IMECE2011-62594
SAND2011-8517C

Materials Degradation in Silicon Microsystems at High Temperatures

Leslie M. Phinney[1], Thomas E. Buchheit[2], and Brad L. Boyce[2]

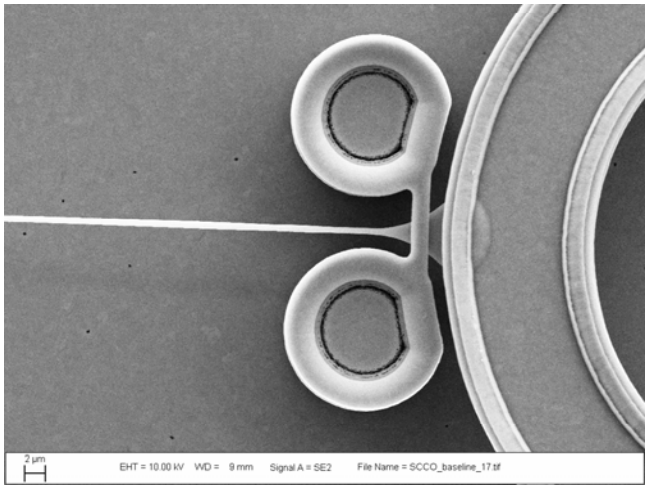
[1]Engineering Sciences Center
[2]Materials Sciences and Engineering Center
Sandia National Laboratories
Albuquerque, New Mexico

November 16, 2011

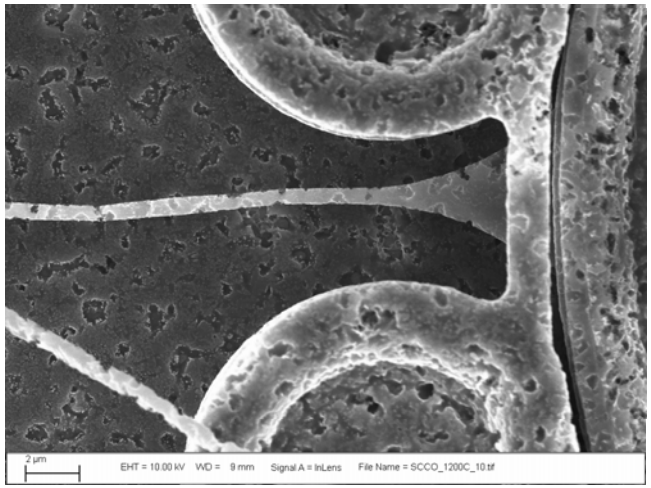
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Motivation

- Materials degradation observed when attempting high temperature creep testing of polycrystalline silicon MEMS materials in an Argon atmosphere.
- Subsequently determined that degradation occurs for SOI parts in Argon atmospheres as well. Also, degradation observed in nitrogen and vacuum environments.
- Need better understanding high temperature behavior of silicon based MEMS to deploy them in harsh environments, develop accelerated reliability testing methods, and optimize packaging environments.



Baseline Sample



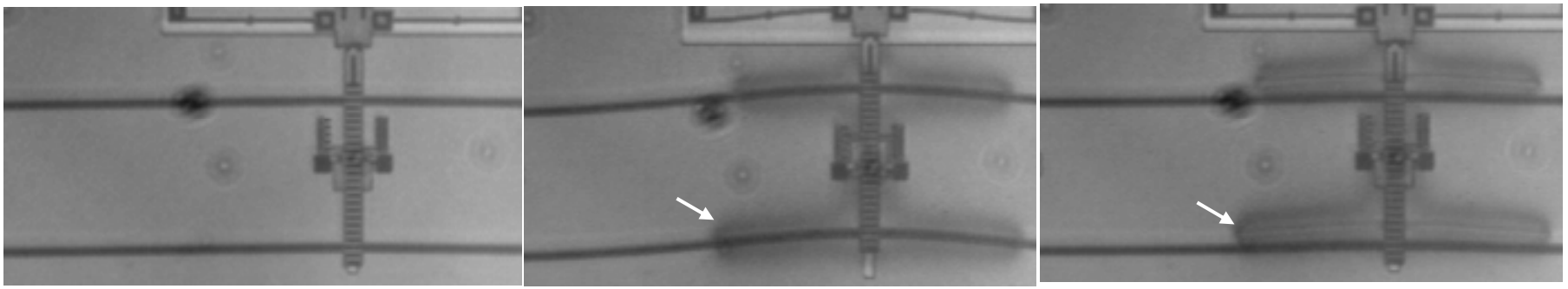
1200C (~1hr) SCCO2 release

Sandia National Laboratories

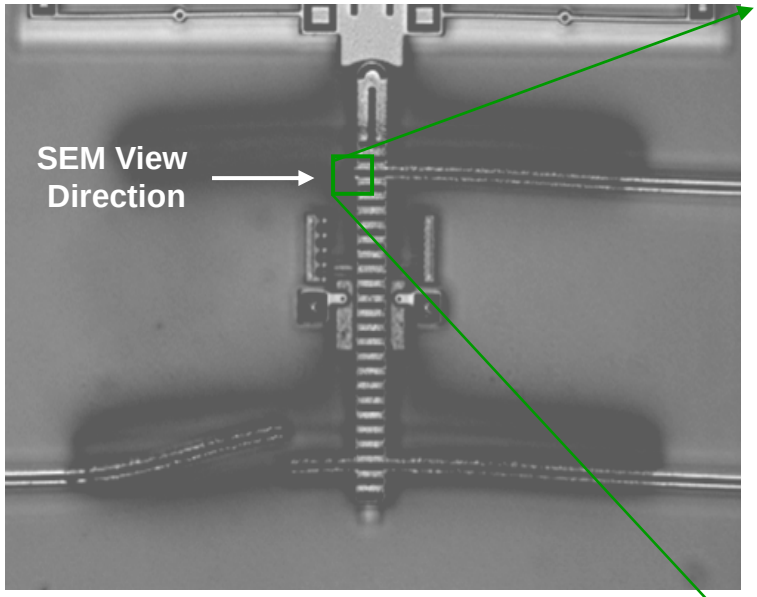
Surface Degradation during Joule Heating of a Thermal Microactuator in Vacuum

54 K cycles at 30 Hz, 35 mW, 1.2 x 10^{-6} Torr vacuum

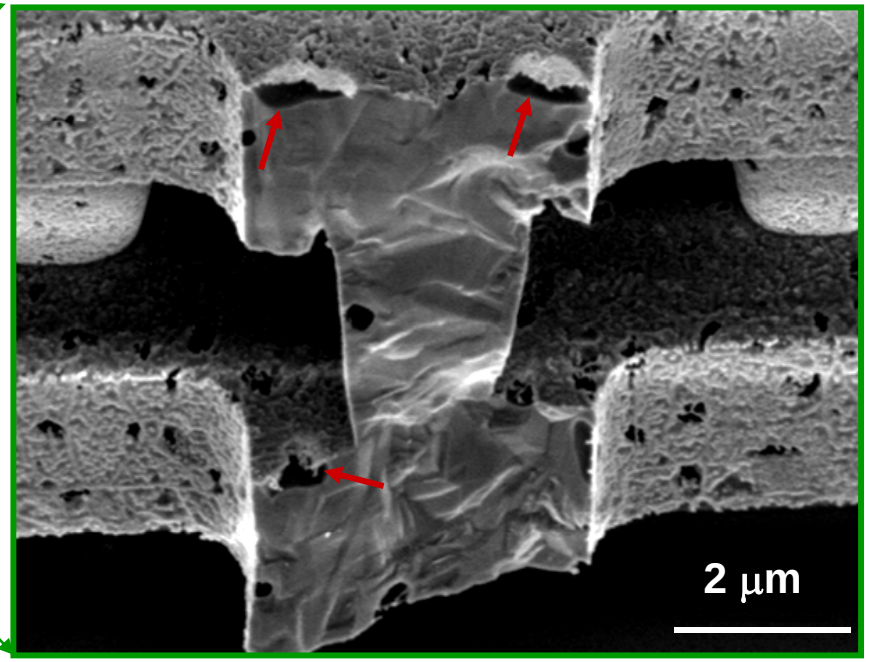
Initial **On** **Off**



Optical Close-up after 2 legs Cleaved



SEM Image

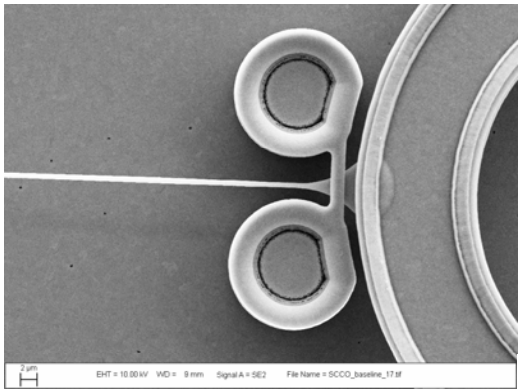


Baker et al. (SAND2004-6635)

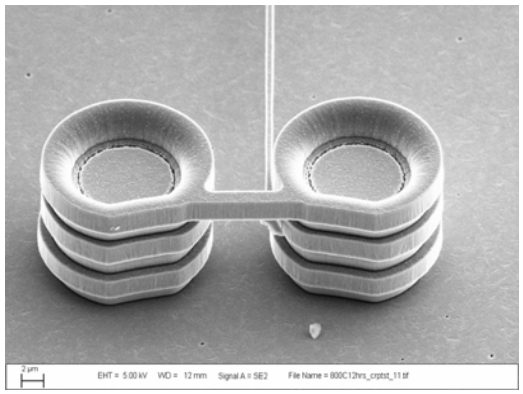
SEM image courtesy of Jeremy Walraven (Sandia)

Initial Thermal Annealing Test Results

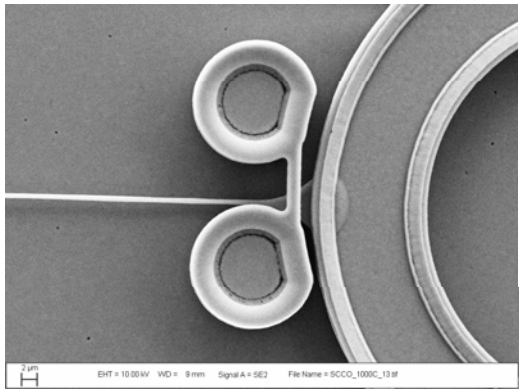
(Environment – Ar with ~5-7 ppm oxygen)



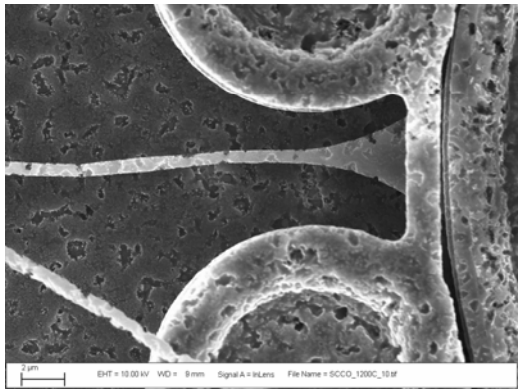
Baseline Sample



800C (~12 hr) $SCCO_2$ release



1000C (~1hr) $SCCO_2$ release

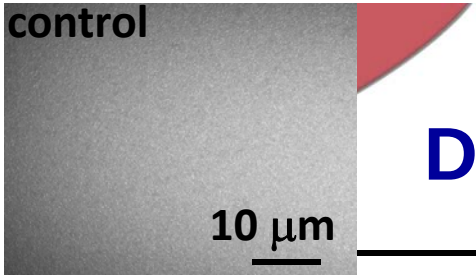


1200C (~1hr) $SCCO_2$ release

	20 min	60 min	180 min	540 min
1200°C	**Argon & Air**	**Argon & Air**	**Argon & Air**	**Argon & Air**
1000°C	**Argon & Air**	**Argon & Air**	**Argon & Air**	**Argon & Air**

Sandia National Laboratories

SUMMiT V Polysilicon: Evolution of Degradation When Annealing in Argon



1200°C (T/T$_{mp}$ = 0.87)

1000°C (T/T$_{mp}$ = 0.75)

20 min | 60 min | 180 min | 540 min

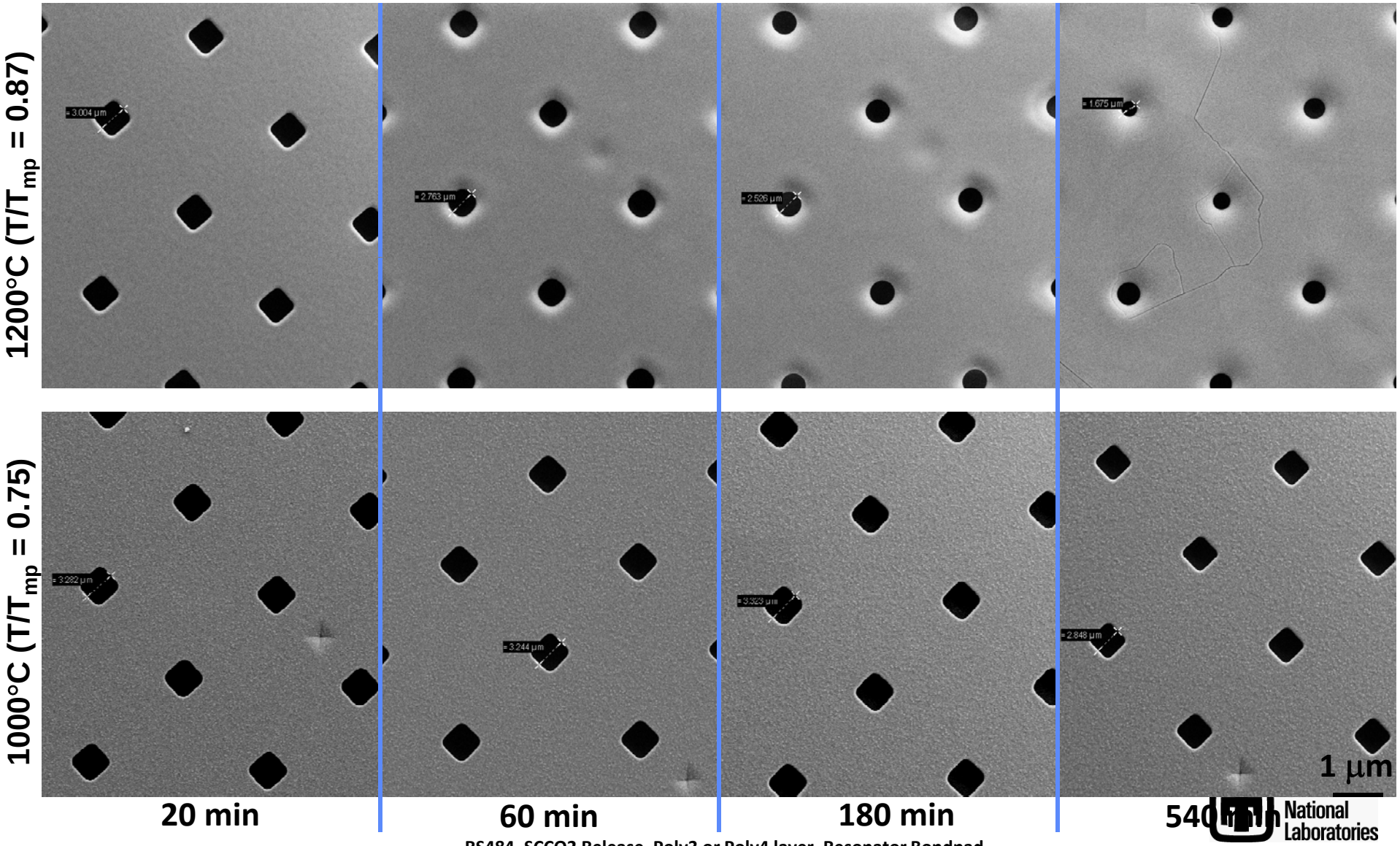
10 μm

RS484 SCCO2 Release Poly3 or Poly4 layer Resonator Bondpad

Sandia National Laboratories

Degradation is Suppressed When Annealing in an Ambient Air environment

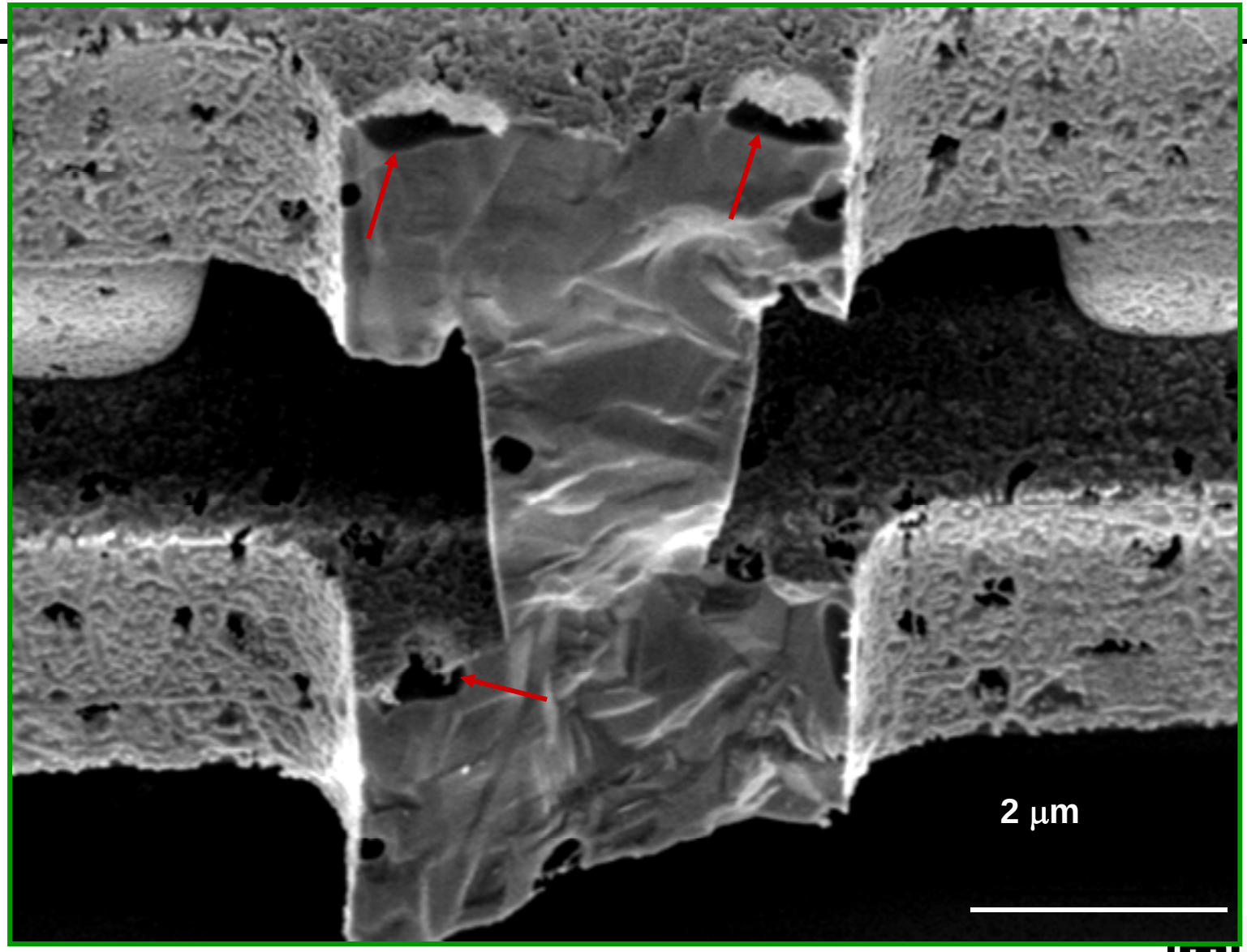
Resonator Plate with Release Holes, SE2 Detector



RS484, SCCO2 Release, Poly3 or Poly4 layer, Resonator Bondpad

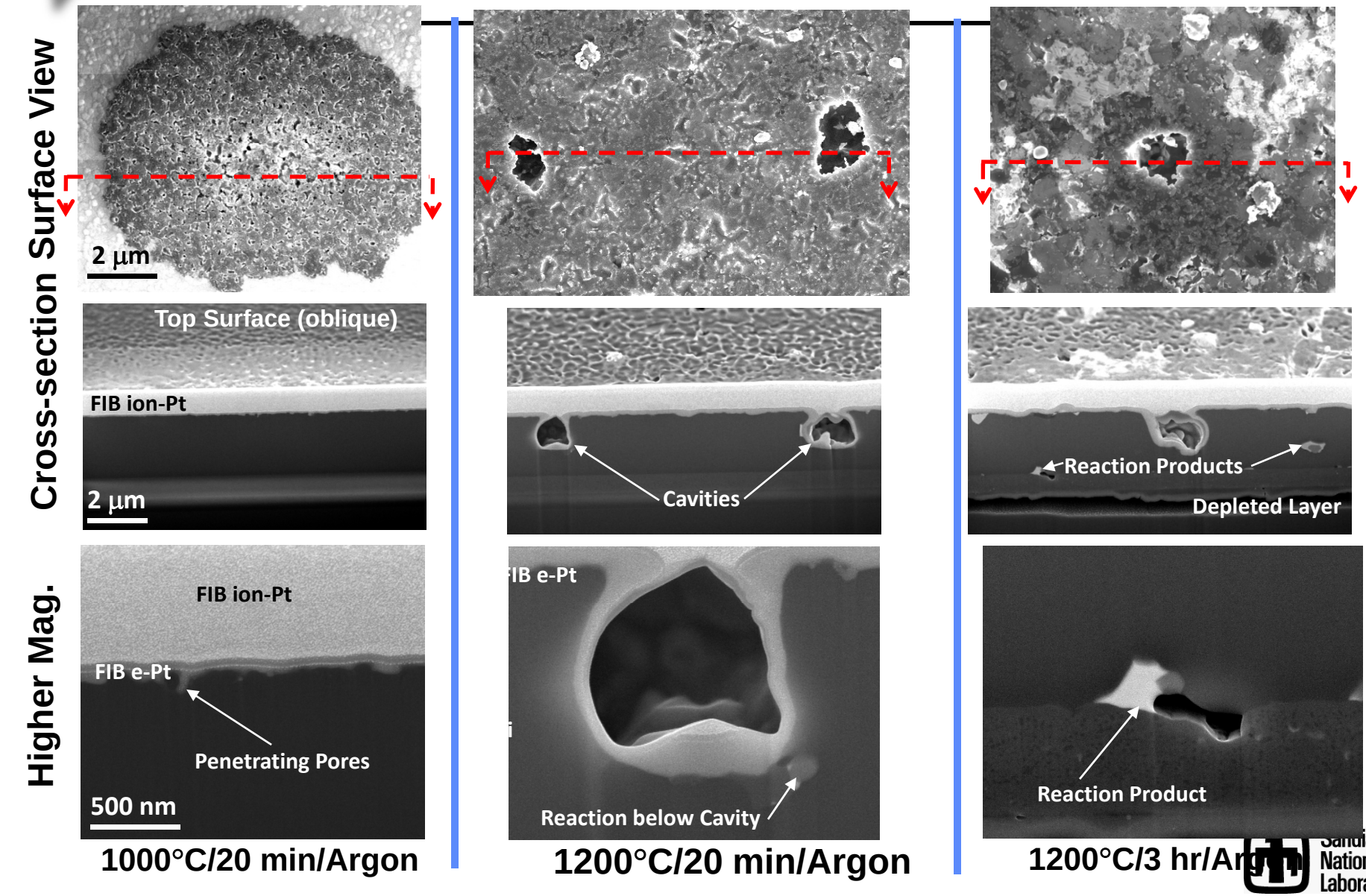
National Laboratories

Cavity Formation



Sandia National Laboratories

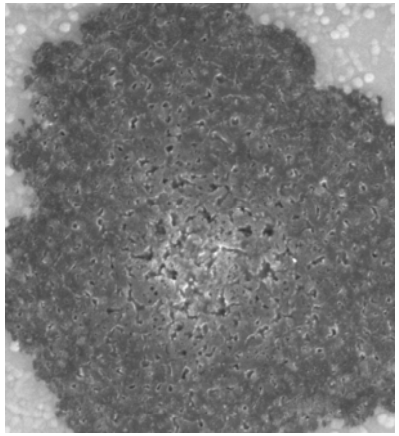
FIB Cross-Sections



Sandia National Laboratories

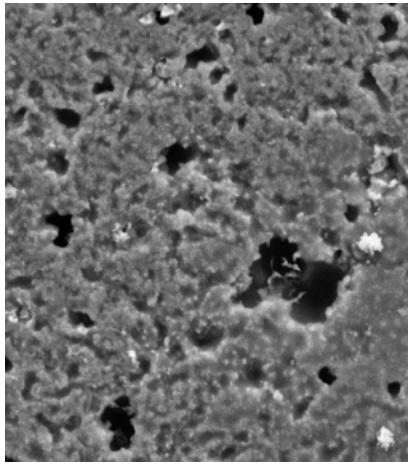
Initiation and Propagation Processes

Nucleation of generalized surface nanoporosity and propagation away from nucleation sites.



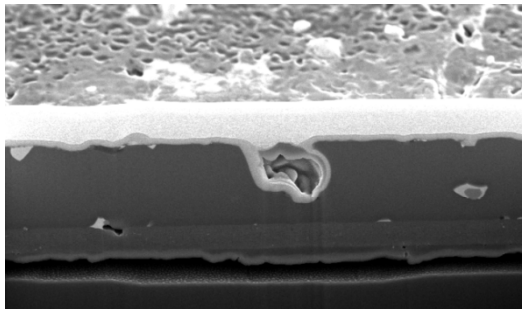
< 1000°C / 20 min

Formation of Penetrating Microcavities



<1000°C / 9 hrs

Depletion/consumption of wafer thermal oxide layer below nitride



<1200°C / 3 hrs

Sandia National Laboratories

Summary and Conclusions

- **Materials degradation observed at elevated temperatures for polysilicon and SOI MEMS devices in Argon, nitrogen, and vacuum environments.**
- **Materials degradation in Argon atmosphere thermal annealing increases with temperature and time. Materials depletion is observed.**
- **Thermal annealing in air suppresses materials degradation. Oxide growth and cracking observed.**
- **Current efforts are focused on determining the thickness of oxide needed to prevent materials degradation for a give temperature.**

Sandia National Laboratories

Acknowledgments

- **Bonnie McKenzie for SEM support.**

Sandia National Laboratories