Thin Solid Films xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Thin Solid Films

journal homepage: www.elsevier.com/locate/tsf

Epitaxial growth of cubic silicon carbide on silicon using hot filament chemical vapor deposition

Philip Hens [a,*], Ryan Brow [b], Hannah Robinson [b], Michael Cromar [b], Bart Van Zeghbroeck [a,b]

[a] University of Colorado Boulder, ECEE Department, CB 425, Boulder, CO 80309, USA
[b] BASiC 3C, Inc., 1830 Boston Avenue, Longmont, CO 80501, USA

ARTICLE INFO

Article history:
Received 1 October 2016
Received in revised form 8 February 2017
Accepted 8 February 2017
Available online xxxx

Keywords:
3C-SiC
Heteroepitaxy
Hot-filament chemical vapor deposition
Raman spectroscopy
X-ray diffraction

ABSTRACT

We are reporting the application of hot filament chemical vapor deposition for the growth of high-quality single-crystalline cubic silicon carbide heteroepitaxially on silicon substrates. Rocking curve X-ray diffraction measurements revealed a full-width at half maximum as low as 333 arcsec for a 15 μm thick layer. Low tensile strain, below 0.1%, was measured using Raman spectroscopy resulting in a wafer bow as low as 6 μm over a full 4″ substrate. We achieved this quality using a carefully optimized process making use of the additional degrees of freedom the hot filaments create. These allow for precursor pre-cracking and a tuning of the vertical thermal gradient, which creates an improved thermal field compared to classic chemical vapor deposition techniques used for the deposition of this material today. Measurements of the material uniformity show an influence of the lateral temperature field and of the stoichiometry, which is influenced by the graphite based sample holder.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

Heteroepitaxial growth of cubic silicon carbide (3C-SiC) on low-cost silicon substrates is of interest for applications in microelectromechanical systems [1], due to its high elastic modulus, and as low lattice misfit templates for the growth of hexagonal and cubic GaN [2]. Further applications can be found in horizontal 3C-SiC metal-oxide-semiconductor field-effect transistors [3] with high channel mobility for high frequency applications. Still, cost effective growth of high quality 3C-SiC has been a significant challenge and a key technical barrier for mass adoption in these applications.

Due to a lack of 3C-SiC bulk material for wafering, a heteroepitaxial growth on foreign substrates, like other silicon carbide polytypes or silicon, is needed. 3C-SiC epitaxy on silicon is traditionally carried out using a classical hot wall chemical vapor deposition (CVD) approach [4]. Hot filament chemical vapor deposition (HF-CVD) has previously been used for the deposition of polycrystalline layers of silicon carbide [5], but its adaptation to epitaxial growth has yet to come to fruition.

While CVD has been extensively used to grow 3C-SiC heteroepitaxially on silicon [4], there are only a limited number of reports of HF-CVD growth of 3C-SiC [6] with preferred grain orientation and even fewer reporting the full width at half maximum (FWHM) of the double rocking curve [7]. Still, the HF-CVD method has the potential to improve growth because the hot filaments precondition the gases, cracking silane and propane and creating monoatomic hydrogen. Since the precursor species are decomposed at the filament, this technique enables growth at lower substrates temperatures than in hot wall CVD [8]. Furthermore, the filaments can act as a second heat source to allow temperature gradient tuning, which is vital when optimizing gas phase chemistry as well as for lowering the strain and wafer bow.

We present an approach for the epitaxial growth of 3C-SiC on low cost silicon substrates using HF-CVD [9]. We demonstrate the growth of high-quality single-crystalline layers on 4 in. silicon (100) substrates using this type of process.

2. Experimental details

For this study, different 3C-SiC *epi* layers ranging in thickness from 2 to 15 μm were grown on full 4″ on-axis (100) silicon wafers in a high-vacuum HF-CVD system as depicted in Fig. 1. The substrate is heated to a surface temperature of 1350 °C using a resistive heater on the backside. Silane (SiH_4) (25 sccm) and propane (C_3H_8) (5.4 to 8.3 sccm) were used as precursors. The precursors, diluted with 5 slm hydrogen as the carrier gas stream, flow through an array of cylindrical filaments covering the whole area of the 4″ substrate before reaching the substrate surface. This array is located approximately one inch from the substrate and heated to 1800 °C by direct current.

* Corresponding author.
E-mail address: philip.hens@colorado.edu (P. Hens).

http://dx.doi.org/10.1016/j.tsf.2017.02.024
0040-6090/© 2017 Elsevier B.V. All rights reserved.

Please cite this article as: P. Hens, et al., Epitaxial growth of cubic silicon carbide on silicon using hot filament chemical vapor deposition, Thin Solid Films (2017), http://dx.doi.org/10.1016/j.tsf.2017.02.024

ARTICLE IN PRESS

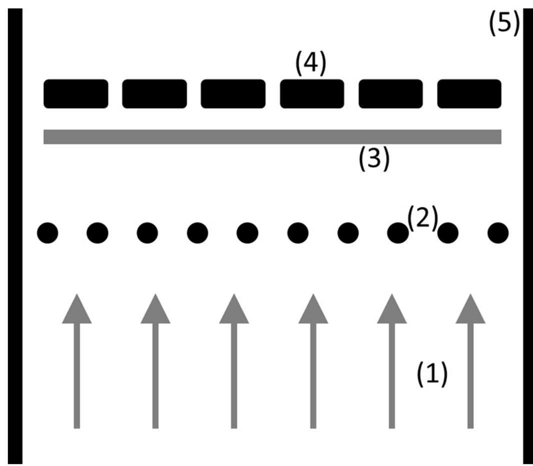

Fig. 1. Schematic drawing of the HF-CVD reactor setup with a resistive backside heater assembly. (1) gas stream with H2 + SiH4 + C3H8, (2) hot filaments at 1800 °C, (3) substrate at 1350 °C, (4) resistive heater, (5) reactor vessel.

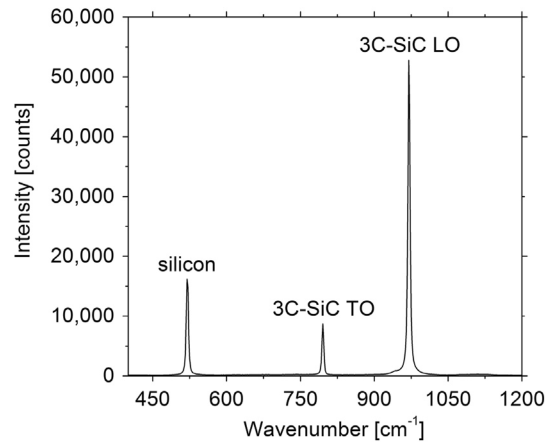

Fig. 3. Raman spectrum of 12 μm thick HF-CVD grown 3C-SiC on silicon showing modes at 520 cm^{-1} (silicon), 795 cm^{-1} (3C-SiC TO mode) and 970 cm^{-1} (3C-SiC LO mode).

All wafers have been wet-chemically cleaned before use and the oxide layer stripped by a hydrofluoric acid dip before being transported to the HF-CVD system in a low-oxygen atmosphere to prevent reoxidation of the silicon surface. A gas pressure in the chamber of 0.4 kPa is applied during growth after a high vacuum outgassing step, following the loading procedure to remove oxygen and nitrogen as a possible dopant from the gas atmosphere in the reactor.

Growth is initiated, after a hot-hydrogen etch at 1000 °C for 3 min, with a standard carbonization procedure [4] under propane and hydrogen, during which the substrate temperature is raised to the growth temperature at 1350 °C. This step forms a silicon carbide seed layer due to a reaction between gas phase supplied carbon and the silicon of the wafer surface.

After reaching the growth temperature, the propane flow is adjusted to vary the carbon to silicon ratio in the precursor flow mixture. After this, the gas flows are kept constant for the remaining runtime. The typical growth rate reached under these conditions is 2–3 μm/h for epitaxial single crystalline growth. Multiple runs were performed with varying carbon to silicon ratios as derived from the precursor supply between 0.65 and 1.0.

The grown layers were analyzed using different techniques. Beside optical microscopy, we applied scanning electron microscopy on surfaces and cleaved cross sections using a Jeol JSM-7401F Field Emission Scanning Electron Microscope (FE-SEM). Raman spectra were obtained on surfaces and cross sections with a Horiba LabRAM HR Evolution confocal micro Raman system. Here a 532 nm green diode laser was used as the excitation source. X-Ray diffraction (XRD) measurements were performed on the 3C-SiC (002) reflection with 2-bounce monochromatized copper K-alpha radiation in line focus mode in a Rigaku SmartLab X-ray Diffractometer.

3. Results

With this setup and process, we were able to produce high quality epitaxial material. Crack-free layers were obtained with surface topology varying from rough to smooth (Fig. 2). The rotational domains caused by the growth of a polar material (silicon carbide) on a nonpolar substrate (silicon) are clearly oriented and increase in size with layer thickness. Measurements of the surface roughness by atomic

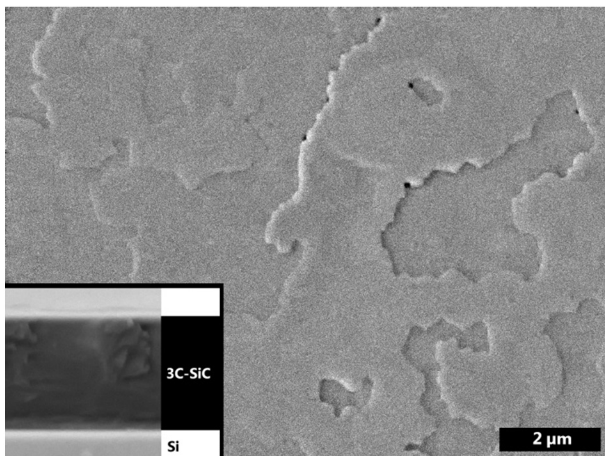

Fig. 2. FE-SEM micrograph of the surface and cross-section (insert) of a 2.25 μm thick 3C-SiC layer on (001) silicon.

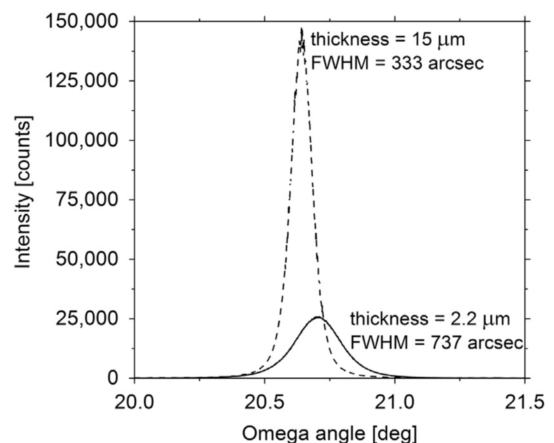

Fig. 4. XRD Omega (Rocking) scans on 2.2 μm (solid line) and 15 μm (dashed line) thick epi layers grown under the same growth conditions.

Please cite this article as: P. Hens, et al., Epitaxial growth of cubic silicon carbide on silicon using hot filament chemical vapor deposition, Thin Solid Films (2017), http://dx.doi.org/10.1016/j.tsf.2017.02.024

Download English Version:

https://daneshyari.com/en/article/5465968

Download Persian Version:

https://daneshyari.com/article/5465968

Daneshyari.com