# Characterization of Large Area 4H-SiC and 6H-SiC Capacitive Devices at 600 °C

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## Abstract

SiC based capacitive devices have the potential to operate in high temperature, chemically corrosive environments provided that the electrical integrity of the gate oxide and metallization can be maintained in these environments. We report on the performance of large area, up to 8 x $10^{-3}$ $cm^2$, field-effect capacitive sensors fabricated on both the 4H and 6H polytypes at 600°C. Large area capacitors improve the signal/noise (S/N) ratio which is proportional to the slope of the capacitance-voltage characteristic. At 600 °C we obtain a S/N ~ 20. The device response is independent of polytype, either 4H or 6H-SiC. These results demonstrate the reliability of our field-effect structure, operating as a simple potentiometer at high temperature.

## Introduction

SiC metal-oxide-semiconductor (MOS) devices can be used in elevated temperature as well as chemically corrosive applications provided that the electrical integrity of the gate oxide and metallization is robust in these environments. The primary mode of oxide breakdown under these conditions is attributed to electron injection from the substrate. Previous studies of the gate leakage current on 4H-SiC and 6H-SiCcapacitors demonstrated current densities less than17 nA/$cm^2$ [1]. These measurements were performed at 330 °C for electric field strengths up to 0.6 MV/cm.

As capacitance is a measure of the stored energy in an electric field, i.e. C = Q/V, capacitors can be used as potentiometers to monitor voltage. The signal to noise (S/N) ratio of this potentiometer is proportional to the slope of the capacitance-voltage (C-V) characteristic, therefore large area capacitors are attractive for increased S/N. In this work we report on large area, up to 8 x $10^{-3}$ $cm^2$, capacitive sensors operating at 600°C. The n-type devices were fabricated on both the 4H and 6H polytypes.

## Experimental

Metal-oxide-SiC n-type capacitors, were fabricated on 6H-SiC and 4H-SiC substrates with a 5 μm epitaxial layer (nominal doping 2 x $10^{16}$N/$cm^3$) grown on highly doped waters. The gate oxide (35 – 47 nm) was grown via dry oxidation at 1150 °C, followed by a 900 °C Ar anneal and a 1175 °C post-oxidation NO passivation anneal [2]. Following a CMOS clean Pt (100 μm thick) metal gates ranging in diameter from 200 to 1000 μm were deposited by dc magnetron sputtering at a substrate temperature of 350°C in argon[3]. Electrical characterization of the capacitors at temperatures up to 620 °C, was performed by mounting the devices on an alumina header with backside Pt heaters. Shown in Fig. 1 is a micrograph of a 1$cm^2$ 4H-SiC chip with an array of 200, 300, 500 and 1000 μm diameter gates.

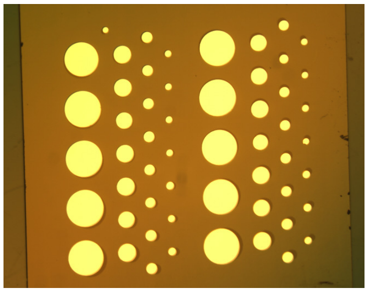

**Fig. 1**: Micrograph of a 1$cm^2$ 4H-SiC chip.

## Results

We focus here on the large area capacitors, as these devices have the highest signal to noise ratios. Typical C-V characteristics for two 1000 μm diameter capacitors are shown in Fig. 2 and 3.

Both devices are n-type, Fig. 2 is on a 4H-SiC substrate while Fig. 3 is for a 6H-SiC substrate. The measurements were performed at 1MHz with a 0.25 V/s sweep rate at a temperature of 600 °C. The oxide thickness for each polytype was determined via spectroscopic ellipsometery. For the 6H device we obtain an accumulation capacitance of 730 pF and for the 4H device 550 pF. These values are consistent with the independently measured oxide thickness and gate area, which confirms the stability of our gate oxide and metallization process for operation at the elevated temperature of 600 °C.

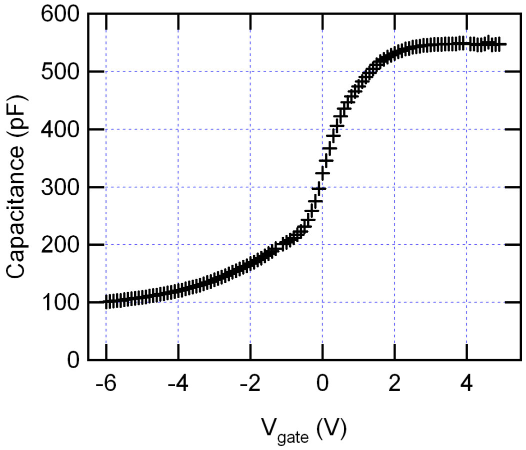

**Fig. 2**: Capacitance-voltage characteristic of a 1000 um diameter n-type 4H-SiC device at 600 °C.

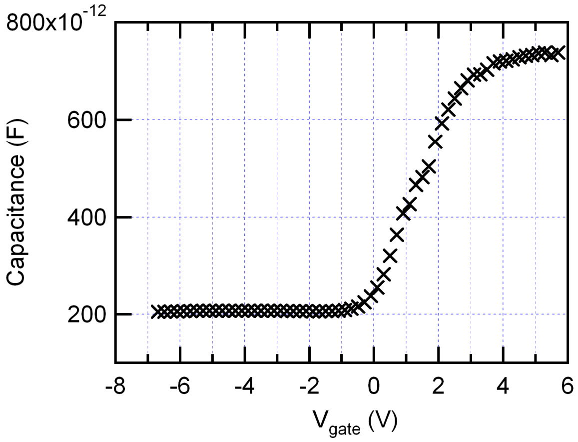

**Fig. 3**: Capacitance-voltage characteristic of a 1000 um diameter n-type 6H-SiC device at 600 °C.

In addition to their use as potentiometers, SiC capacitors with a refractory metal gate, such as a Pt-SiO$_2$-SiC MOS structure, can be used to detect hydrogen gas at high temperature [4]. The Pt metal gate acts as a catalyst to dissociate molecular hydrogen. Atomic hydrogen diffuses through the Pt metallization and is adsorbed at the metal-oxide interface creating a dipole layer. This results in a shift in the device potential ΔV, which is logarithmically related to the hydrogen concentration via a Nerstian relationship [3]. During sensor operation, the device capacitance is held constant by an external circuit, and the corresponding gate voltage is recorded as the sensor signal ΔV. Therefore the role of SiC capacitor is that of a sensitive potentiometer.

The response of two 4H-SiC and 6H-SiC devices to hydrogen gas at 620 and 600 °C are given in Figures 4 and 5 respectively. Plotted is the sensor response over 3 1/2 decades of hydrogen concentration ranging from 0.0025 to 10% (the balance gas is nitrogen). As expected from theory the sensor response is a logarithmic function of hydrogen gas.

For *both* the 4H-SiC and 6H-SiC polytypes we obtain a sensitivity of ~85 mV/decade. These results confirm that the SiC MOS capacitor is functioning as a simple potentiometer irrespective of the polytype of the substrate. The sensor response is determined by the chemical reactions at the catalytic Pt gate, which is the same for both the 6H and 4H-SiC devices. These measurements also testify to the reproducibility of our fabrication process. The two chips were processed independently on different substrates of different polytype, yet we obtain the same sensor response at 600 °C.

The signal to noise ratio of the potentiometer scales linearly with the area or capacitance of the device [4]. For the 6H-SiC 1000 μm diameter capacitors we obtain S/N ~ 20/1 at 600 °C. The robustness of our gate oxide merits further investigation into the limit of how large a gate is capable of surviving at high temperature.

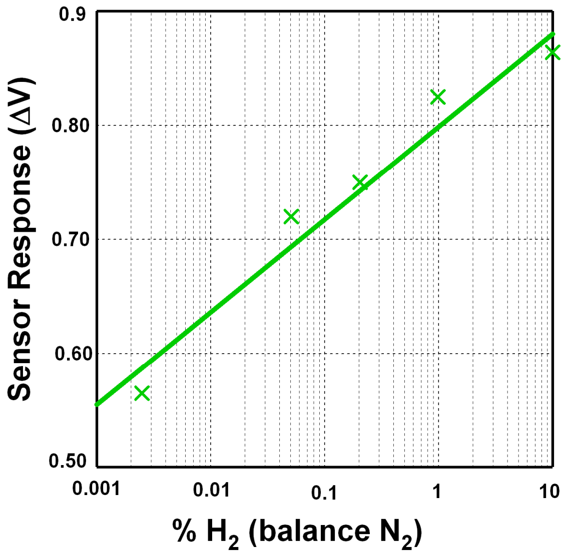

**Fig. 3**: Response of a 4H-SiC sensor to hydrogen at 620 °C. The device sensitivity is 84 mV/decade. The SiC structure is used as a sensitive, high temperature potentiometer.

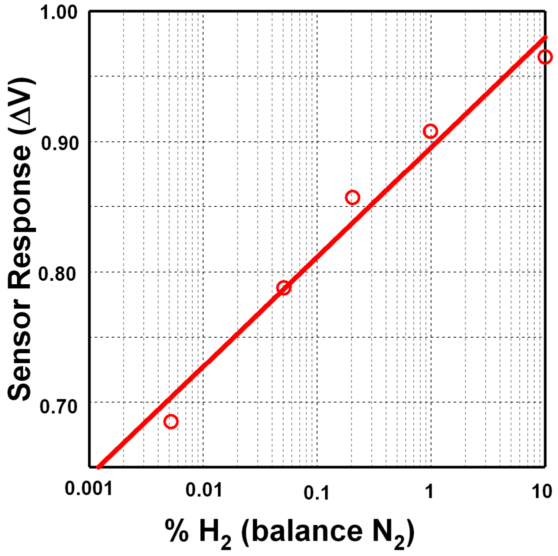

**Fig. 4**: Response of a 6H-SiC sensor to hydrogen at 600 °C. The device sensitivity is 85 mV/decade from 50 ppm to 10 % $H_2$. The signal/noise ratio is 20/1.

**Conclusion**:

We have demonstrated reliable operation of 4H-SiC and 6H-SiC large area capacitive devices at high temperature. Signal to noise ratio of 20/1 was obtained for 1000 μm diameter capacitors 600 °C. At these temperatures any defects in the gate oxide, from either the oxidation or the gate metallization process, would lead to irreversible damage of the MOS capacitor. Our data demonstrates that suitable fabricated SiC MOS structures are capable of continuous potentiometric measurements at temperatures as high as 600 °C.

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