DIFFERENCES BETWEEN SOLID-STATE REACTION OF PT THIN FILM DEPOSITED ON C- AND ON SI-FACE OF 6H-SIC

Stefan Gasser, Ilan Shalish[1], Elzbieta Kolawa [2], L.Burstein[1] and Marc-A.Nicolet
California Institute of Technology, Pasadena, CA 91125 (818) 395-6555
[1] : Tel-Aviv university, Department of Physical Electronics,
Ramat-Aviv, Tel-Aviv IL-69978 (972) 3-642-3508
[2] : Jet Propulsion Laboratory, Pasadena, CA 91109 (818) 393-2593

Abstract

Thin films (100nm) of platinum were sputter-deposited on a single-crystal (6H) alpha SiC substrates with (0001)-oriented faces terminated by either carbon or silicon, and annealed

chemically before loading into a sputter-deposition system. Their changes were monitored by 2MeV $^{4}He^{++}$ backscattering spectrometry, x-ray diffractometry and X-ray photoemission spectroscopy.

the carbon face of 6H-SiC, but not on the silicon face. The initial stages of a reaction on the

resemble those of the oxidation process of 6H-SiC in that (1) there is a non-symmetry in the reaction between the carbon and the silicon faces, and (2) the carbon face is the more reactive one of the two.

INTRODUCTION

Excellent physical and chemical stability, combined with a large bandgap (2.86eV for 6H-SiC) and a good electron mobility are the reasons why SiC is one of the most promising semiconductor for high-temperature electronics as well as high-power devices [1]. SiC is also used in fiber-reinforced metal-matrix composites because of its high strength, light weight, and superior chemical stability. The interface between metal and silicon carbide is of great interest for both electrical and composite application. In metal-matrix composites, the interface influences the load transfer between the metal matrix and the silicon carbide reinforcement and affects the mechanical properties of the composites [2]. In electronics, the interface determines the properties of the electrical contact (ohmic or rectifying). Since there has a dangling comparative difference in the oxidation kinetics of 6H- SiC surfaces [5,6] depending the polarity of the SiC face, it is important to investigate if there is also a difference in solid-state reaction of thin metal layers with single-crystal 6H-SiC, depending on the polar face. Solid state reactions of Pt thin films with single-crystal SiC have been studied for Beta-SiC [3] as well as for 6H-SiC [4]. We have attempted to answer this question using Pt thin films deposited on both polar faces of 6H-SiC. The solid-state reactions at temperatures between 300 and

spectrometry, x-ray diffraction and, for selected samples, x-ray photoemission spectroscopy.

EXPERIMENTAL PROCEDURES

The (0001) oriented single-crystal 6H-SiC substrate was provided by CREE Research

Inc. featuring a wafer thickness of 0.33mm (13mil), 10^{18} net n-type doping, production grade, and both sides polished. The top side of the wafer was Si-face and the backside of the wafer was C-face-oriented. Before loading into the deposition chamber, the SiC substrates were degreased in ultrasonically agitated solvent baths and chemically etched by 10% water-diluted HF for 10 min. RF-magnetron sputtering with Ar gas was used to deposit a Pt thin film of 100nm thickness in a vacuum of $6x10^{-7}$ Torr base pressure. The substrate plate was neither cooled nor heated externally and was placed 7 cm below the planar magnetron cathode of 7.5 cm in diameter. The Pt films were deposited on both sides of the same substrate in two separate deposition runs to study reactions on the C- as well as on the Si-face. The SiC/Pt samples were annealed in a vacuum furnace

pressure of $5x10^{-7}$ Torr. The elemental composition profiles of the samples before and after thermal annealing were characterized by 2.0 MeV $^4He^{++}$ backscattering spectrometry. The samples

beam direction, and the scattering angle of

identification was obtained using Debye-Scherrer x-ray diffraction with a collimated Co K_α (hν=6925eV) beam incident on the s position-sensitive detector. Reference data were taken from JCPDS-ICDD PDF-2 database. Selected samples were also analyzed for their depth concentration profiles of Pt, Si and C by X-ray photoemission spectroscopy. These measurements were carried out in ultra high vacuum ($3x10^{-10}$ Torr) using a PHI5600 Multitechnique System with spherical capacitance analyzer and monochromatized Al K_α radiation (hν = 1486.6eV) source using a spectrometer pass energy of 117eV with an energy interval of 0.50eV. Sputtering was done with 4keV Ar ions at beam current of 1mA. For better uniformity the samples were rotated during sputtering. The area of the sample sputtered off by ions was about 7 mm^2. Data acquisition and sputtering were done alternately.

RESULTS AND DISCUSSION

Backscattering spectrometry and X-ray photoemission spectroscopy

Figure 1a)-d) shows the backscattering spectra of SiC/Pt samples from carbon- as well as from the silicon face before and after

min. Due to the small size of the samples, variations in the $^4He^{++}$ ion beam direction, and insufficient beam focusing, a spurious signal from the carbon backplate in addition to that of the samples could not be avoided, so conventional total charge method to calibrate the yield of the spectra could not be applied. Therefore the spectra were calibrated by integrating counts from the surface energy of carbon (0.505 MeV) over the silicon and the platinum signals up to 2.0 MeV, assuming that mass was conserved..

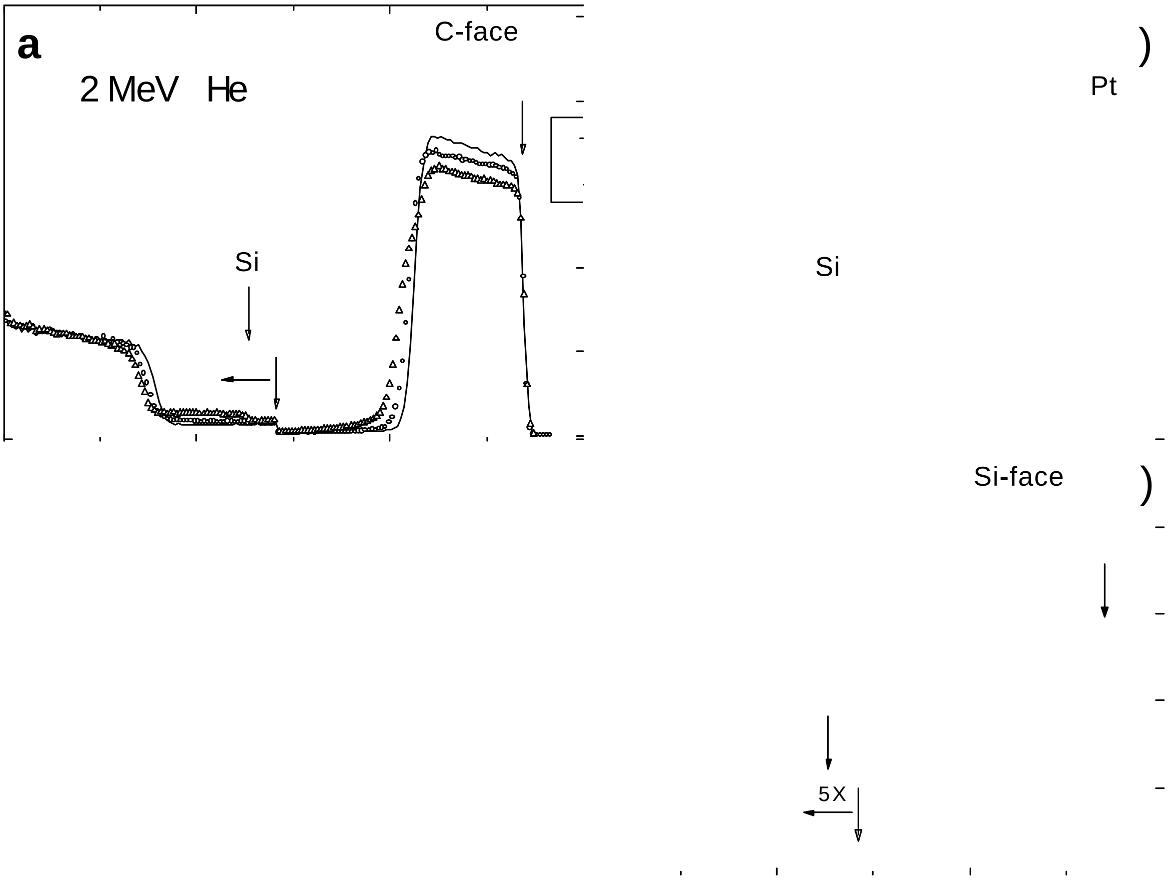

Fig.1 2.0MeV ^{4}He^{++} backscattering spectra of SiC/Pt samples before and after annealing on C- and on Si-face. **a)** -face **b)** -face **c)** -face **d)** -face.

The backscattering spectrum of the Si-face of

shows any change after annealing neither in case of the 30 min nor the 120 min anneal. On the other hand, the spectrum of the C-face sample annealed

typical signs of reactions between Pt and Si. The Pt signal broadens at the low energy edge and its height decreases. The edge of the silicon signal shifts backwards, which means that some Si has reacted with the Pt.. After a further anneal of 120 min, silicon exists throughout the whole Pt layer, creating a plateau-like Si signal reaching the surface energy position of silicon.

Contemplating the spectrum of the C-face

further broadening of the Pt signal can be seen together with a clear step in its low-energy edge. The change in the Pt signal is accompanied by the appearance of a large step in the Si signal at the surface energy of Si. The backscattering spectrum of the Si-

for 30min, (Fig.1d) shows a very initial stage of the reaction, namely the low energy edge of the Pt signal is slightly broader.

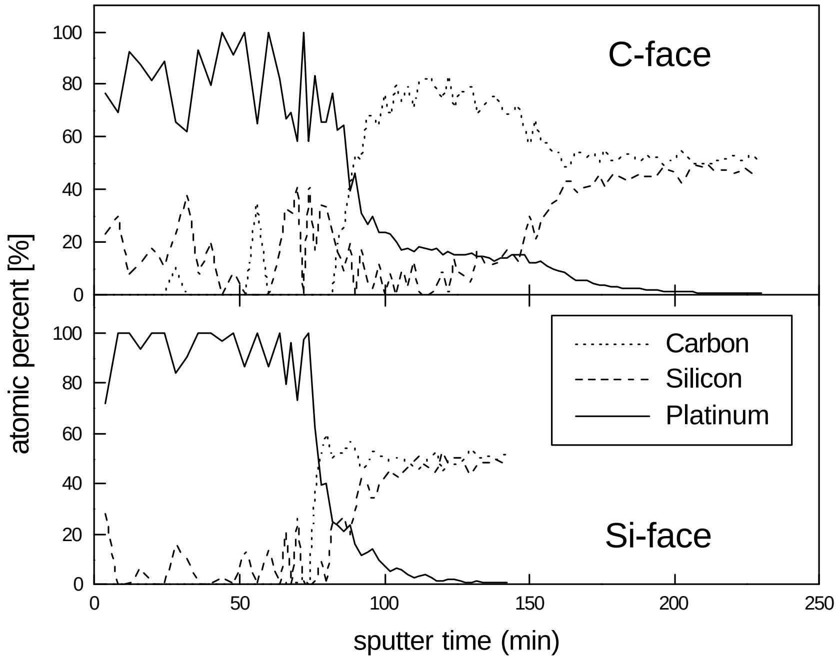

Fig.2 X-ray photoemission spectra of SiC/Pt C- and Si-

nnealing temperature the difference between the carbon and the silicon polar faces disappears. Both faces show a bilayer structure in the Pt signal of the backscattering spectra. The tail at the low energy edge of the Pt signal is enhanced in the case of the Si-face and leads to a increased background down to the Si signal. This higher background level on the Si-face is discernible already at the spectrum of the

We also have performed by photoemission spectroscopy for selected samples. This is important especially for carbon which profile

^{4}He^{++}

backscattering spectrometry. Figure 3 shows the photoemission spectra of the C- and the Si-

30 min. The formation of a carbon rich interlayer can be observed in the spectrum of the C-face, while on the Si-face no signs of a carbon accumulation are indicated. Since Pt does not form any compound with carbon, and since formation of a amorphous interlayer between Pt and β-SiC could be observed by high-resolution cross-sectional TEM [3], the carbon rich interlayer discovered by photoemission spectroscopy is suggested to be amorphous. Comparing the decrease of the carbon with the silicon signal at the interface between Pt and SiC on the Si-face, a slight interdiffusion of Si and Pt might be observed. This would be consistent with the small change at the low energy of the Pt signal in the corresponding backscattering spectrum.

X-ray diffraction

The x-ray diffraction spectra of the as-deposited sample and samples annealed at

The as-deposited samples show diffraction peaks of pure Pt on both faces. Pure Pt peaks still can be seen in the spectrum of the

the C-face new peaks of Pt_3Si can be

the pure Pt phase have completely disappeared in the spectrum of the C-face, while they still remain on the Si-face. The peaks from the C-face can be designated as Pt_3Si. Peaks from the same phase can be observed in the spectrum of the Si-face, but together with the stronger peaks from pure Pt. The difference between the two faces disappears at the spectrum of the sample

The phases $Pt_{12}Si_5$ as well as $Pt_{64}Si_{36}$ and PtSi can be seen, indicating that the system is not yet in thermal equilibrum.

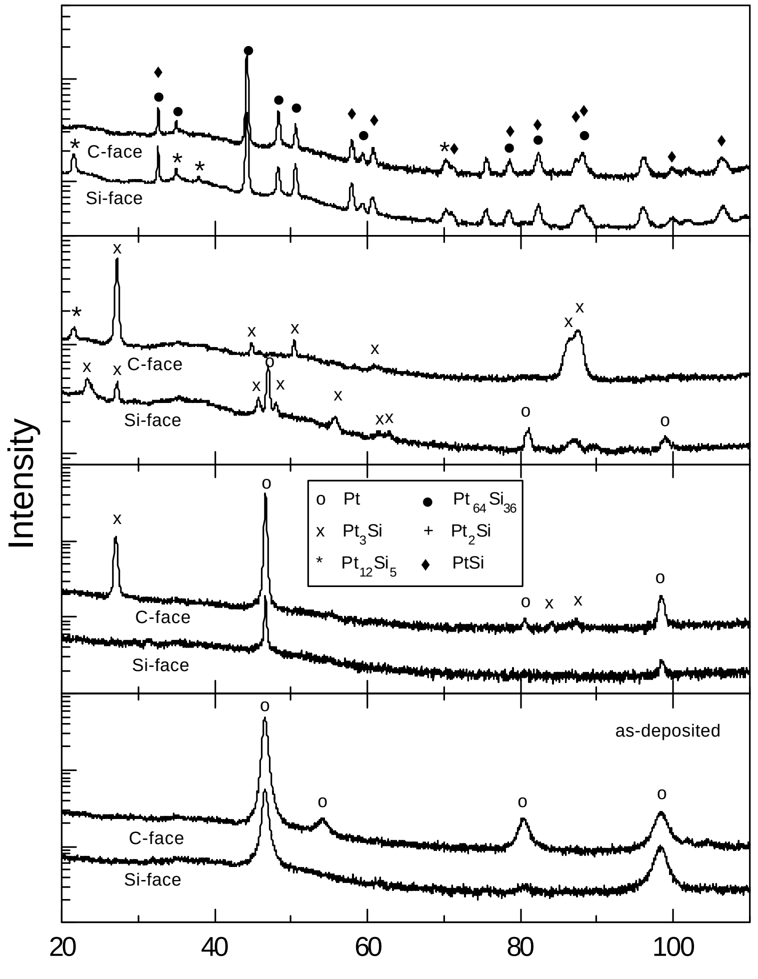

Fig.3 X-ray diffraction (Co K_α - and Si-face.

Photoemission spectroscopy measurements of the pure 6H-SiC substrate surface, prepared by the same chemical cleaning process applied for the Pt-covered samples, showed fluorine originating from the HF etch. The atomic concentration of fluorine was around 20% on the C-face, whereas on the Si-face around 10% could be detected. The question whether this dissimilar concentration of fluorine or of some other impurity is related to the observed solid-state reactions remains open.

Additional experiments were performed to eliminate the effect of slightly different exposure time to oxygen containing atmosphere of the C- and Si-face samples.

Reactions between Pt and β-SiC were previously investigated by J.S.Chen et al. [3]. Similarly, a first change of the backscattering spectra of annealed samples could be

well as in the present investigation, Chen designated the first product phase as Pt_3Si.

A distinct face dependence of the reactivity with annealing could also be detected by photoemission spectroscopy and Schottky barrier height measurements on Ni, Ti and Al contacts. Generally, the C-face showed a significantly higher reactivity than the Si-face [7]. A face dependence could also be observed measuring the contact resistance of tungsten-contacts on 6H-SiC, whose values were 2-2.5 times higher on the C-face than on the Si-face for the same doping level [8].

SUMMARY

Evident dependence on surface polarity of solid-state reactions of Pt thin films with single-crystal 6H-SiC

annealing temperature evokes a reaction on the C-face, while on the Si-face reaction was

difference disappears which shows that it is a kinetical process in nature. However, the cause of the difference remains obscure. Further investigations are necessary to improve the understanding of the phenomenon.

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