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Micro-Raman imaging on 4H-SiC in contact with the electrode at room temperature

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ABSTRACT

Raman images (30 μm × 30 μm × 180 μm) of a bulk 4H-SiC wafer in contact with a Ni/Au electrode film in 100 nm/200 nm thick were measured with Micro-Raman spectroscopy at room temperature. As the imaging area approached the interface between the SiC and electrode, the center frequency of the $\boldsymbol{E_2}$**(TO)** mode (778 cm^{-1}) immediately declined; in the Raman imaging, relative distribution of compressive residual stress around residual tensile stress, and linewidth were broadened due to crystal distortion. For ***LOPC*** (LO-phonon-plasmon-coupled) mode (970 cm^{-1}), center frequency showed variation right next to the interface, while linewidth decreased slowly as the imaging area approached the interface. We evaluated the temperature dependence of the line broadening and the center frequency of the ***LOPC*** mode in 4H-SiC in a high-temperature region. Free carrier concentration increased with temperature, and remained almost constant in the center frequency after impurities were ionized completely.

1. Introduction

4H-SiC is a wide bandgap semiconductor used to produce high-power (>3 kV) high-temperature electronic devices [1] that require thick, high-quality epitaxial layers >30 μm. Homoepitaxial growth of 4H-SiC by chemical vapor deposition (CVD) is the key enabling technology for improving the quality of such thick SiC films.

These films, however, often suffer from polytype inclusions; SiC displays >200 polytypes with bandgaps varying from 2.3 eV for the thermodynamically favorable 3C cubic polytype to 3.4 eV for the 2H hexagonal polytype. Differences among the various SiC polytypes derive from the stacking sequence of double layers of Si and C atoms. The stacking sequence in the (0001) direction for the hexagonal polytype (also known as α-SiC) 4H is ABCB…, where A, B, and C represent the three possible positions of the double layers. The stacking sequence for the cubic 3C polytype, also known as β-SiC, in the (111) direction is ABC. Changes in stacking sequence have a profound effect on the electrical properties [2].

The most important polytype for electronic devices is 4H-SiC (bandgap 3.2 eV), a 50% cubic/hexagonal polytype [3]. However, the ability to replicate this polytype without extraneous polytypes (e.g., 3C) is critical to ensuring high-quality epitaxial layers for device fabrication. As one of the most promising wide bandgap semiconductors, 4H-SiC is an ideal material for high-voltage high-temperature applications. Seminal work on the Raman scattering of SiC polytypes was reported by Nakashima and Harima, who examined the crystalline quality and polytype inclusions with Raman analysis [4]. They were able to obtain the electron density and electromobility by fitting calculations to spectra of the ***LOPC*** mode [4]. Yugami et al. [5] reported that the red shift in the ***LOPC*** Raman peaks with increasing C/Si ratio and can be attributed to the impurity (doping) concentration, which decreases as the C/Si ratio increases.

As an ideal material for high-power devices, the properties of SiC at different temperatures, especially at high temperatures, are significant to its practical application. The wide gap 4H-SiC semiconductor as a power MOS-FET has been used in various power-electronics applications such as the EV electric car. As one of the most promising wide bandgap semiconductors, 4H-SiC, is an ideal material for high-power inverter applications with high electric mobility and high breakdown voltage with low current leakage. However, when 4H-SiC is used as a MOS-FET for high-power inverters in high temperatures, the difference of values in the thermal expansion coefficient between the electrode contact and surface of the 4H-SiC crystal could lead to the electrode peeling and developing a crack on the electrode contact interface [6]. On the other hand, the variation of the ***LOPC*** mode by Raman imaging in high temperatures would be important for such applications.

Very recently, Yang et al. [7] obtained the temperature dependence of the ***LOPC*** mode in 4H-SiC alone using only point analysis, and discussed the relation between the Raman shift and electric density. The perturbative effect on both the $\boldsymbol{E_2}$**(TO)** and ***LOPC*** modes due to electrode film on 4H-SiC has not yet been reported at room temperature.

In this study, we perform 3D-Raman imaging measurements on 4H-SiC bulk wafers in contact with an electrode at room temperature, and

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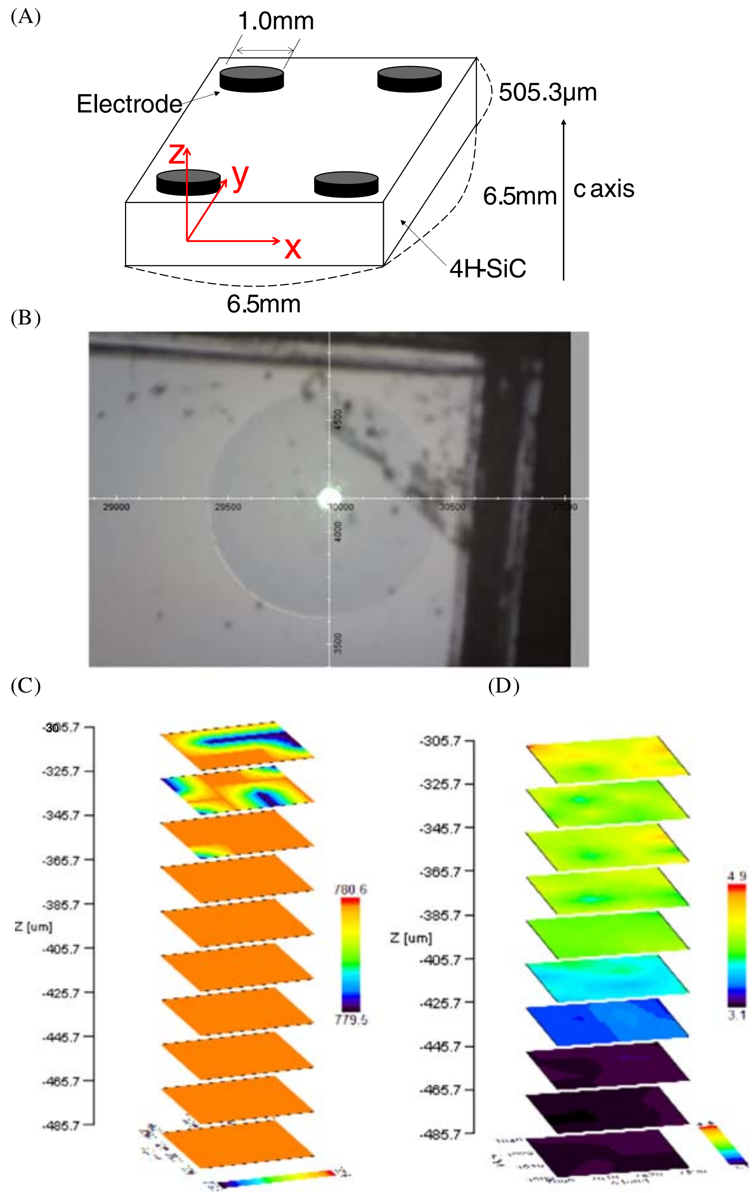

Fig. 1. (A) The sample condition for 3D-Raman imaging and a photograph of the bottom surface with no electrode in 4H-SiC sample film. In 3D-Raman imaging measurement, the incident laser (λ = 532 nm, P = 17.4 mW) was emitted to this bottom surface with no electrode film. (C) The center frequency, and (D) linewidth of Raman imaging of $\boldsymbol{E_2}$**(TO)** of 4H-SiC crystal as the area approaches the interface along the z direction (interface positioned at approximately z = 200 μm in Fig. 1(C) and (D)).

discuss the relative distribution of residual stress and the carrier concentration of free electrons. We also perform Raman imaging measurements for the ***LOPC*** mode over a series of temperatures ranging from 290 to 573 K on 4H-SiC bulk wafers.

2. Experimental Procedures

A confocal micro-Raman spectroscope system, NRS-4100 with a 2400 l/mm grating, was employed to study the Raman mode shift of 4H-SiC samples at room temperature. Spectral resolution of the system was up to 0.4 cm^{-1}, and the accuracy of the wavenumber was within ±0.1 cm^{-1}. The samples in the temperature-controlled microscope stage (Linkam 10002L) were mounted on an XYZ automated stage in the micro-Raman spectroscope system. Bulk 4H-SiC samples (5 mm × 5 mm × 0.5053 mm [c axis]) with a carrier concentration of 2.3 × 10^{18} cm^{-3} and electric mobility of 115 cm^2/Vs in the Hall effect measurement were prepared by the MOCVD method. A Ni/Au electrode film in 100 nm/200 nm thick and 1 mm in diameter was then deposited on one side surface of the 4H-SiC samples by vacuum deposition, as shown in Fig. 1(A). The 4H-SiC samples in contact with the electrode were prepared in this way. In 3D-Raman imaging measurement, an incident laser (λ = 532 nm, P = 17.4 mW) was emitted to the bottom surface with no electrode film (Fig. 1(B)).

3. Results and Discussion

4H-SiC crystal belongs to the space group C_6^4 and has 20 Raman active modes, including LO-TO splitting in the equation, according to the group theory. The phonon at wavevector $\boldsymbol{q} = \boldsymbol{0}$, obtained from an analysis on