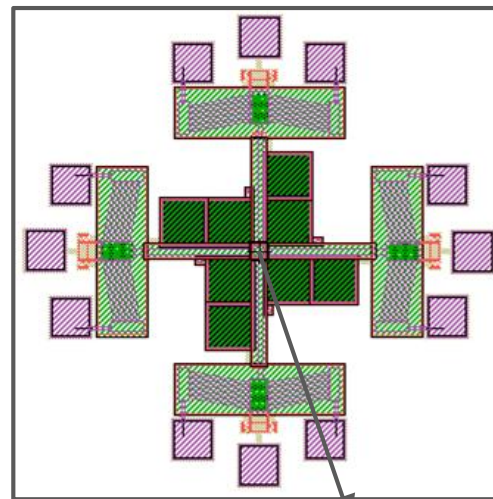
MEMS Actuators for Staining 2D Materials

Uniaxial Strain

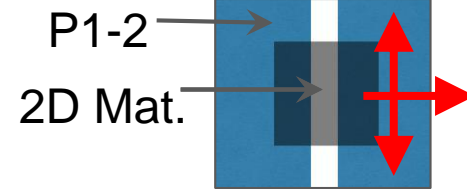
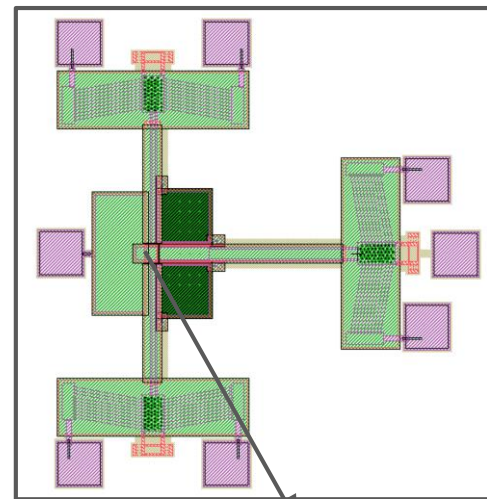


Displacement

Biaxial Strain

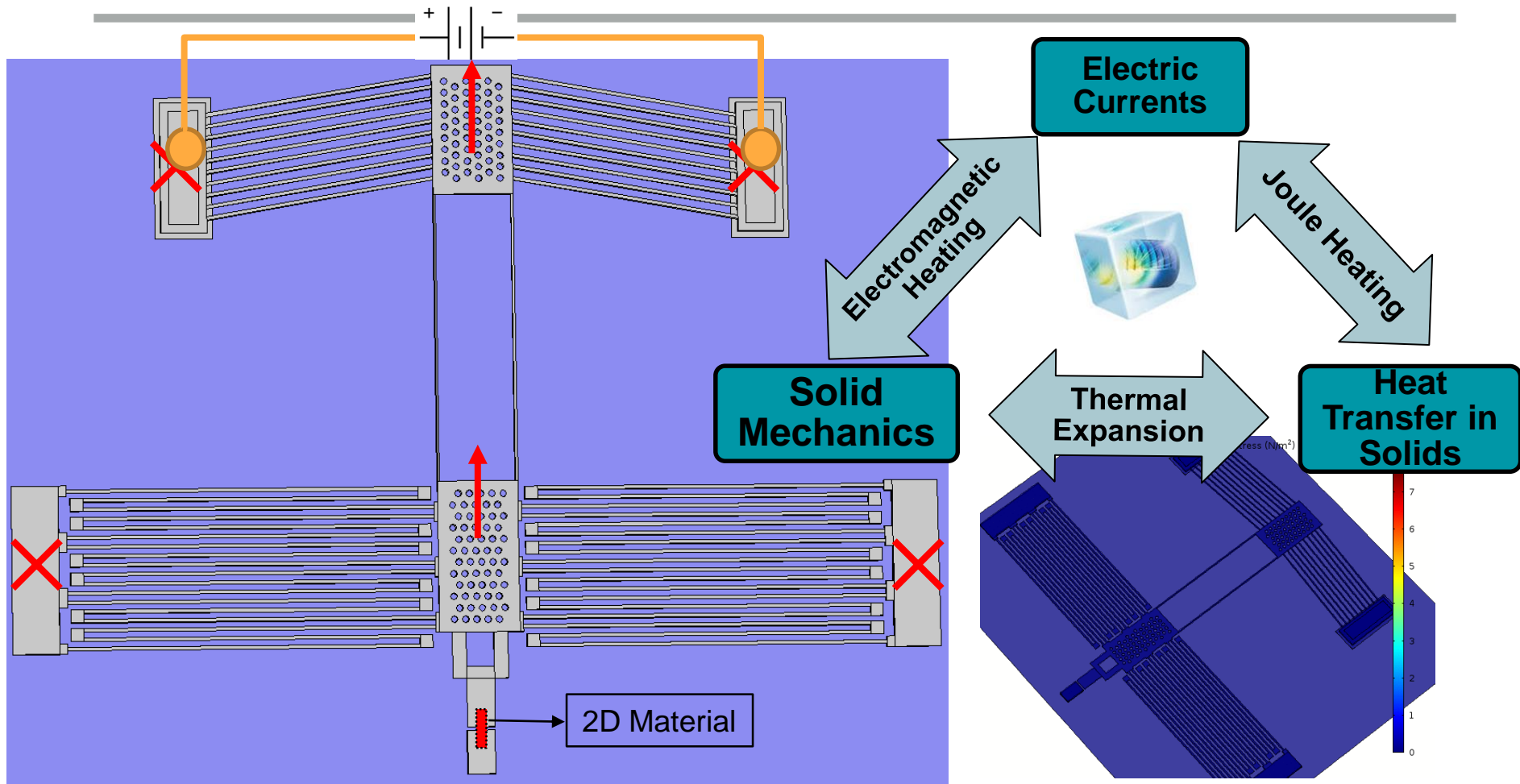


Shear Strain



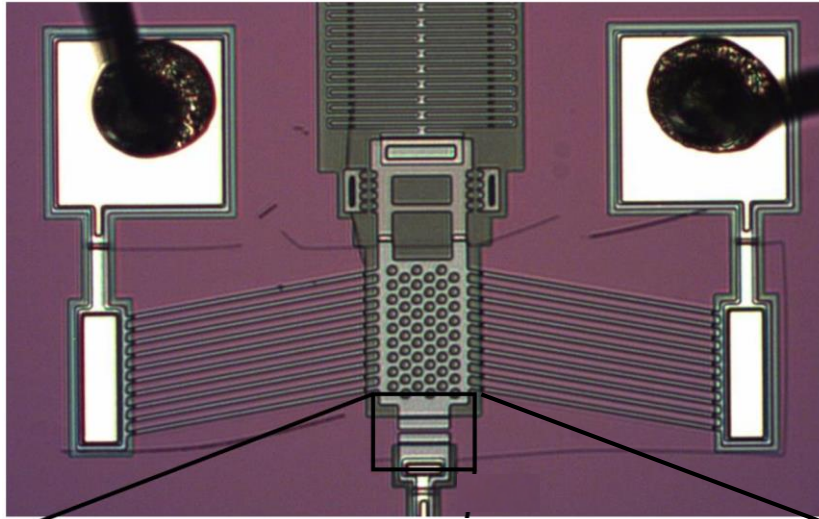
Simulation of Chevron Actuator on COMSOL 5

5

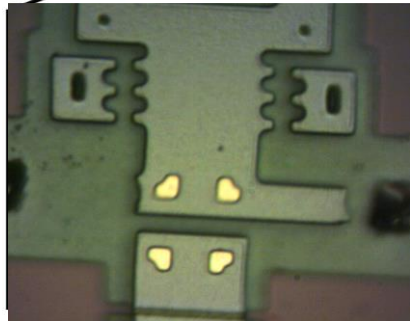


Testing of the Chevron Actuator

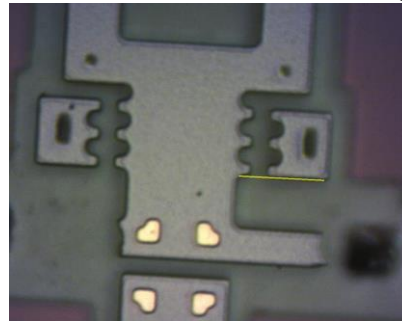
7



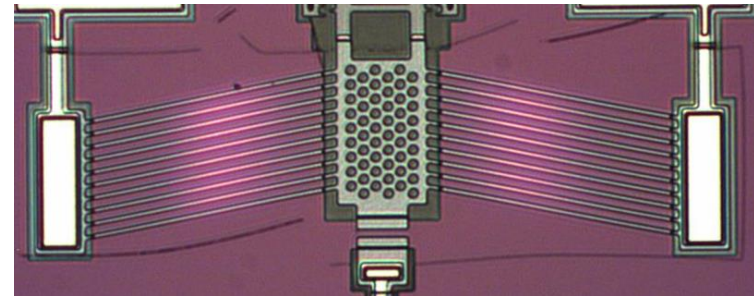
<u>Parameter to be probed...</u>	<u>Obtained by...</u>
Displacement	Optical microscope measurements using on-site verniers
Current	Device is probed between the ball-bonded pads
Temperature	Raman Spectroscopy
Vacuum Measurements for Convective and Radiative losses	Actuation of the device in an SEM



Un-Actuated



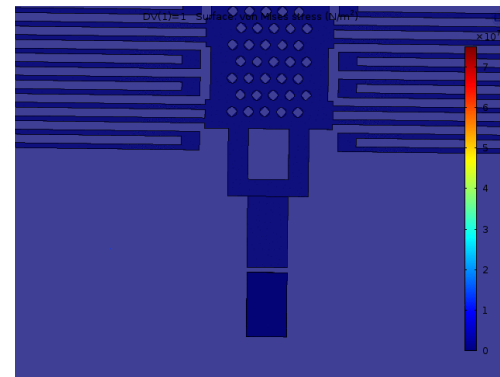
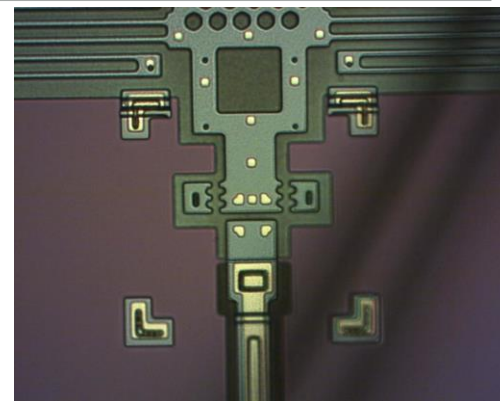
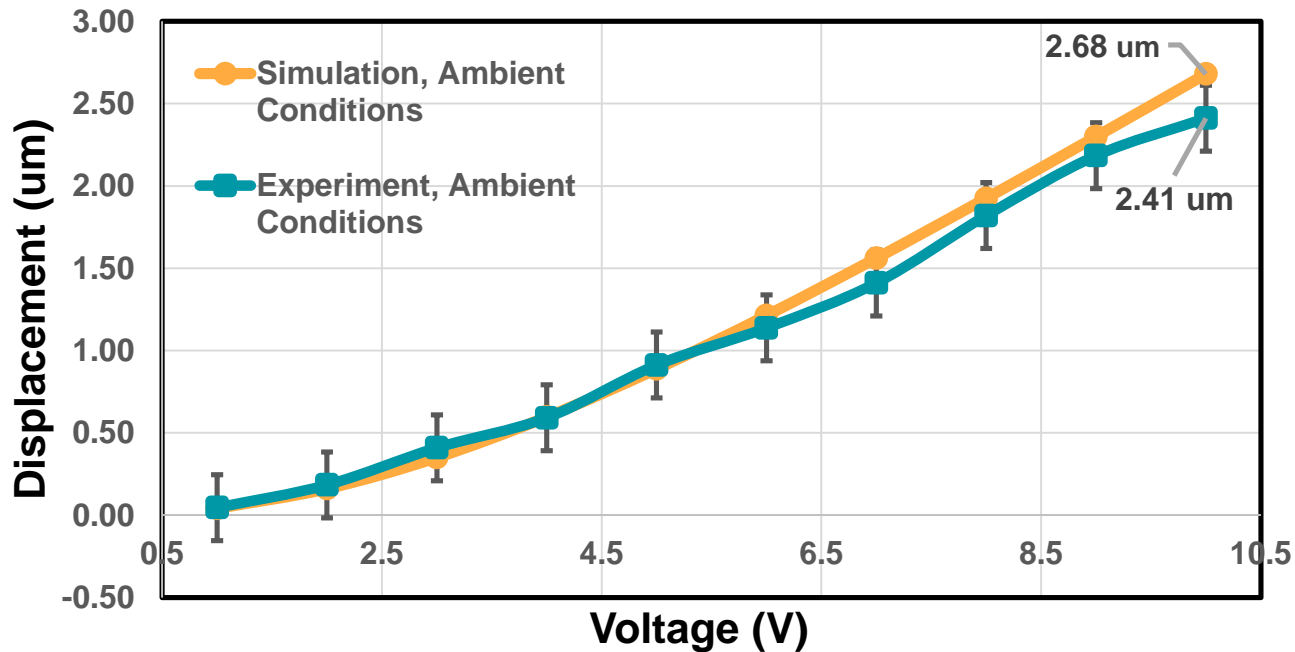
Actuation



Glowing beams at high voltage

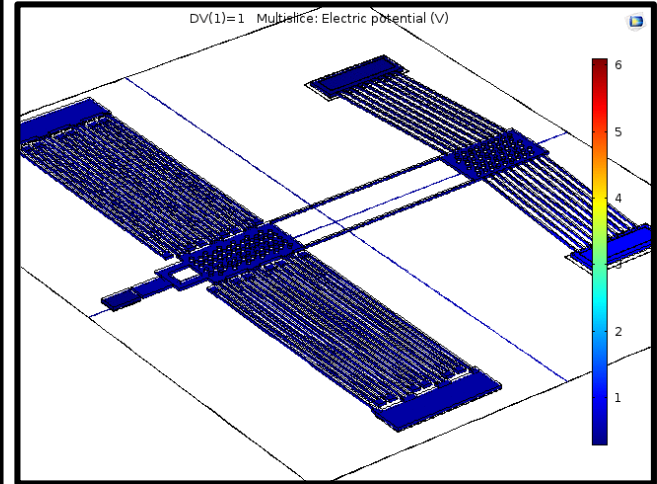
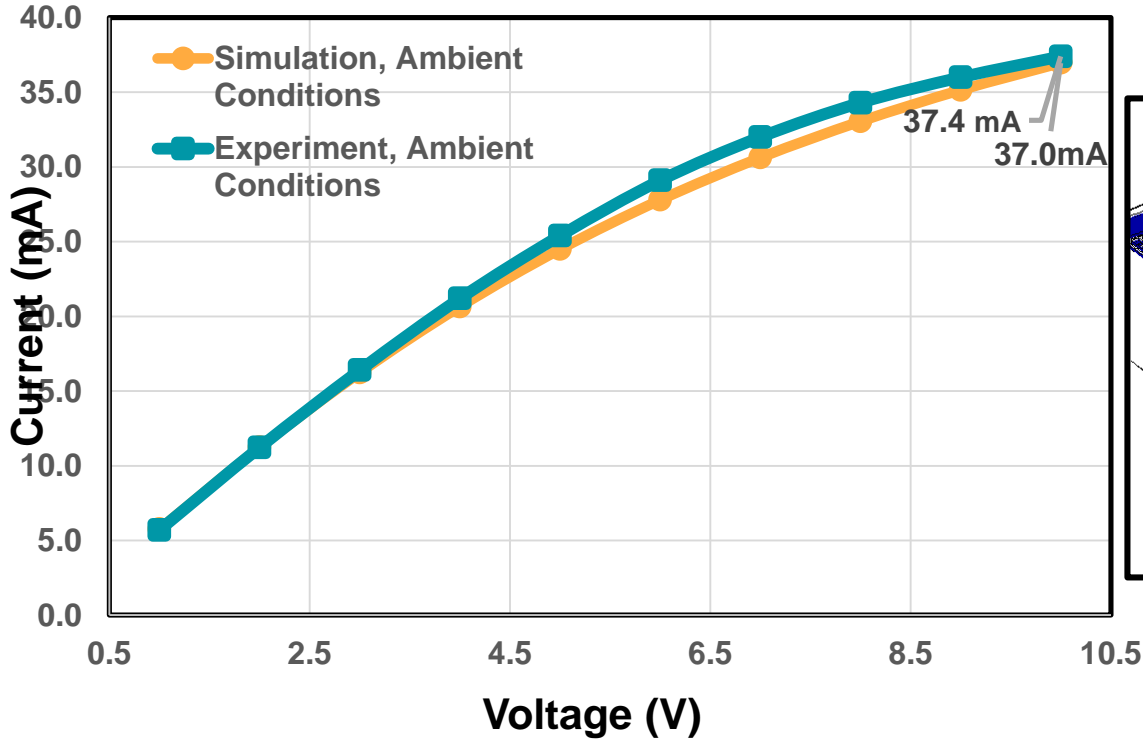
Comparison between Model and Experiment

Displacement vs Voltage



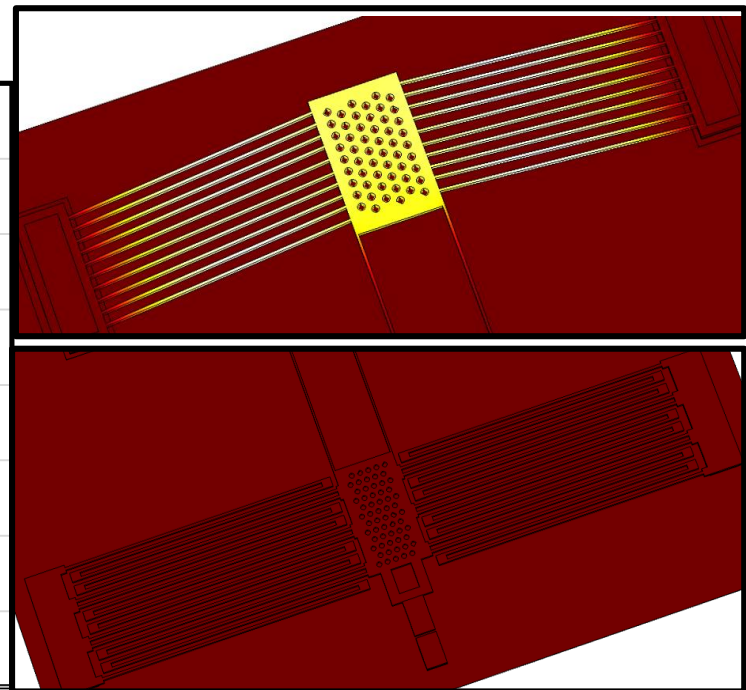
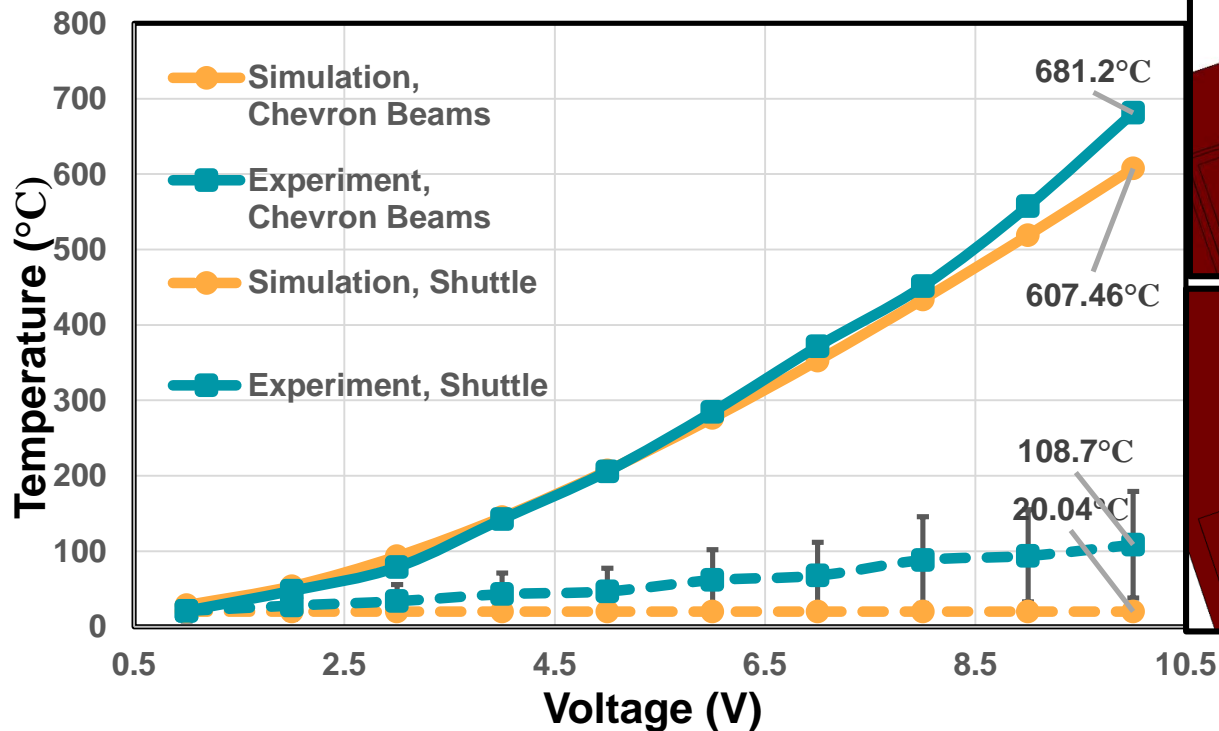
Comparison between Model and Experiment

IV Characteristic

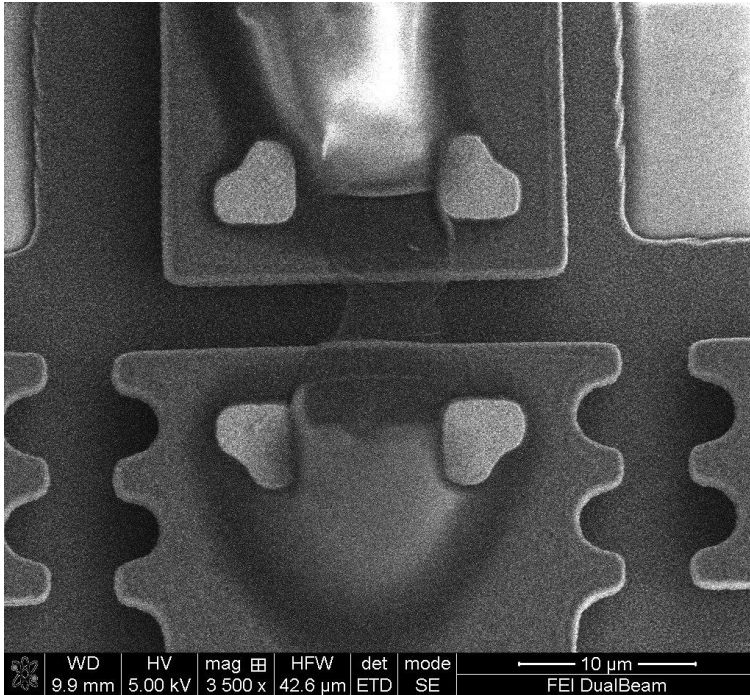


Comparison between Model and Experiment

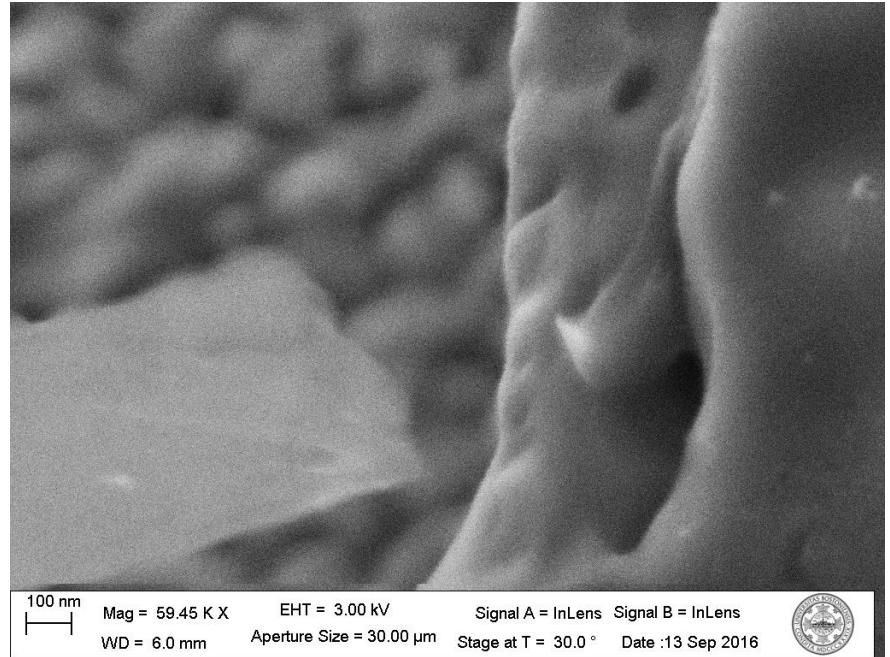
Temperature vs. Voltage



Current Progress



Graphene slipping from MEMS device under actuation.



SEM image showing graphene slipped from anchor side.

Technical Road Map

- ✓ Build reliable and predictable model of the Chevron Actuator
- 1. Simulating 2D on MEMS Actuator
 - Thin Layer Membrane interface
 - Analyze displacement dependent strain in graphene

-
- ✓ Friction Engineering of MEMS Actuator

- 1. Advanced Strain Geometry
 - Shear and Biaxial Devices

- 2. Low Temperature

- 3. 4 Point Electrical Contact



Electronics Applications:

- Scalable
- Industry standard integration

Acknowledgments

COMSOL CONFERENCE 2016 BOSTON

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Bennett Goldberg

Collaborators:

David Bishop

Graduate Students:

Jason Christopher
Travis Kohler

Optical Characterization and Nanophotonics Laboratory, Boston University

Funding: NSF DMR 1411008

THANK YOU!