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ScienceDirect
Thin Solid Films 516 (2008) 644–647
www.elsevier.com/locate/tsf

SiCOI structure fabricated by catalytic chemical vapor deposition

Kanji Yasui, Hitoshi Miura *, Masasuke Takata, Tadashi Akahane

Nagaoka University of Technology, Department of Electrical, Electronics and Information Engineering, 1603-1 Kamitomioka, Nagaoka, Niigata 940-2188, Japan

Available online 10 July 2007

Abstract

Epitaxial growth of SiC on SOI substrates using a hot-mesh chemical vapor deposition (CVD) technique was investigated. This technique utilizes a catalytic reaction involving hot tungsten wires arranged in a mesh structure. Using this hot-mesh CVD method, SiC epitaxial growth on SOI substrates with a thin top Si layer was realized without formation of voids, which form readily in the thin Si top layer at temperatures above 800 °C. The SiC film grown on an SOI structure exhibited a large gage factor (GF) of −27, which is approximately the same as that (GF = −31.8) of a SiC epitaxial film on Si(100) grown at 1360 °C using atmospheric pressure CVD.

Keywords: Catalytic CVD; Tungsten mesh; Silicon carbide; SiCOI; Piezoresistance

1. Introduction

Silicon carbide (SiC) is a wide bandgap semiconductor that is expected to be used in electronic devices for high frequency, high power and high temperature applications [1,2]. Out of the many SiC polytypes, cubic SiC that possesses a zincblende structure, can be grown on Si substrates. To reduce the cost of production, it is desirable to be able to fabricate SiC devices on Si wafers having large diameters. However, in order to be able to fabricate electronic devices in the SiC layer that have high speeds and low power consumptions, it is necessary to electronically isolate the SiC layer and the Si substrate. Consequently, the application of Si on insulator (SOI) techniques to SiC on insulator (SiCOI) structures has been eagerly investigated [3,4]. Because of their mechanical strength and chemical inertness, SiCOI structures have also been investigated for use in piezoresistive sensors and microelectromechanical systems that can be operated in physically and chemically harsh environments [5]. SiCOI structures can be fabricated by epitaxial growth of SiC on SOI substrates that have ultra-thin top Si layers (<10 nm) after a carbonization process [6].

However, SiC growth on SOI substrates having ultra-thin top Si layers is very difficult owing to the thermal instability of the thin top-Si layer. Depending on the top Si layer thickness, Si atoms agglomerate and Si islands and voids are formed during thermal annealing of SOI substrates at substrate temperatures lower than 1000 °C [7,8]. Due to the out-diffusion of Si atoms into the SiC layer during the initial stage of SiC growth on a Si layer, voids form at lower temperatures than in the case of thermal annealing [9]. Thus, SiC must be grown at much lower temperatures than 1000 °C.

In a previous study by us, 3C–SiC epitaxial films were grown at 750 °C by hot-mesh CVD (HM-CVD), a kind of hot-wire CVD which involves the catalytic decomposition of source gases by hot tungsten (W) wires arranged in a mesh structure [10,11], in which monomethylsilane (MMS) is used as the source gas. Hot-mesh CVD is thus considered to be effective for the low temperature growth of SiC on SOI substrates. In this study, epitaxial growth of 3C–SiC films on SOI substrates by the hot-mesh CVD method was investigated. In addition, their piezoresistive properties were measured with the intention of assessing their suitability of use in pressure sensors.

2. Experimental details

Heteroepitaxial growth of 3C–SiC films on SOI substrates was performed in an HM-CVD apparatus (see [10] for details) using H_2 and MMS. The base pressure in the chamber was under 1×10^{-4} Pa. SOI substrates (p-type (100)) 15×15 mm^2 in size and having a 100-nm-thick top-Si layer and a 200-nm-thick buried oxide layer were cut from SOI wafers. A W mesh (wire diameter of 0.1 mm, 30 mesh/inch) was placed above the

* Corresponding author.
E-mail address: miura@stn.nagaokaut.ac.jp (H. Miura).

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doi:10.1016/j.tsf.2007.06.187

substrate holder. The distance between the substrate and the W mesh was 80 mm. The W-mesh temperature and the substrate temperatures during growth were 1200–2000 °C and 700–800 °C, respectively. The source gas (MMS) was supplied directly onto the substrate surface. H_2 gas was supplied onto the W mesh, where it was decomposed into H radicals; these high-density H radicals diffused downward to the substrate. The flow rate of H_2 gas during SiC growth was maintained at 100 sccm. The gas flow ratio of H_2 to MMS was approximately 400. The total pressure during SiC growth was 530 Pa. The crystal structure, crystal orientation and chemical bonding structure were evaluated using X-ray diffraction (XRD; Rigaku, RAD IIIA) and Fourier-transform infrared spectroscopy (FT-IR; Mattson Instruments, RS/1). The SiC/Si interface was observed by cross-sectional scanning electron microscopy (SEM; Hitachi, S-400). The piezoresistive properties were measured by forming a bridge circuit composed of metal-film resistors.

3. Results and discussion

Fig. 1 shows XRD spectra of the SiC films grown on (a) Si and (b) SOI substrates by HM-CVD at substrate temperatures of 700, 750 and 800 °C. The W-mesh temperature during SiC growth was maintained at 1600 °C. In these SiC films on Si and SOI substrates, a (100) oriented SiC crystal was grown at substrate temperatures of 750 °C and 800 °C. The spectra of SiC on SOI substrates have equivalent diffraction intensities and full widths at half maximum as spectra of SiC on Si substrates grown at the same temperatures.

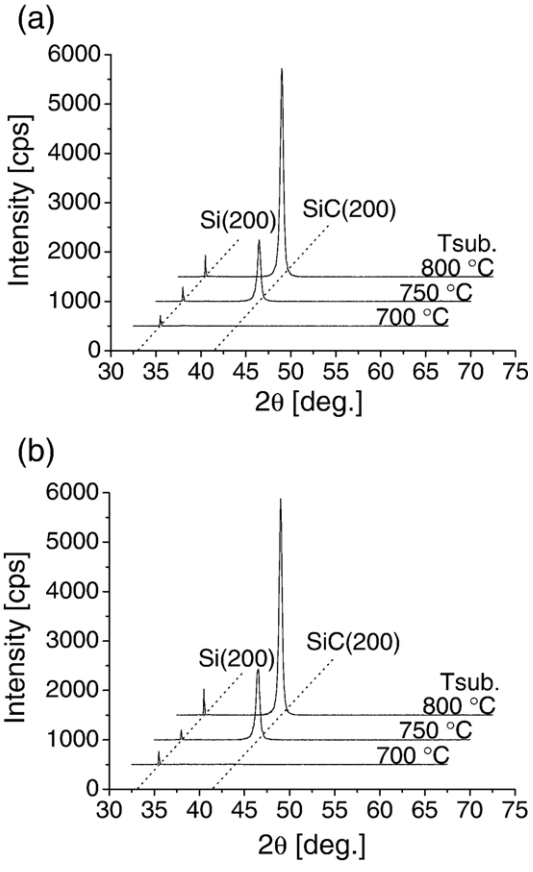

Fig. 1. XRD spectra of SiC films grown on Si and SOI substrates at 700–800 °C. (a) Si substrates. (b) SOI substrates.

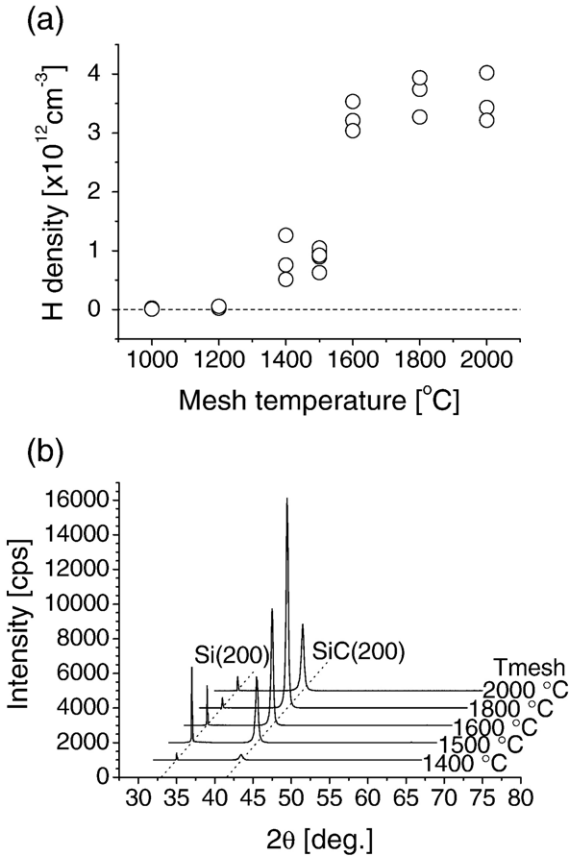

Fig. 2. The W-mesh temperature dependences of (a) the H-radical density in the chamber and (b) the X-ray diffraction spectra of SiC films grown at 750 °C.

Fig. 2(a) and (b) show the W-mesh temperature dependences of the H-radical density in the chamber and of the X-ray diffraction spectra of SiC films grown at 750 °C, respectively. The H-radical density was estimated by the change in the optical density of tungsten phosphate glass (Sankei, HAS-A20) in conjunction with the data of Morimoto et al. [12]. Fig. 2(a) shows that the decomposition efficiency remains low until 1200 °C and the increases remarkably above 1400 °C. The X-ray diffraction intensity also increased for mesh temperatures above 1400 °C. This clearly demonstrates the effect of the chemical reactivity of the H radicals on the SiC growth and on the formation of a crystalline structure. The crystallinity deteriorated at mesh temperatures above 1800 °C. The excessive concentration of H radicals supplied during SiC film growth is suspected of producing a Si-rich chemical composition, since hydrogen radicals are capable of extracting methyl groups [13]. However, as Fig. 2(a) shows, the H radical density generated by the W mesh saturated at temperatures above 1800 °C and no difference in the chemical compositions of the SiC films grown at 1800 °C and at 2000 °C could be confirmed by X-ray photoelectron spectroscopy. Although the exact cause of