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Growth of a Ge layer on 8 in. Si (100) substrates by rapid thermal chemical vapor deposition

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ABSTRACT

We have made the successful growth of Ge layer on 8 in. Si (100) substrates by rapid thermal chemical vapor deposition (RTCVD). In order to overcome the large lattice mismatch between Ge and Si, we used a two-step growth method. Our method shows the uniformity of the thickness and good quality Ge layer with a homogeneous distribution of tensile strain and a lower etch pit density (EPD) in order of $10^5\ cm^{-2}$. The surface morphology is very smooth and the root mean square (RMS) of the surface roughness was 0.27 nm. The photocurrent spectra were dominated by the Ge layer related transition that corresponding to the transitions of the Si and Ge. The roll-off in photocurrent spectra beyond 1600 nm is expected due to the decreased absorption of Ge.

1. Introduction

Ge is an ideal candidate material for photoreceivers at optical communication wavelengths because of its high optical absorption and compatibility with an existing Si technology. Consequently, the integration of Ge photodetectors on Si substrates has been an active area of research, and its potential for a much shorter absorption length and higher carrier mobilities of Ge compared to Si, which allows device miniaturization down to a few microns [1–3]. Thus, monolithical integration of photodetectors on a Si platform, compatible with complementary metal-oxide semiconductor (CMOS) circuitry would simplify fabrication processes and reduce costs.

One of the major advantages of growing a Ge layer on Si is that the Si (001) substrate has far superior mechanical properties than bulk Ge (001): lighter, less brittle and considerably less expensive to be produced. Currently, Ge wafers can also be produced in small wafer sizes (≤ 100 mm) only which are incompatible with the majority of fabrication facilities. Typically these facilities operated with at least 200 mm diameter wafers, while the latest, most highly developed, fabrication tools are designed for 300 mm and 450 mm Si wafers. However, the 4.2% lattice mismatch between Si and Ge means that only extremely thin layers of Ge (few nm) can be grown pseudomorphically on Si (001). Thicker layers will be related to the Ge bulk lattice parameter through the formation of misfit dislocations in the wafer plane, and these cannot be terminated at an edge, threading dislocation arms that can penetrate upwards to the free surface unless they are annihilated within the structure.

For the application of Ge/Si heterojunction in the field of quantum devices, such as a quantum well infrared photodetector [4–7], heterojunction bipolar transistor [8], two-dimensional hole gas field effect transistor [9], and resonant tunneling diode [10], the abruptness of the SiGe/Si interface is an important factor. The interfacial abruptness in Ge/Si heteroepitaxy has been studied by Iyer et al. [11], Fukatsu et al. [12], Zalm et al. [13] and Copel and Tromp [14] with films grown by MBE, as well as Choi et al. [15] and Park and

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Choi [16] with films grown by chemical vapor deposition (CVD). The two-temperature method, reported by V.A. Shah et al. [17] and Keun Wook Shin et al. [18], can give smooth and low threading dislocation density Ge layers directly on a Si(001) wafer, grown by reduced pressure-chemical vapor deposition (RP-CVD) and ultrahigh vacuum-chemical deposition (UHV-CVD).

In this study, we report the successful growth of high quality Ge layer on 8 in. Si (100) substrates by rapid thermal chemical vapor deposition (RTCVD). The rapid thermal chemical vapor deposition (RTCVD) is defined as a CVD technique capable of rapid switching of the process temperature [19]. Growth takes place only during the limited period when the system is at high temperature. Gas switching occurs during the low-temperature segment of the process thus removing the transient effect of gas residence times. Therefore, RTCVD has the potential ability for growth of structures with very abrupt interfaces between thin films of various materials. Furthermore, the growth temperature, as well as other growth conditions, can be optimized separately for each material. This combination of characteristics makes RTCVD an interesting alternative to the conventional CVD for the growth of heterostructures and also for in situ processing. In order to overcome the large lattice mismatch between Ge and Si, we used a two-step growth method. The structural properties were investigated using atomic force microscopy (AFM), transmission electron microscope (TEM) electron diffraction pattern, scanning electron microscope (SEM), and high-resolution X-ray diffraction (HR-XRD), and etch pit density (EPD) was measured by using an optical microscope. The optical properties were investigated using Raman spectroscopy and photocurrent spectra measurements.

2. Experimental

The Ge layers were grown on boron doped p-type Si (100) wafers (8 in. in diameter, resistivity=5–15 Ω cm) by using RTCVD. Fig. 1 shows a schematic drawing of the RTCVD reaction chamber used for the Ge layer growth. The upper dome is fabricated from high-quality quartz. It has an oval cross section which enables both vacuum operation and large-area deposition (up to 8 in. diameter substrate) while the infrared output of tungsten–halogen lamps is placed on the upper part of the chamber. The Si substrate is placed on a SiC susceptor. The tungsten–halogen lamps for rapid heating of the wafer, the lamps are enclosed within a stainless-steel chamber which has a reflective coating on the inner wall and is nitrogen-cooled. The reactor consists of a water cooled stainless steel outer chamber, rotation system, and an optical pyrometer.

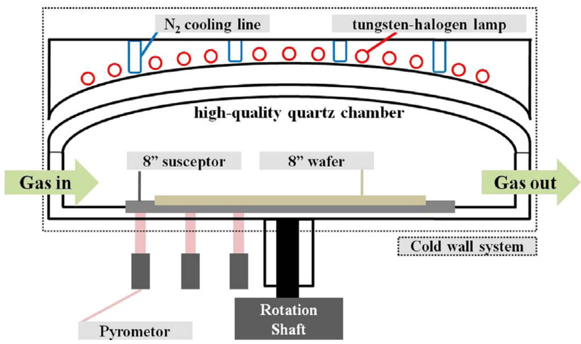

Fig. 1. A schematic drawing of the RTCVD reaction chamber used for Ge layer growth.

The Si wafers were wet cleaned in HF (HF:DI=6:1) before Ge layer growth. Ge growth on Si is done without precleaning process by the two-step mechanism. Ge buffer layers were grown at 350 °C with the thickness of 100–110 nm in first step. The RTCVD technique, also known as limited reaction processing, uses continuous gas flow of appropriate precursors in conjunction with the rapid heating and the ramping rates are 300 °C/s. And then, high temperature Ge layers were grown at 500 °C with the thickness of ~2 μm. The process pressure was set to 20 Torr. For each steps, GeH_4 (20% in H_2) source gas and H_2 carrier gas were used at 30 sccm and 20 slm, respectively.

The surface morphology and root mean square (RMS) of surface roughness of the films were inspected by atomic force Microscopy (AFM). The thickness and crystallinities were measured using a transmission electron microscope (TEM) and electron diffraction pattern. The composition and defect tendency were measured using scanning transmission electron microscopy–energy dispersive X-ray (STEM–EDX) mapping and dark field images. EPD was measured by secco etchant using an optical microscope. In order to investigate the crystalline homogeneity and the microscopic strain state of the Ge epilayer, HR-XRD analysis was performed.

The Raman spectra were measured using a He–Ne laser (633 nm) with 20 mW power to determine the strain percentage of the Ge layers. The photocurrent spectra were measured at temperature ranged from 10 to 300 K. For the photocurrent measurements, the sample was cut into 3×3 mm^2 pieces, and two coplanar electric contacts with a 1 mm spacing were formed with indium solder. The ohmic contacts were confirmed by the *I–V* characteristics. A quartz–tungsten–halogen lamp (ORIEL 1000 W) was used as the photo-excitation light source. The photocurrent spectrum was analyzed by using a 500 mm grating monochrometer. The photocurrent signal was picked up with a lock-in amplifier and then recorded by a computer. A bias of 0.5 V was supplied by a voltage source using a Keithley 236 unit for the current measurements.

3. Results and discussion

The Ge layer has grown on boron doped p-type Si (100) wafers (8 in. in diameter, resistivity=5–15 Ω cm) by using the RTCVD. We have observed the surface morphologies of Ge depended at first step growth temperature (low temperature) by AFM analysis. Fig. 2. shows that 5 μm × 5 μm area AFM images of Ge layers grown at 500 °C (high temperature) with the Ge buffer layers grown at various first step temperatures of 350 °C, 375 °C, and 400 °C. In this experiment, low temperature growth at 350 °C is so effective for the buffer layer growth and it caused strain relaxation very well. Ge nuclear density is not uniform as the low-temperature rises up. For this, we have fixed the low-temperature at 350 °C in the first step growth mechanism. Figs. 3 and 4 show the surface roughness of