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# Growth of low-temperature cubic SiC on tilted and non-tilted (100)Si with 60 V breakdown Schottky barriers

C.W. Liu and J. C. Sturm

Dept. of Electrical Engineering, Princeton University, Princeton, NJ 08544

ABSTRACT: The growth properties of cubic SiC on (100) Si grown at temperatures of 700 to 1100°C, using a single precursor (methylsilane), were investigated. An optimun growth window was found at 800°C and a "two-step growth" technique was utilized to improve the crystalline quality of high temperature growth. Simple Pt-Schottky barriers fabricated on n-type SiC on Si exhibited a "hard" reverse breakdown with a record high breakdown voltage of 60 V.

## 1. INTRODUCTION

Due to the lack of suitable cubic SiC substrates, cubic SiC is commonly grown on Si (100) substrates heteroepitaxially. But the conventional high growth temperature (>1300°C) of SiC on Si by chemical vapor deposition (Davis 1991) prevents the possibility of integration of SiC with or into Si-based devices. Furthermore, the low material quality of cubic SiC on (100) Si is reflected in very leaky Schottky barriers with previous highest reported soft breakdown of 8-10 V (Ioannou 1987). In this paper, we report the low temperature growth of SiC on (100) Si by using methylsilane ($SiCH_6$) as a single precursor for both Si and C sources (Goleki 1992). High device quality material was demonstrated by fabricating Schottky barriers on n-type SiC grown on (100) Si with 60 V breakdown voltage. This is the first time that sharp breakdown has been observed and to the best knowledge of the authors, represents the highest breakdown voltage reported to date for Schottky barriers on cubic SiC under any conditions.

## 2. GROWTH AND CHARACTERIZATION

The SiC films were deposited on Si (100) not-tilted and tilted (4° towards <110>) substrates by Rapid Thermal Chemical Vapor Deposition at growth temperatures of 700-1100°C. The growth pressure was 1 torr with 1.5 sccm methylsilane flow and 500 sccm hydrogen flow. For low growth temperatures (700-800°C), the substrate temperature was accurately determined by infrared transmission through the wafer (Sturm 1991). Growth temperatures higher than 800°C were controlled by the tungsten-halogen lamp power which was previously calibrated with a thermocouple welded into Si wafer. The SiC thickness was measured by fitting the optical reflection spectra from 500-700 nm with the SiC index of refraction of 2.6. Fig.1 gives the Arrhenius plot of growth rate of SiC on not-tilted (100) Si. The growth rate in the range of 700-800°C varied exponentially with inverse temperature and the activation energy for this reaction-limited growth was 3.6 eV. At higher growth temperature (800-1100°C), the growth rate had weak temperature dependence, indicating mass-transport limited growth. The X-ray diffraction (XRD) of 80 nm films grown at 750°C on not-tilted substrates exhibited a single crystalline feature with a broad unresolved CuKα1 and CuKα2 (400) peak (FWHM of 2θ = 1.6°), but transmission electron microscope (TEM) diffraction in Fig. 2 (a) showed evidence of some slightly in-plane rotated textures and very fine spots in <110> directions. The FWHM (2θ) of the unresolved (400) peak in the XRD spectra of 0.3 μm 800°C films on not-tilted substrates was as small as 0.75°, and TEM diffraction revealed single crystalline patterns, as shown in Fig. 2 (b). The 800°C films on tilted substrates had similar XRD spectra and TEM diffraction patterns, but had a smoother surface which facilitated Schottky barrier fabrication. On the other hand, the XRD spectra of films grown at 1000°C and 1100°C consisted of extra (111) and (220) peaks, indicating the growth of polycrystalline material.

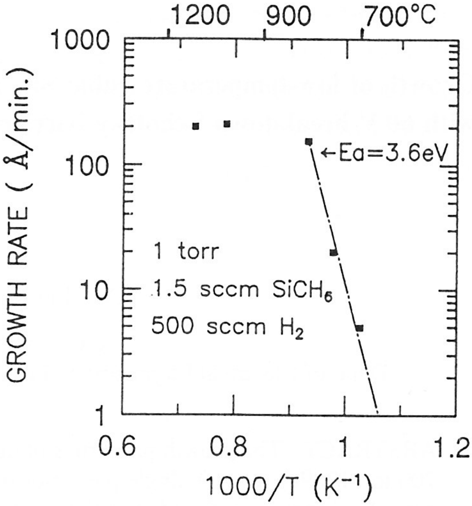
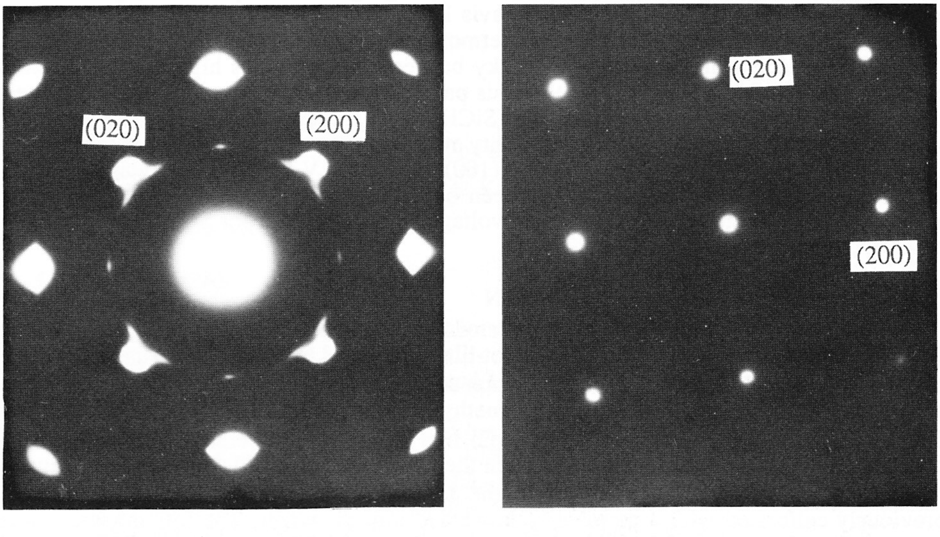


Fig.1 Arrhenius Plot for the growth rate of SiC on not-tilted (100) Si. The activation energy in reaction-rate limited region is 3.6 eV.



(a)

(b)

Fig.2 TEM diffraction patterns of (a) 80 nm SiC grown at 750 °C on not-tilted (100) Si, and (b) 0.3 μm SiC grown at 800 °C on not-tilted (100) Si. The 800 °C film has better single crystalline feature.

However, "two step growth," namely, a thin layer grown at 800°C first, then followed by high temperature growth, again yielded single crystalline films, as determined by XRD. This shows that a low growth temperature (800°C) at the Si surface is essential for single crystalline growth by this technique, in contrast to what is often observed in conventional growth techniques. The Fourier transform infrared (FTIR) spectra of the 0.3 μm 800°C film displayed an absorption peak at 796 $cm^{-1}$ with FWHM of 50 $cm^{-1}$ which is similar to that of the films grown by conventional high temperature methods (Li 1993). Raman spectra of the same sample showed a broad peak at 960 $cm^{-1}$ with FWHM of 60 $cm^{-1}$ which was about 10 $cm^{-1}$ below the LO phonon shift (~ 970 $cm^{-1}$) and probably correlated with the interface defects between SiC and Si (Feng 1988).

## 3. SCHOTTKY BARRIER FABRICATION

All samples used for Schottky barriers were grown at 800°C. Since the unintentionally doped SiC films were n-type with carrier concentrations around $10^{18}$ $cm^{-3}$, boron compensation was necessary to reduce the net dopant concentration of SiC films. Before metal evaporation, the samples were cleaned in dilute HF without any extra polishing, oxidation and etching (Ioannou 1987). The size of Schottky barriers were defined either by photolithography or by shadow masks. Two kind of Schottky barriers were studied: (1) Al (500nm) Schottky barriers of size $1.3\times10^{-4}$ $cm^2$ were fabricated on 0.4 μm, $3\times10^{17}$ $cm^{-3}$ n-type SiC with 2 μm, $1\times10^{16}$ $cm^{-3}$ n-type Si buffer on not-tilted n-type (100) Si substrates; (2) Pt (80nm) Schottky barriers of size $1.3\times10^{-3}$ $cm^2$ were fabricated on 1 μm, $1\times10^{16}$ $cm^{-3}$ n-type SiC with similar buffer, but on tilted p-type substrates. Instead of being held at elevated temperature (Papanicolaou 1988), our samples were not intentionaly heated during Pt evaporation by e-beam. The net dopant concentrations of SiC were measured by Capacitance-Voltage ( C-V) method afterward.

## 4. RESULTS AND DISCUSSION

The diodes were evaluated using measurements of current-voltage (I-V) and high frequency C-V (1 MHz) in a light-tight box. One probe made contact to the Schottky barrier itself and the other to a large metal contact away from the barrier. The reverse I-V characteristics of Al Schottky barriers had a hard breakdown voltage of 13 V. The depletion depth at breakdown was about 0.2 μm (obtained from the C-V measurement), and completely confined in the SiC layer. The breakdown electric field calculated from breakdown voltage and doping concentration was $1\times10^6$ V/cm, about one third of the theoretical value for cubic SiC (Bhatnagar 1993). The temperature coefficient of breakdown voltage showed a slightly positive value, about $2\times10^{-4}$ $°C^{-1}$ from room temperature to 120 °C, and became negative above 190 °C with softer breakdown. Unlike previous reported negative values (Neudeck 1993 and Bhatnagar 1992), this is the first observation of positive temperature coefficient in cubic or 6H SiC. The Al Schottky barriers showed the same I-V characteristics after annealing at 500 °C for 10 min. in forming gas without any degradation.

The reverse I-V characteristics of Pt Schottky barriers in Fig.3 shows 60 V breakdown voltage, and the depletion depth at breakdown was about 2.5 μm obtained from C-V measurement, implying that the entire SiC layer was punched through. The electric field in SiC and Si , calculated from Poisson's equation, does not reach the breakdown value of either SiC (1x10$^{6}$ V/cm) or bulk Si (~4x10$^{5}$ V/cm). The breakdown probably occured at interface defects between SiC and Si, which has been suggested by Raman spectroscopy. The temperature coefficient of breakdown voltage had a negative value of 4x10$^{-4}$ °C$^{-1}$ from room temperature to 120 °C. The Pt Schottky barriers degraded after forming gas annealing at 500 °C for 10 min., showing a soft breakdown arround 10 V. This is contrary to the results of Papanicolaou (1989) where the Pt Schottky barriers showed improved reverse I-V characteristics at reverse bias of a few volts after isochronal annealing.

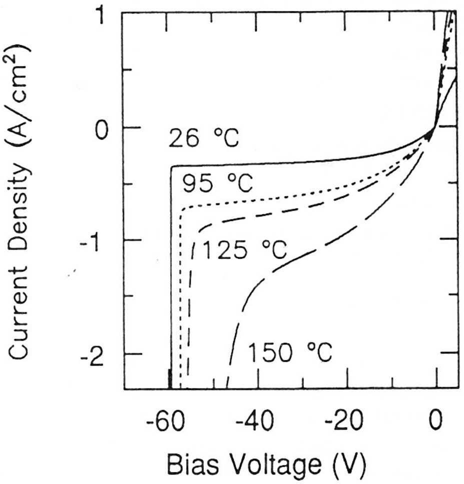


Fig.3 I-V characteristics of a Pt Schottky barrier at different measurement temperatures. The breakdown voltage decreases as temperature increases.

## 5. SUMMARY AND ACKNOWLEDGEMENTS

Device quality SiC has been grown at 800 °C using methylsilane. Schottky barriers on n-type SiC on (100) Si demonstrated a record high breakdown voltage of 60 V. The support of ONR (N00014-90-J-1361) and the assistance of E. A. Fitzgerald (AT&T) and P. Pirouz, J.W. Yang (Case Western Reserve University) for initial TEM is gratefully acknowledged. Assistance of M. Sarikaya and M. Qian of Princeton University for TEM is also appreciated.

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