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Concept Demonstration of Dopant Selective Reactive Etching (DSRIE) in Silicon Carbide

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Outline

- Reactive Ion Etching: The Basics
- Observed Phenomenon
- Technical Approach
- Results
- Innovation and Impact on Mission
- Next Steps

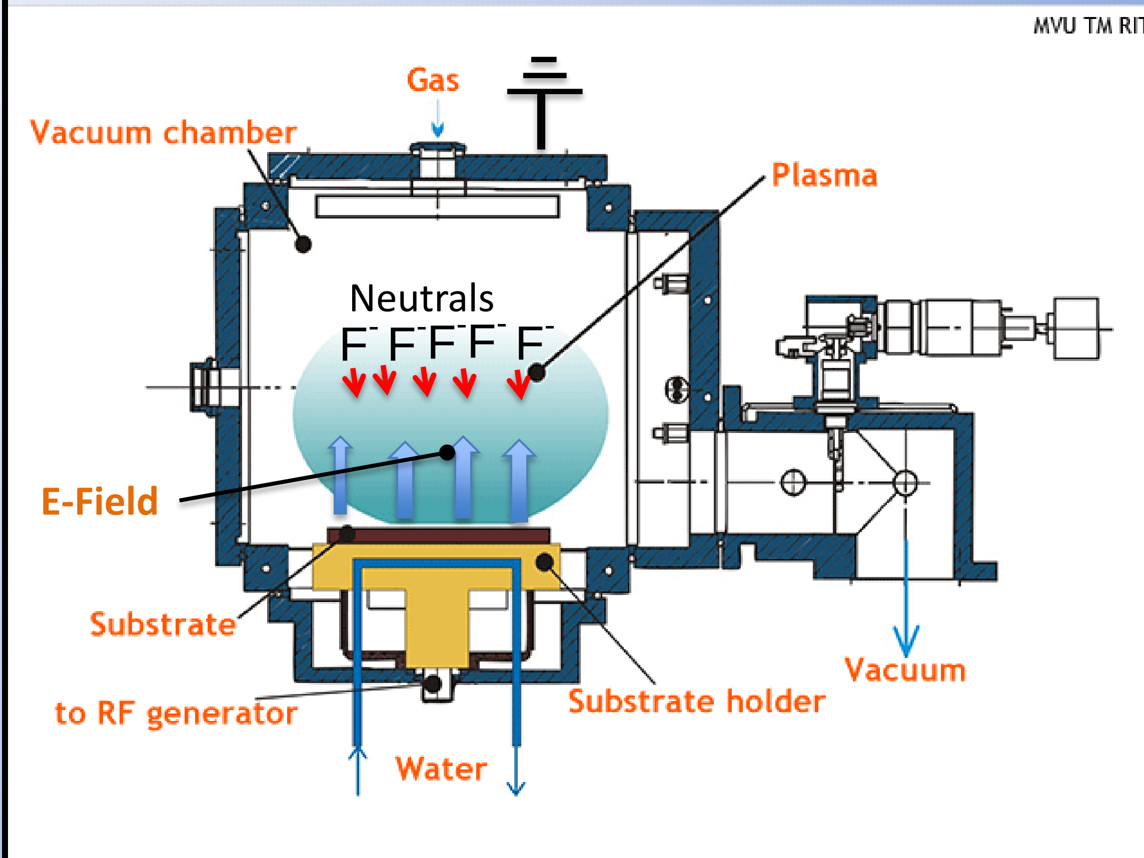
Reactive Ion Etching (RIE): The Basics

Halogen based gas (i.e., SF_6) is ionized to create F ions and neutrals. Neutrals react chemically with target.

F ions accelerate toward the target substrate under E-field and are adsorbed.

F ions assist neutrals chemical reaction, leading to enhanced chemical etching of target.

With argon added and ionized, Ar^+ physical bombardment of target causes erosion. Results in increased chemical reaction and higher etch rate.



P.H. Yih et al.: A Review of SiC Reactive Ion Etching in Fluorinated Plasmas, phys. stat. sol. (b)202, 605 (1997)

Observed Phenomenon

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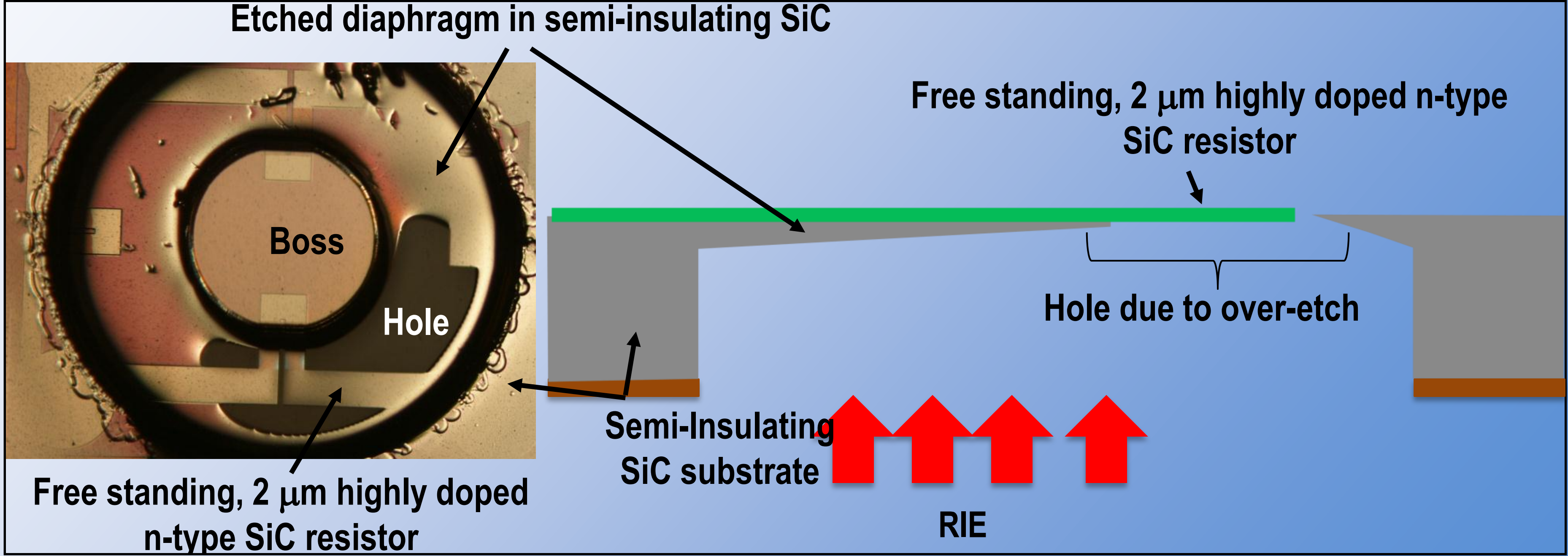
Unintentional rupture of micro diaphragms was observed during routine RIE (with SF_6 + Ar) of semi-insulated (SI) 4H-SiC substrate.

Observed free standing 2μm thick "cantilevers" of the patterned highly doped n-type homoepitaxially grown 4H-SiC piezoresistor layer on the SI SiC.

Etch selectivity between SI and highly doped n-type SiC is proposed



Technical Approach

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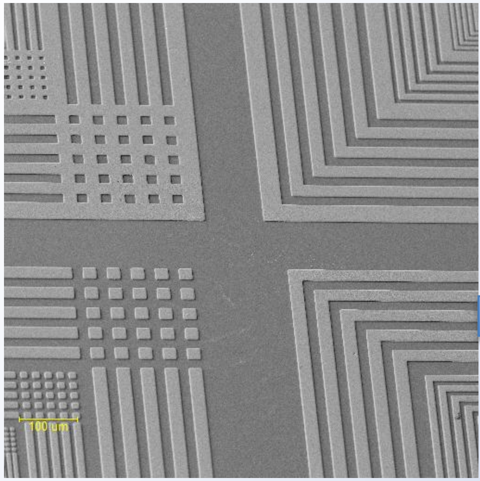
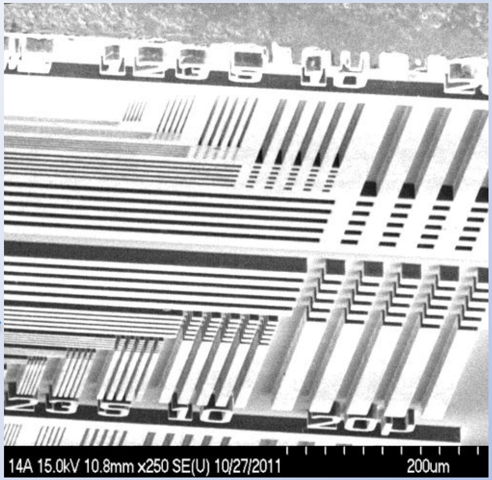
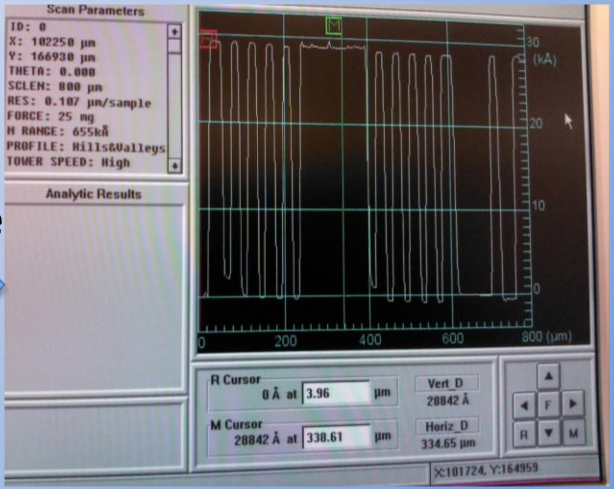


RIE



Depth Profile



Photolithography and Al pattern definition with calibration mask

Calibration patterns etched in n-type and semi-insulating SiC samples.

Al mask stripped off and performed depth profile measurement

Fixed process conditions:
RF Power=400 W;
Base Pressure = 25 mT;
Etch Time=2 hours

SF_6= Flow Rate (sccm)	SI	N-Type(N_d=3.8 x 10^{19} cm^{-3})
45	3	8
60	4	9
75	5	10

Selectivity Between SI and N-Type 4H-SiC

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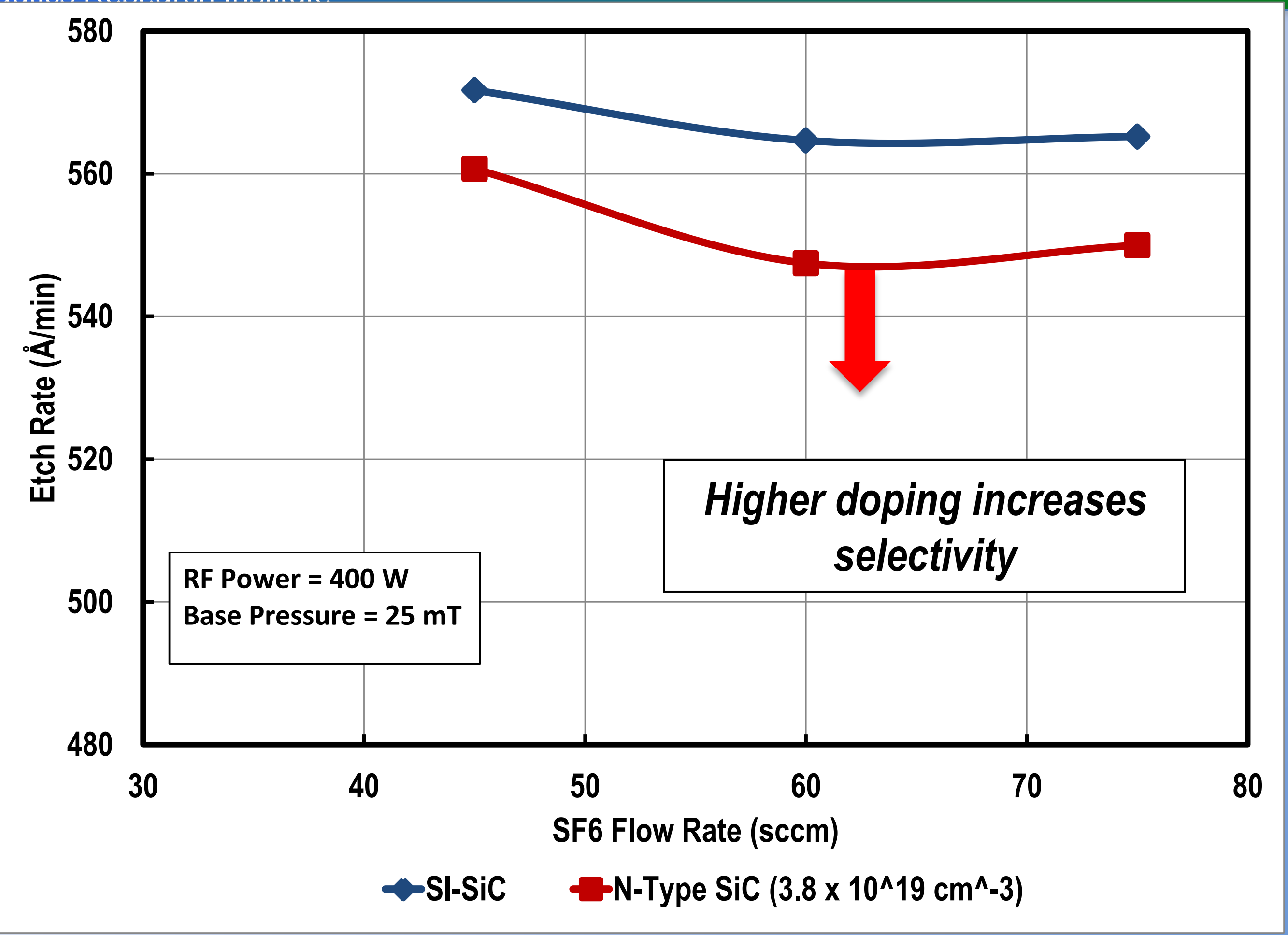

Etching selectivity between SI and highly doped n-type substrates in SF_6 gas only.

Selectivity Between N- and P-Type 4HSiC

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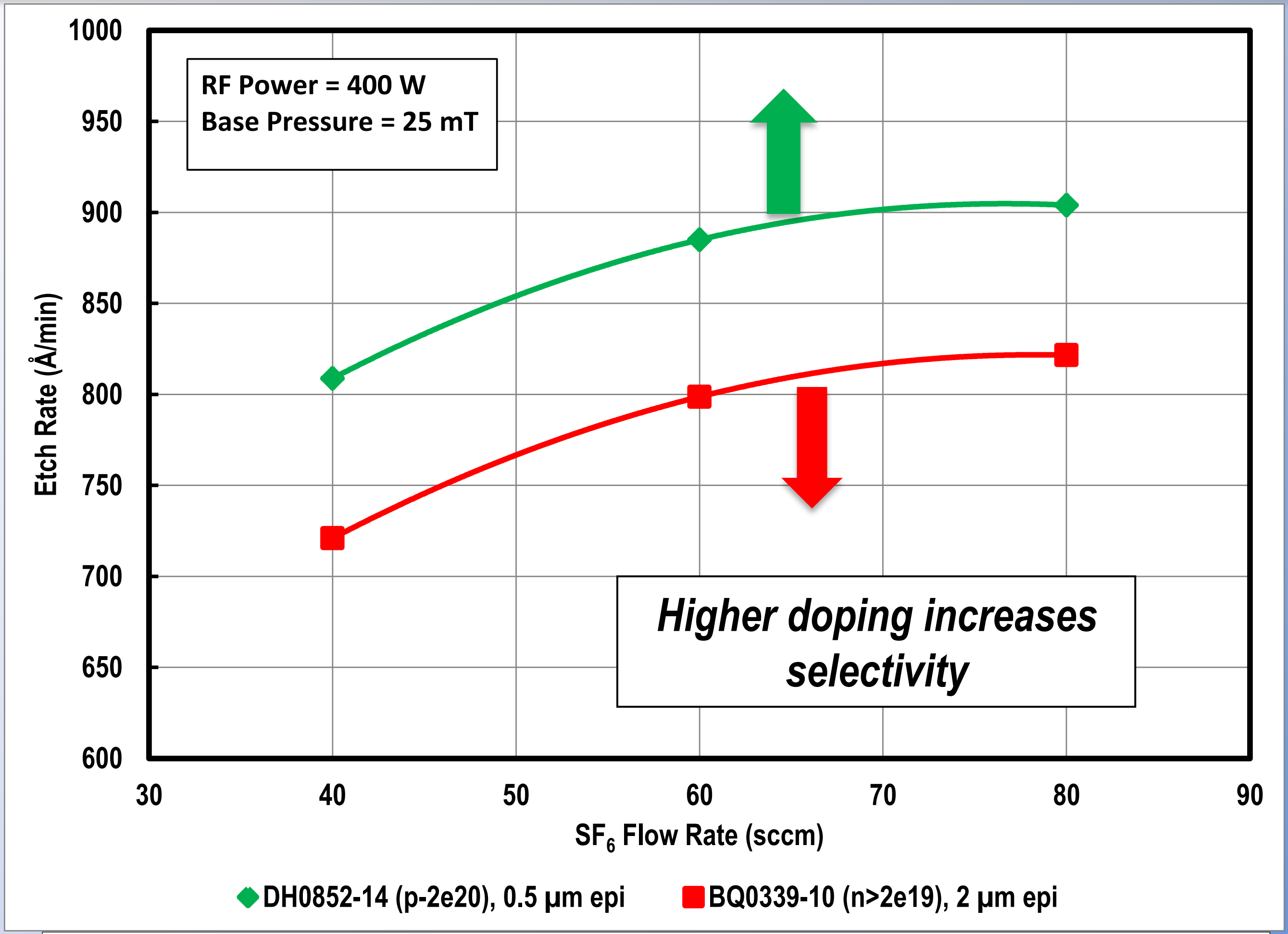
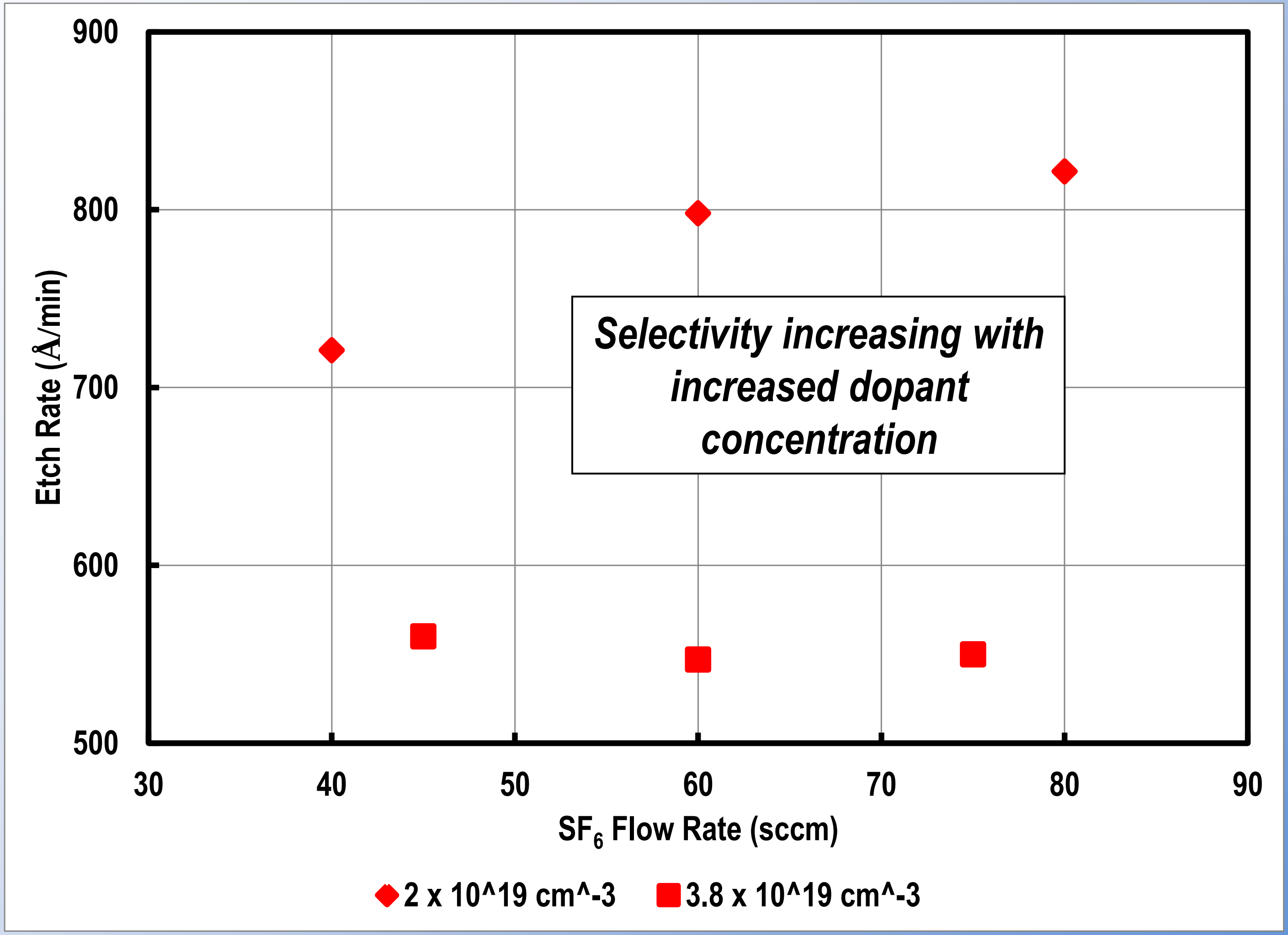


Etching selectivity between highly doped p- and n-type 4H-SiC substrates in SF_6 gas only.

Selectivity in N-Type Concentrations



DSRIE Release of N-Type Cantilevers

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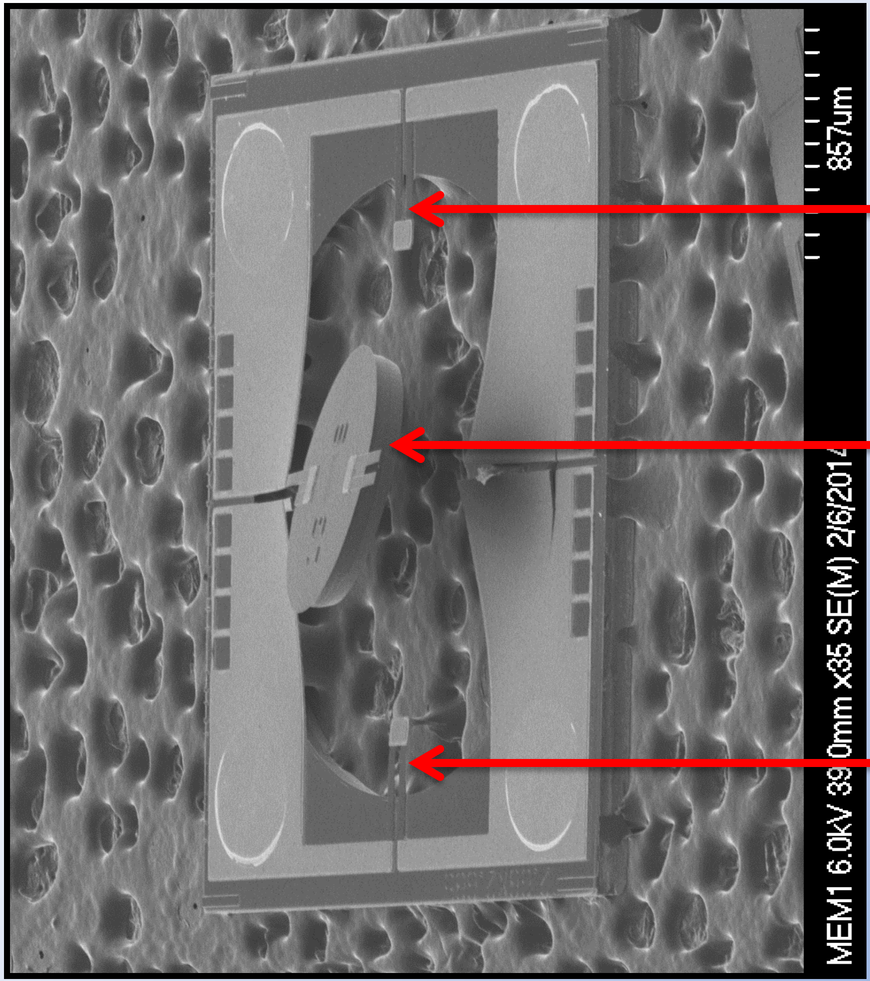
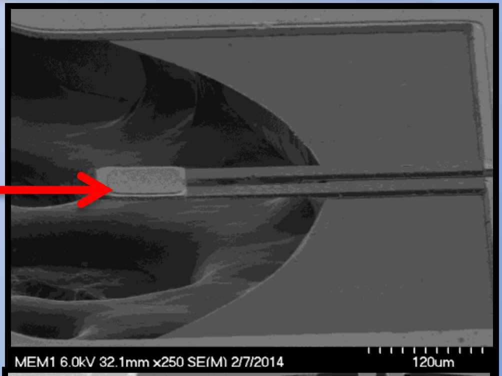
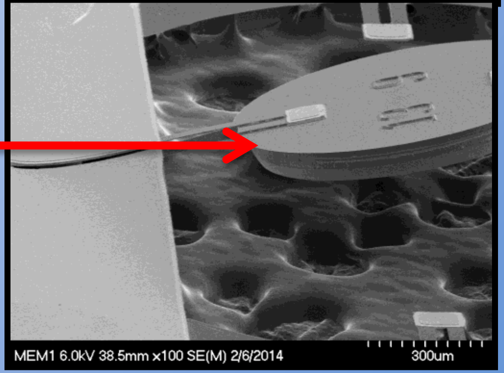
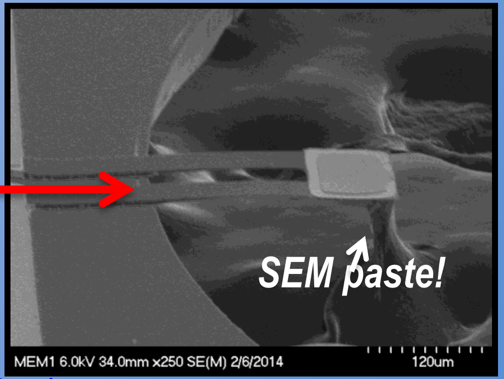




Suspended 2 μm thick single crystal SiC piezoresistor



Proof mass suspended by 2 μm thick single crystal SiC piezoresistor



Suspended 2 μm thick single crystal SiC piezoresistor

DSRIE Release of N-Type Cantilevers

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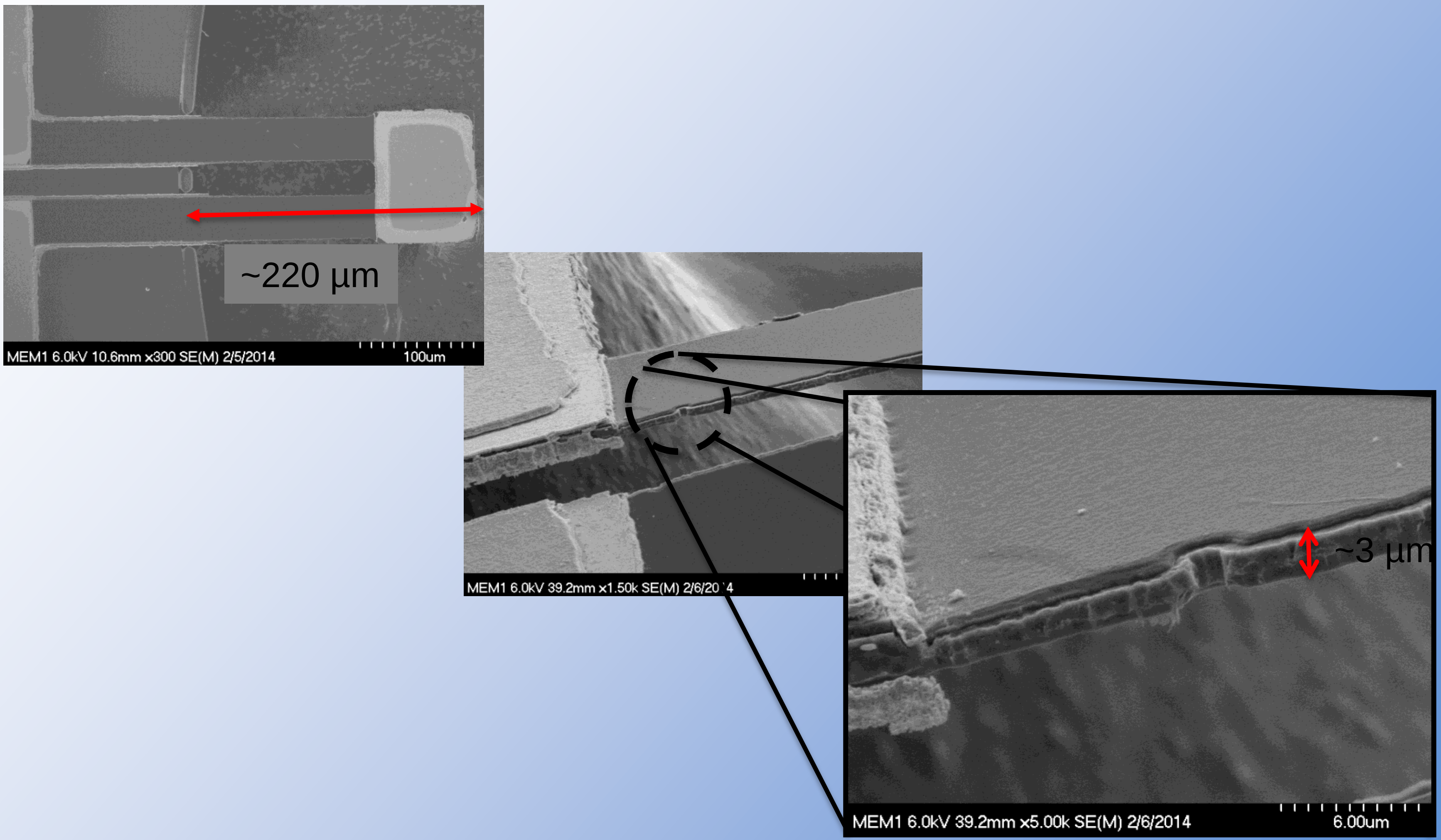


Innovation and Impact on Mission

Mission Challenges: Thermoacoustic instabilities in combustors are known to be precursor to flame-out or damage to engine components.

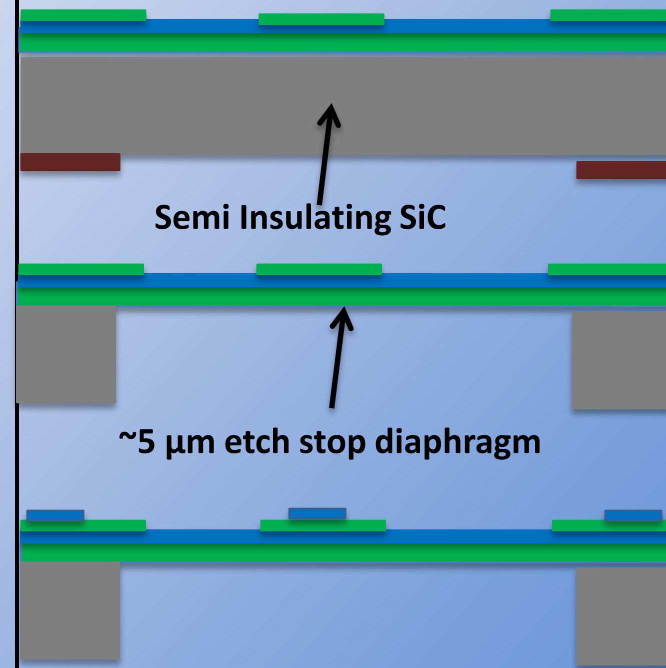
Existing instability prediction models have high uncertainty margins. Need environmentally robust and reliable pressure sensors for model validation and improvement.

Existing Technology Gap: SoA sensors placed feet from test article-limits frequency bandwidth; Water cooling adds “vortex noise” to corrupt signal.
Robust and reliable sensors needed for direct (no water cooling) measurement of sub-psi dynamics at >500 °C.

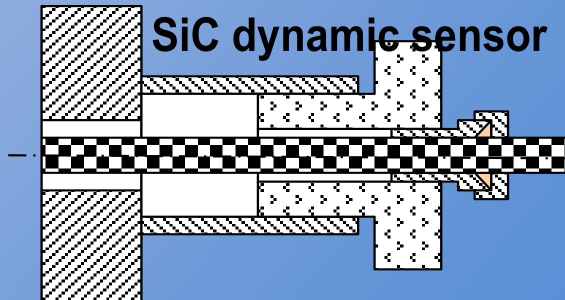
600 °C SiC pressure sensor technology currently exists, but SiC fabrication technology cannot produce the ultra-thin diaphragms to achieve the high sensitivity needed to resolve sub-psi pressure dynamics.

Innovation: DSRIE will result in ultra-thin (< 10 µm) SiC diaphragms to accurately resolve sub-psi dynamics at temperatures in excess of 500 °C (current capability).

Benefit of SiC Etch Stop Mechanism



Flush mounted SiC dynamic sensor

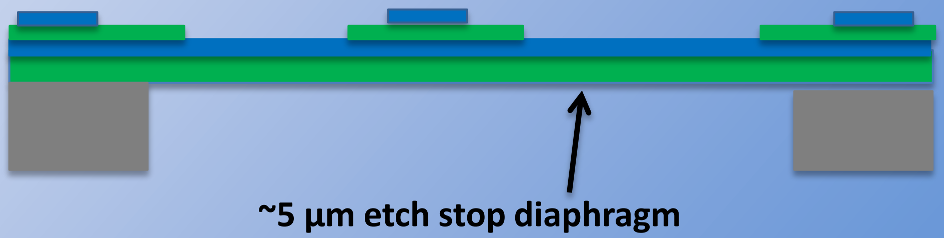


Next Steps

- **Improve further understanding of the DSRIE mechanism**
  -Investigate various doping levels and other halides to optimize etch selectivity

- **Demonstrate 5-10 µm thick diaphragm SiC pressure sensors**
  -Based on circular plate theory, maximum deflection (for deflections << thickness) of a clamped circular plate is expressed as:

$$\omega = \frac{3Pr^4}{16Eh^3}(1 - v^2)$$



Where: ω=maximum deflection (m); P=applied pressure (Pa); r=diaphragm radius (m); E=Young's Modulus (Pa); h=diaphragm thickness (m); υ=Poisson ratio

For E =475 GPa for SiC; h =5 µm; r =1 mm; υ = 0.212

The predicted ω ~ 1 µm and applied pressure is ~345 Pa (0.05 psi)

Summary/Conclusion

- Confirmed existence of dopant and conductivity selectivity in SiC during reactive ion etching with SF_6 gas;
- While the etch selectivity ratio between the SI and n-type SiC using SF_6 gas is < 2, free standing n-type cantilever structures were realized;
- Validation of this proof of concept allows the investigation of other halides in which the etch selectivity ratio may be higher.
- More experimental data is needed to determine the effective role of doping concentration and conductivity.

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