Carbon MEMS Accelerometer
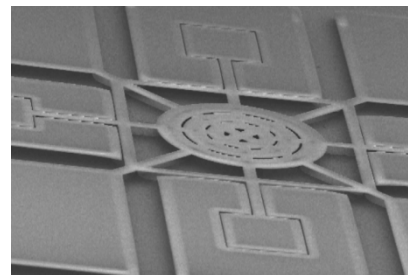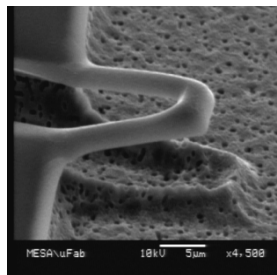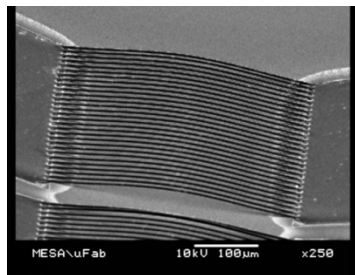
Jennifer Strong[1], Cody M. Washburn[2], Randy Williams[2], Patrick Finnegan[1], Brad Hance[2], Doug Greth[2], and Dave R. Wheeler[2]

[1]LMATA Government Services, LLC
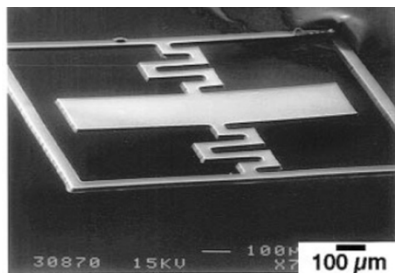[2]Sandia National Laboratories

Project Goals

- Intent is to design a MEMS accelerometer that is hyper-sensitive over a dynamic range from micro-G to hundreds of G's

- The design will utilize photo-patternable material with blended nano-materials

- The blend undergoes pyrolysis, resulting in a carbon-carbon composite with pyrolytic carbon comprising the bulk of the material
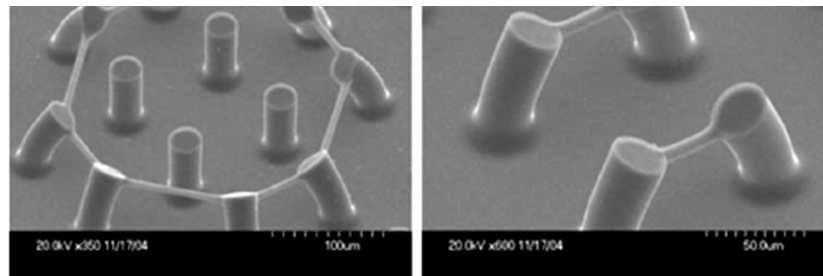
Background

- The pyrolysis of photo-patternable materials and the basic properties of pyrolytic carbon have been described by G. Whitesides [1]

- M. Madou [2] and R. McCreery [3] have developed carbon on carbon approaches to develop carbon MEMS

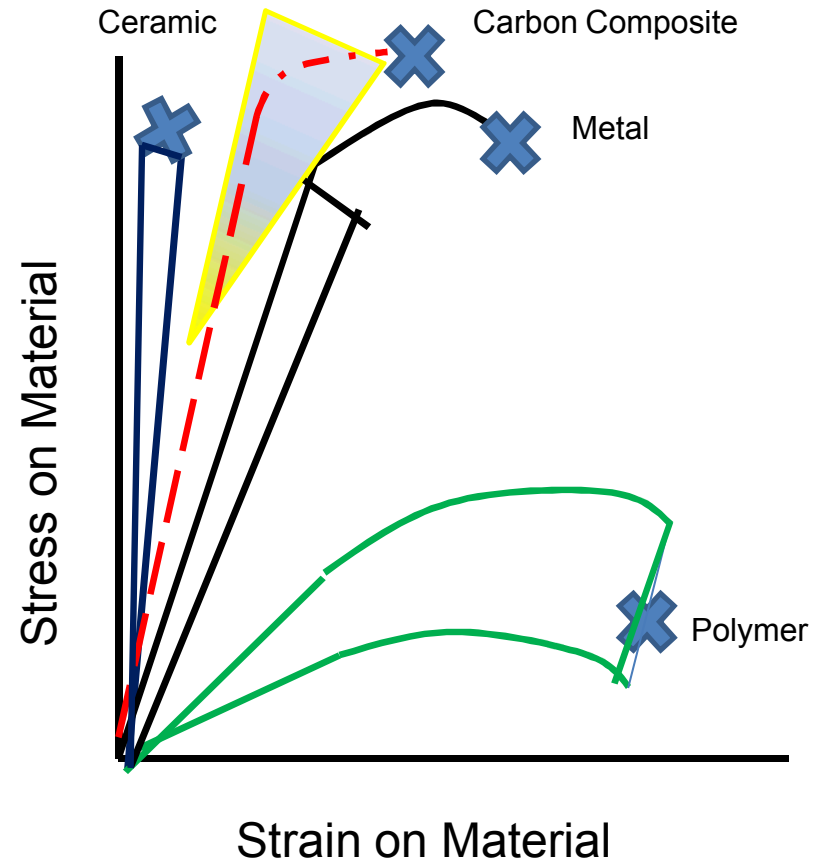- Pyrolytic carbon structures have survived 150 G's

Free-Standing Pyrolytic Carbon Structure by G. Whitesides [1]

Suspended C-MEMS Structures by M. Madou [2]

Tuning Pyrolytic Carbon

- Pyrolytic carbon alone does not have the electromechanical properties desired

- By blending nano-materials such as CNTs into the photoresist before pyrolysis, the properties of the carbon can be tuned to better suit the design

- First attempt uses MWCNTs 40-70 nm in diameter and 0.5 – 5.0 µm in length

Ceramic

Carbon Composite

Metal

Polymer

Stress on Material

Strain on Material

Outline of Work

Composite Characterization

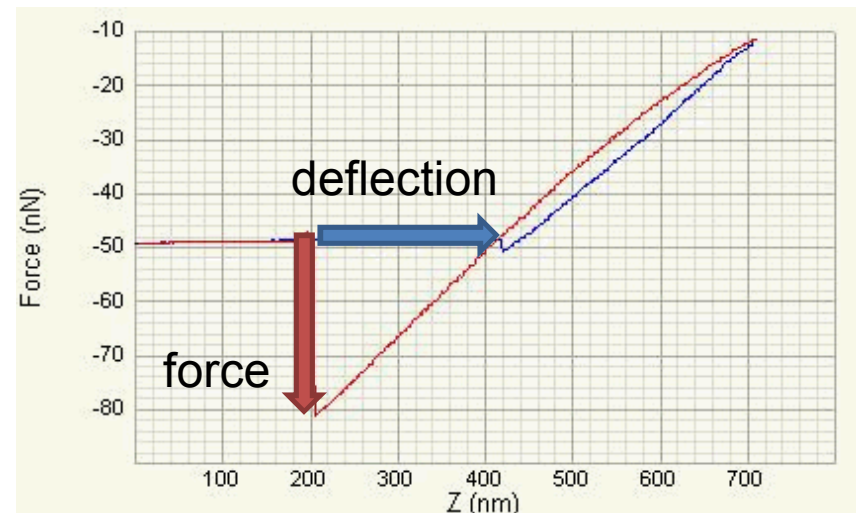- Fabricate test devices and preliminary designs from a variety of carbon-carbon composites

- Collect physical data

- Calculate basic material properties

- Use COMSOL to validate the calculations

Device Design

- Correlate the COMSOL models with physical data

- Use the COMSOL models to drive design optimization with less need for fabrication

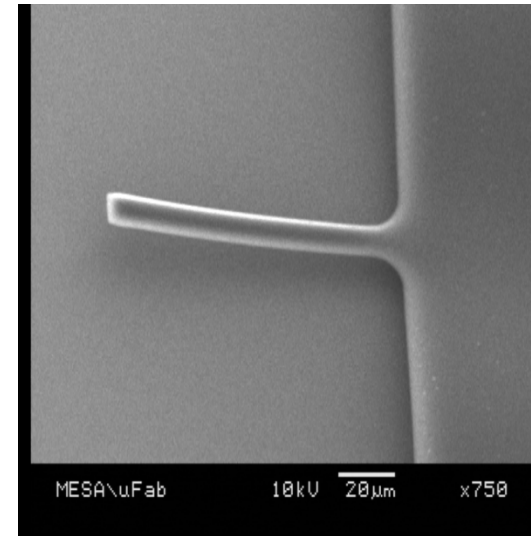- Use COMSOL to explore and screen new designs pre-fabrication

AFM Measurements

- Atomic Force Microscopy (AFM) is used to explore the basic mechanical functioning of the composites
- AFM provides a basic look at device deflection versus applied force
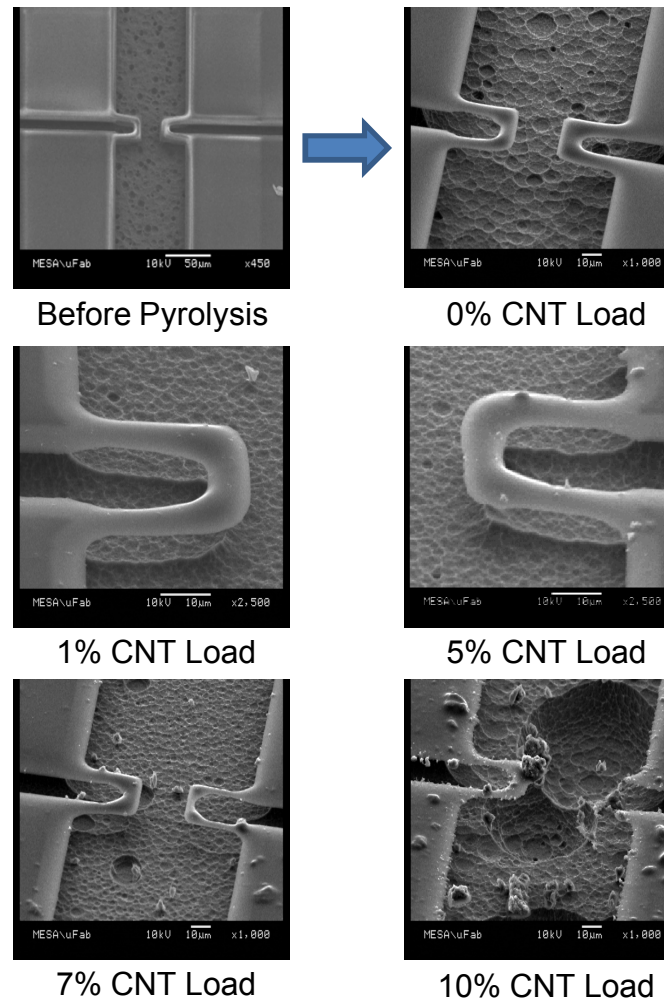
Young's Modulus

- By examining the relationship between force versus deflection for simple cantilever devices, a value for Young's modulus can be extracted

- This requires the assumption that the measurements are in the linear elastic range

MESA\uFab   10kV 20μm x750

$$k = \frac{F}{\delta} \qquad E = \frac{4FL^3}{bh^3\delta}$$

Early Results

- First composite devices show promising fabrication results

- The geometries reduce ~80% during pyrolysis

- CNT loading over 5% results in damage to structures

- Better dispersion techniques will help

Before Pyrolysis

0% CNT Load

1% CNT Load

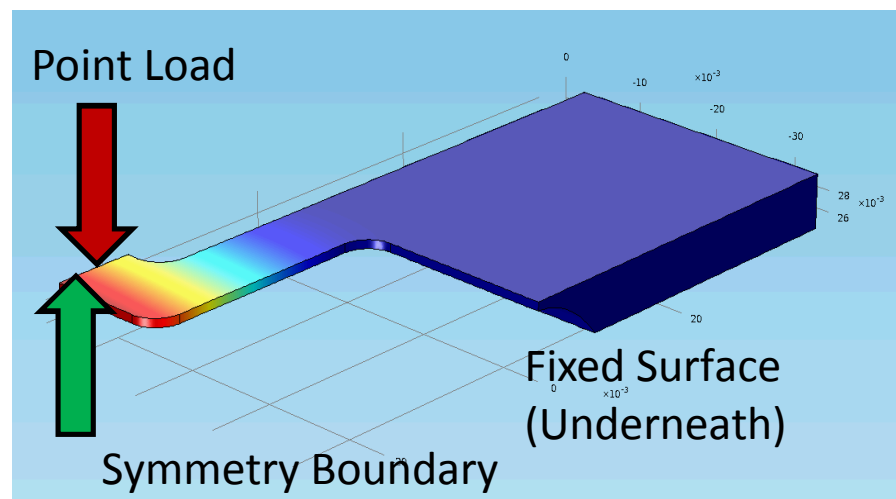5% CNT Load

7% CNT Load

10% CNT Load

Early Results

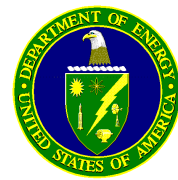- Values for Young's modulus are lower than expected – problem may lie in initial AFM measurements

- COMSOL model exhibits deflection within 5% of what is expected for the given Young's modulus

CNT Loading	Young's Modulus (GPa)
0%	2.22
1%	2.16
5%	3.01
7%	1.94
10%	2.16

Point Load

Fixed Surface (Underneath)

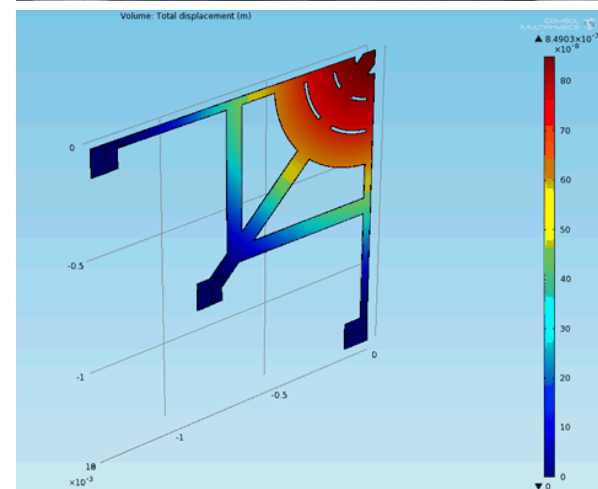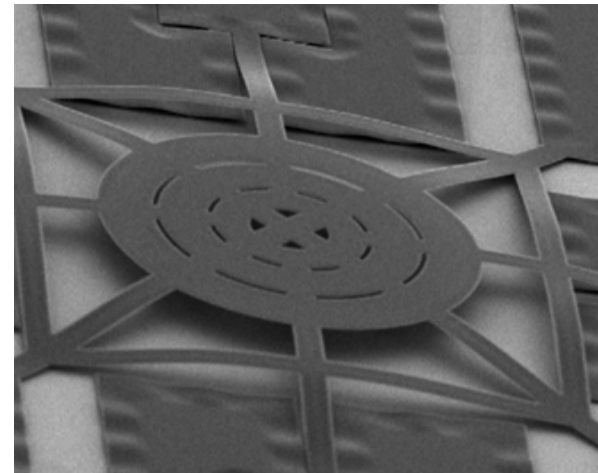Symmetry Boundary

Recent Results

- More recent AFM measurements yielded a Young's modulus of 52.3 GPa for unloaded pyrolytic carbon

- This is much higher than the 2.22 GPa calculated previously

- This value is higher than expected – previous literature cites a value of ~15 GPa [1]

- In comparison, aluminum has a Young's modulus of ~69 GPa

- More measurements are needed to establish consistency

Recent Results

- Recent AFM data also included measurements for a diaphragm device

- The COMSOL model of the device did not behave as expected

- The model deflected 849nm – 238nm was expected

- Internal stresses may be playing a role in the physical device

Volume: Total displacement (m)

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The Value of COMSOL Modeling

- Comparing a physical device to its COMSOL model yields valuable insight regardless of the outcome being favorable or not

- Good correlation gives confidence that the model can be used to make meaningful predictions

- Poor correlation leads to troubleshooting
  - There is an error in the model
  - Fabrication artifacts are not being taken into account
  - There is a misunderstanding of the physical structures or materials

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Going Forward

Composite Characterization

- Establish consistency in the AFM measurements
  - More data points
  - Use of a "test wafer" to ensure that the AFM tip is consistent from one set of measurements to the next
- Attempt to create larger devices that can be used in macro-scale testing

Device Design

- Troubleshoot differences between the physical data and the COMSOL models
- Refine device fabrication methods to eliminate unwanted physical artifacts
- Eventually use COMSOL for design optimization and for evaluating and comparing different designs

Acknowledgements and References

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1. G. Whitesides, et. al. Chem. Mat. 1997, 9, 1399-1406
2. M. Madou, et. al. Carbon 2006, 44(13), 2602-2607
3. R. McCreery, et. al. Journal of The Electrochemical Society, 147, (1) 277-282