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Evaluation of Interface Trap Buildup in SiC Power MOSFETs using Subthreshold Characteristics

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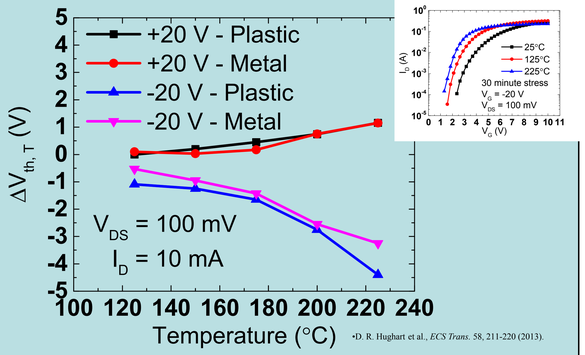
ABSTRACT

A method for extracting interface trap density (D_{IT}) from subthreshold I-V characteristics is used to analyze data on a SiC MOSFET stressed for thirty minutes at 175°C with a gate bias of -20 V. Without knowing the channel doping, the change in D_{IT} can be calculated when referenced to an energy level correlated with the threshold voltage.

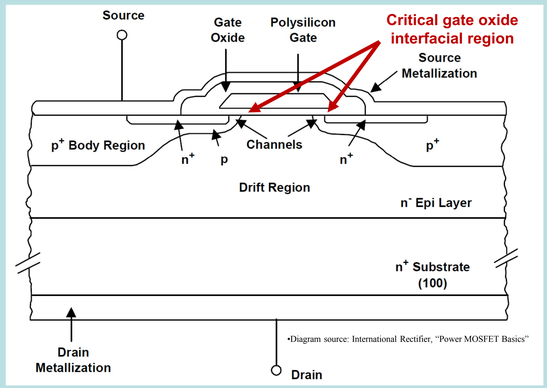
BACKGROUND

- Silicon Carbide (SiC) devices are theoretically superior to Si for power electronics applications
- Reliability concerns have limited implementation
  - High interface trap density
  - V_{th} instability at elevated temperature and biases



•D. R. Hughart et al., *ECS Trans.* 58, 211-220 (2013).

- Graphs are for first generation SiC power MOSFETs showing VT shifts after elevated temperature gate bias stress for plastic and metal packaging. The inset shows typical I-V curves.
- Increases in interface trap density are worse at elevated temperatures



•Diagram source: International Rectifier, "Power MOSFET Basics"

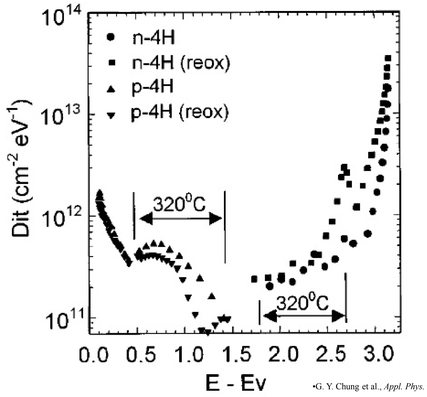
Stress: V_{GS} = +20 V, V_{DS} = 0.1 V

- Evaluation of interface trap density on vertical SiC power MOSFETs can be difficult without MOS capacitors and processing information from the manufacturer
- The increase in interface trap density after stress can be extracted from the subthreshold I-V curves

APPROACH

- High interface trap densities cause a change in subthreshold slope
  - Modulates the fraction of V_G that determines the barrier between source and drain

$$S = \ln(10)\frac{kT}{q}\left(1+\frac{C_d + C_{it}}{C_{ox}}\right)$$



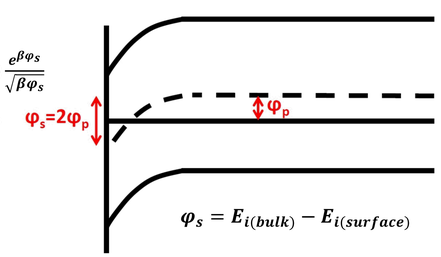
•G. Y. Chung et al., *Appl. Phys. Lett.* 76, 1713 (2000).

- SiC has D_{IT} profiles that rise sharply towards the band edges
- Subthreshold slope varies with gate voltage
  - Enables extraction of D_{IT} profiles

- Drain current can be related to surface potential:

$$I_D = I_{D0}(V_D)\frac{e^{\beta\varphi_S}}{\sqrt{\beta\varphi_S}}$$

- Effectively relates V_G to φ_S (band bending)
- Solve for I_{D0} at threshold

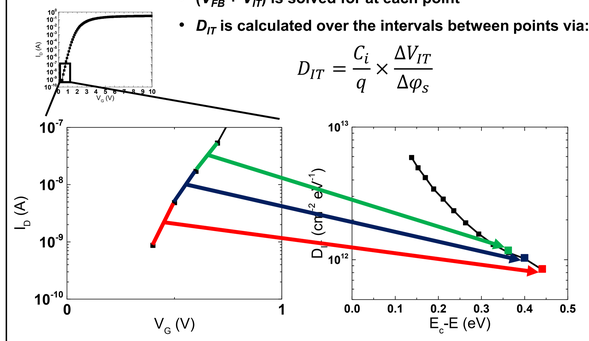


- Using V_G to φ_S , (V_{FB} + V_{IT}) can be solved for:

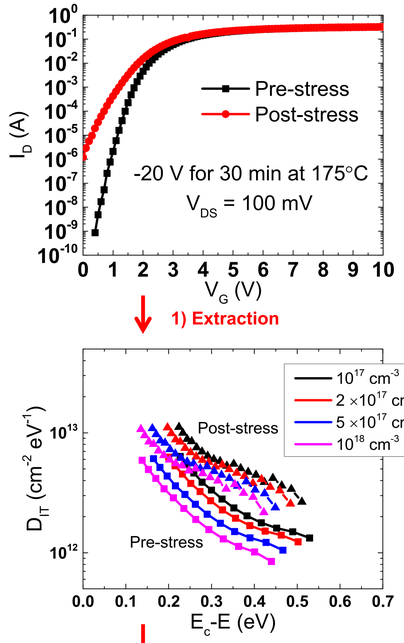
$$(V_{FB} + V_{IT}) = V_G - \varphi_S - \frac{a}{\beta}\sqrt{\beta\varphi_S - 1}$$

- (V_{FB} + V_{IT}) is solved for at each point
- D_{IT} is calculated over the intervals between points via:

$$D_{IT} = \frac{C_i}{q} \times \frac{\Delta V_{IT}}{\Delta\varphi_S}$$



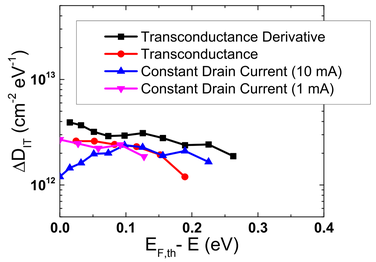
RESULTS



- Variation in assumed doping values causes shifts in the D_{IT} profiles
- Varying the assumed doping changes the bulk potential, altering φ_s at V_{th}
- D_{IT} profiles can be aligned by normalizing the energy level to the Fermi level
- Variations in assumed doping cause changes in calculated D_{IT} concentrations
- ΔD_{IT} profiles are independent of assumed doping concentration when referenced to $E_{F,th}$

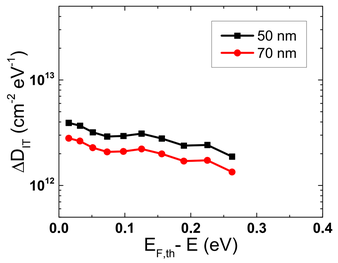
DISCUSSION AND CONCLUSIONS

- Three sources of uncertainty: Doping, V_T selection, oxide thickness
- ΔD_{IT} has been shown to be independent of assumed doping

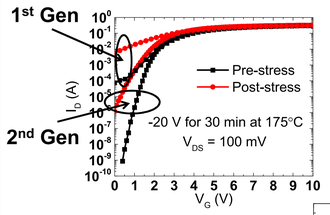


- Three different V_T extraction methods were tested on the same data set
- g_m derivative method and g_m method show similar trends
- Constant current method may produce unphysical results

- Calculated ΔD_{IT} varies with oxide capacitance
  - Oxide thickness
- ΔD_{IT} changes by the ratio of the assumed C_{ox}
  - 70nm/50nm = 1.4
- Typical oxide thickness range small

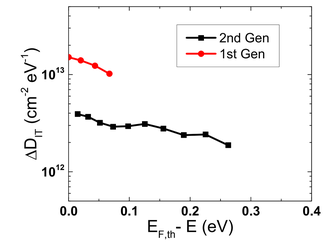


- ΔD_{IT} profiles for first and second generation SiC power MOSFETs have been extracted for identical stress conditions



- D_{IT} has reduced from the first generation to the second

- Less information for first generation devices
  - Equivalent voltage sweep covers fewer energies due to higher D_{IT}
  - Fewer data points on first generation I-V curves



- **This method provides a fast and easy way to evaluate the effects of BT stress on SiC vertical power MOSFETs using only subthreshold curves**
  - **Independent of assumed doping**
  - **Threshold voltage extraction technique must be carefully considered**
  - **Minimal effects of oxide thickness uncertainty**

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