SAND2015-7588C

Exceptional service in the national interest

Sandia National Laboratories

D. R. Hughart, W. C. Kao, M. Goryll, C. Jiao, S. Dhar, J. A. Cooper, D. K. Schroder, S. Atcitty, J. D. Flicker, M. J. Marinella, and R. J. Kaplar

Elimination of Fast Interface States Using Phosphorus Passivation in 4H-SiC MOS Capacitors for Improved Power MOSFET Performance and Reliability

1. Motivation

- Wide-bandgap semiconductors such as Silicon Carbide (SiC) have material properties that make them theoretically superior to Silicon for power electronics for energy storage systems
  - *SiC promises to reduce the size, complexity, and cost of power conversion systems*
  - *However, questions about reliability have limited their implementation in systems*
- ***Our work this year evaluates various passivation techniques, their effects on interface trap densities, and how they are correlated with channel mobility. By understanding the device physics, system level performance can be improved.***
- We characterized SiC MOS capacitors fabricated with three different passivation methods
  - NO annealing (industry standard)
  - N plasma
  - Phosphosilicate glass (PSG) treatment

2. WBG Power Electronics Benefit Power Conversion Systems for Energy Storage

13.5 kV, 100 A Si IGBT module

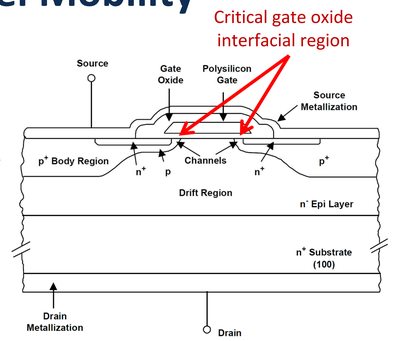
M. K. Das et al., ICSCRM 2011

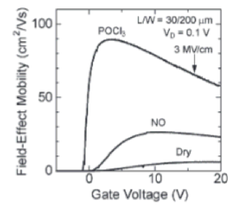
10 kV, 120 A SiC MOSFET module
10% weight and 12% volume of Si module

- All energy storage systems require power conversion
- Due to their higher switching frequency and higher temperature capability, WBG devices enable considerable size, weight, and complexity savings compared to Si
- ***WBGs thus enable new functionality, reduce system cost, and increase system reliability***

3. Interface States and Channel Mobility

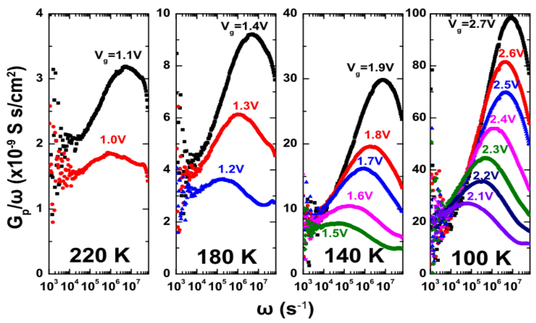
- Large interface trap densities near the conduction band edge affect channel mobility
- However, passivation treatments to reduce interface traps don't always result in improvements to channel mobility
  - 'Fast interface states'
- ***Using a phosphorus doped gate oxide has increased channel mobility***

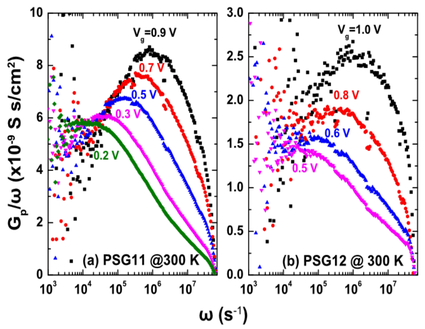




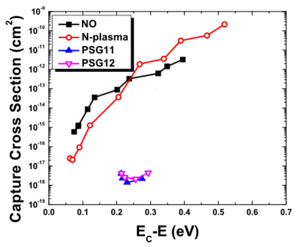
D Okamoto et al., *IEEE Electron Device Lett.* 31 710-2 (2010

4. Conductance and High-Low Frequency C-V Measurements

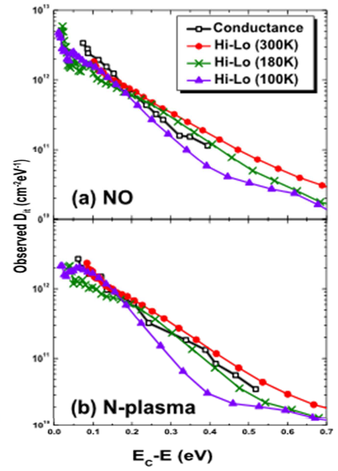


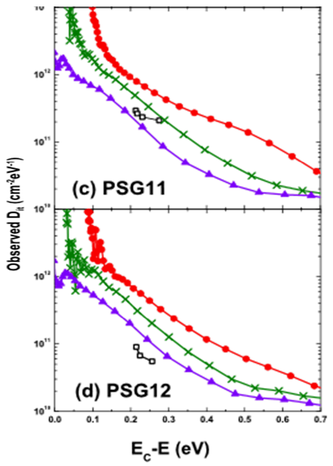


- N-plasma passivated samples show larger and more distinct peaks as the temperature is reduced (NO samples similar)
- PSG samples showed distinct peaks at room temperature, but not at lower temperatures
- Lower peak magnitude indicates lower interface trap density
- Extracted capture cross sections differ greatly between samples



- Samples show decreasing D_{IT} as temperature decreases
- At lower temperatures traps with slow time constants become too slow to be measured and traps with fast time constants become measurable
- Samples with PSG passivation show sharper decreases in D_{IT} as temperature decreases





5. Conclusions

- Conductance and high-low frequency C-V measurements show lower densities of 'fast interface states' in SiC MOS capacitors with PSG passivation compared to nitrogen passivation techniques
- The use of a PSG passivation reduces the density of 'fast interface states'
- Correlation with higher channel mobilities
- ***Improvements in mobility have implications at the system level as larger current densities enable devices to further shrink, reducing the footprint of power systems***

U.S. DEPARTMENT OF ENERGY

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.

We thank Dr. Imre Gyuk and the DOE Office of Electricity Energy Storage Program for funding this work