Interfacial Studies of $HfO_2/CrSi_2$ thin films as High k Metal Gate Dielectric layer on SiC

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ABSTRACT

High k dielectric metal oxide films have attracted much attention as promising candidates providing many advantages over SiO_2. To increase the capacitance while reducing the tunneling current, various kinds of high dielectric materials have been investigated as possible alternatives to SiO_2. The use of high –k/metal gate technology will provide cost, performance and power savings. Owing to handle high critical electric field, electron saturation velocity and thermal conductivity SiC has advantages over Si, quantitatively put together 186 times better than Si. In this work, we have studied the low leakage electrical properties of nano HfO_2 thin films on SiC. The bandgap of HfO_2 thin films was observed to be 5.8 eV. MIS structures ($HfO_2/CrSi_2$/SiC) with Ni as a top and bottom electrode were fabricated to study the leakage current properties. The devices exhibited leakage current density of 30 nA/cm2.

Keywords: Semiconductor-metal interfaces, MOS devices, Semiconductor device fabrication, thin film

1 INTRODUCTION

HfO_2 has a dielectric constant varying from 15-26 with a bandgap of 5.8 eV, with a favorable conduction and valance band offsets with respect to SiC [1]. HfO_2 exhibits better thermodynamic stability, as would follow from the more negative Gibbs energy of formation -260 kcal mol^{-1}. It has refractive index of 1.92 at 0.6 μm and 2.1 at 250 nm [2]. HfO_2 has higher density of 6.6-7.9 gm cm^{-3} compared to most of the oxide materials in alternate dielectric applications [3].

Silicides are alloys of silicon with metals (metallic silicides) and gases (silicon dioxide) formed by thermodynamic alloying. These silicides find their applications in altogether as different class of materials like SiC or as a supporting materials system in Si based microelectronic applications [4]. The metallic silicides have been of significant interest to the CMOS processing due to stability at high temperature, low resistivity, easy for pattern etching, stability at different levels of processing like wet/dry etching, passivation, oxidation and low reactivity with the final metal. The most challenging aspect in CMOS processing is the metal absorption into Si thus forming metal spikes leading to short junctions or cause excess leakage thus damaging the device. The excess current forms voids in the interconnects and results in a device failure [5]. Metallic silicides have been explored to address the metal spiking in Si matrix. Metallic silicides tend to be highly conducting as well as semiconducting depending on the metal to Si concentration and processing conditions. Detailed information on the classification, type and applications can be found elsewhere [6]. The nanodispersed CrSi-oxynitride alloys exhibiting thermoelectric power of 90 μVK^{-1} at room temperature have been also reported for thermoelectric sensor applications [7]. $CrSi_2$ has found its unique place in BiCMOS processing that demand small temperature coefficients and compatible with CMOS fabrication methods. $CrSi_2$ is implemented as diffused regions in the emitter and base regions or in drain-source regions in IC fabrication methods.

In this paper, we discuss the interfacial studies of growth of $HfO_2/CrSi_2$/SiC thin films. The optical and properties are discussed. The electrical evaluation of $HfO_2/CrSi_2$ is carried out for MOS applications and the temperature stability is discussed.

2 EXPERIMENTAL

Metal-Oxide-Semiconductor (MOS) devices are fabricated by depositing $HfO_2/CrSi_2$ (20 nm/30nm) as a high k dielectric by RF sputtering on SiC. $CrSi_2$ thin films are deposited by RF sputtering (75 W) from a high purity $CrSi_2$ target (99.99% purity) at a base vacuum of 2 X 10^{-9} T in the chamber at room temperature. Si and Nanocrystalline substrates are used to deposit $CrSi_2$ thin films. Ni MOS diodes of area 200 μm^2 are fabricated using shadow mask and then the back contacts are fabricated.

$HfO_2/CrSi_2$ thin films are evaluated for morphology using SEM Hitachi S-4800. The structural properties are evaluated using X-Ray Diffraction (XRD). Device samples are electrically evaluated using HP4145B Semiconductor Parameter Analyzer at room temperature and at elevated stage temperatures in the range 50-300°C.

3 RESULTS AND DISCUSSION

3.1 UV-VIS Absorption measurements

Figure 1 shows the optical transmission spectra for the $HfO_2/CrSi_2$ films deposited on Al_2O_3 substrate. The films exhibited 78–82% optical transmission in the visible and UV range. The film showed a sharp drop in the optical transmission at 210 nm corresponding to a band-gap of 5.81 eV, which is close to the bulk HfO_2 bandgap value [8]. As the HfO_2 film will be studied for transport properties at higher temperatures, the as deposited film was annealed at 500C in oxygen. The optical transparency is reduced by 3-4% when the film was annealed at 500^o C in oxygen due to the oxidation of $CrSi_2$ films.

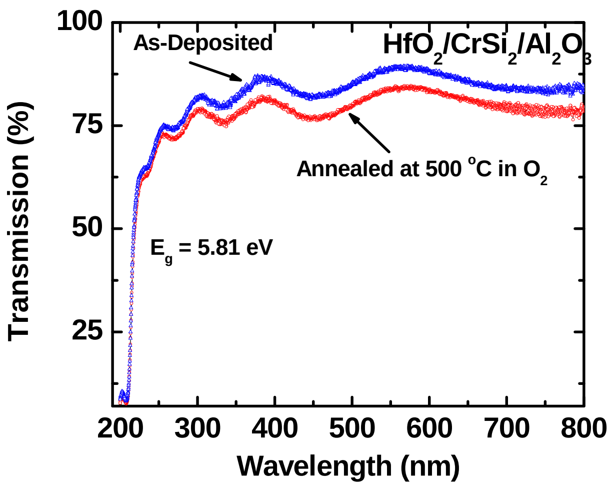

***Figure 1**. UV-Visible Transmission spectra of $HfO_2/CrSi_2$ samples for as deposited and annealed films in O_2 at 500 ^{o}C.*

3.4 Current-Voltage characteristics of $HfO_2/CrSi_2$ thin films

The Metal –Insulator-Metal structures are fabricated using the shadow mask process. First, the SiC substrate was cleaned in the dilute HF, and then annealed in nitrogen for 15 minutes. Afterwards, the SiC were cleaned in bufered oxide etch solution to obtain oxide free clean surface. Ni was then evaporated to form the back ohmic contact. The contacts were then annealed in nitrogen for 30 minutes at 500^{o}C. SiC substrate with the back ohmic Ni contact was then used to deposit $CrSi_2$ and HfO_2 bt reactive sputtering. After, $HfO_2/CrSi_2$ deposition, Ni circular top metal contacts were fabricated through shadow mask.

Figure 2. shows the schematic of $HfO_2/CrSi_2$ (in the form of circular metal dots deposited through shadow mask) on SiC. MIS structures ($HfO_2/CrSi_2$/SiC) with Ni as a top electrode and $CrSi_2$ as a bottom electrode were fabricated to study the leakage current properties.

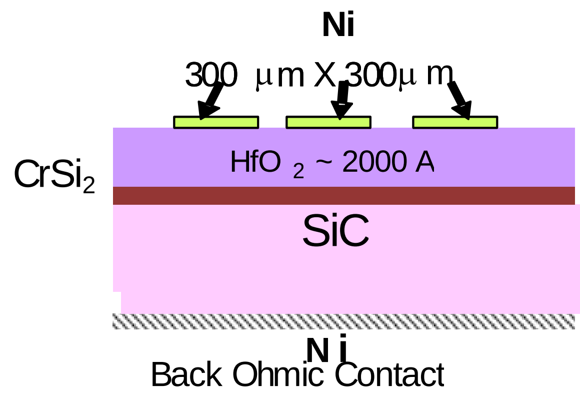

***Figure 2.** Schematic of $HfO_2/CrSi_2$ on SiC. Ni Ohmic contacts are fabricated through shadow mask.*

I-V measurements **(Figure 3)** were recorded as a function of temperature from room temperature to 200^o C in steps of 25^o C. The devices exhibited low leakage current density of 80 nA cm^{-2} at room temperature and remained stable till the device elevated to 75^o C with a leakage current density increased to 10 μAcm^{-2} for an applied voltage of 2 V corresponding to breakdown field of 1 MV/cm. The leakage current reached 0.1 mA-cm^{-2} at 175^o C. The breakdown field being mentioned in the study does not correspond to the actual breakdown voltage of the device; rather it is safe value of field to handle the device.

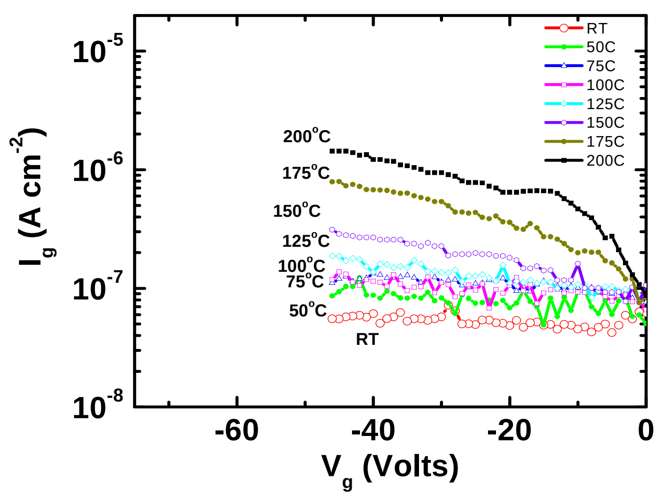

Figure 3. I-V characteristics of $HfO_2/CrSi_2$ on SiC

The actual field may be higher than this value. The rate limiting conduction process is evident in the temperature activated region because of the Frenkel-Poole (FP) or Schottky emission from the Si conduction band into the $HfO_2/CrSi_2$ dielectric insulator. However, below 75^o C the leakage current is independent of temperature and is due to the tunneling of carriers across the bands. This tunneling mechanism might be due to emission of trapped holes in the lower filled band in dielectric insulator.

Conclusion

$HfO_2/CrSi_2$ are grown on SiC by sputtering at room temperature. The structural, optical and electrical properties of $HfO_2/CrSi_2$ thin films are studied. Thin films exhibit high temperature stability when used in MOS configuration without significant device leakage. The Schottky barrier height of $HfO_2/CrSi_2$ on SiC is computed to be at 0.62 eV. $CrSi_2$ is shown to be an ideal candidate as metallic contact for high k metal dielectrics for MOS device applications.

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