Vacuum 89 (2013) 86–89

Contents lists available at SciVerse ScienceDirect

Vacuum

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

Characterization of damage behavior induced by low-temperature BGe molecular ion implantation in silicon

J.H. Liang [a,b,*], C.H. Wu [b]

[a] Institute of Nuclear Engineering and Science, National Tsing Hua University, Hsinchu 300, Taiwan, ROC
[b] Department of Engineering and System Science, National Tsing Hua University, Hsinchu 300, Taiwan, ROC

ARTICLE INFO

Article history:
Received 8 September 2011
Received in revised form
22 November 2011
Accepted 24 November 2011

Keywords:
Molecular ion implantation
Raman scattering
Damage
Crystalline
Amorphous
Rapid thermal annealing

ABSTRACT

The present study utilized Raman scattering spectroscopy (RSS) to characterize damage behavior induced by implanting 77 keV BGe molecular ions into Si<100> wafers at low substrate temperatures under various ion fluences. The low substrate temperatures under investigation included liquid nitrogen temperature (LT) and room temperature (RT). Rapid thermal annealing (RTA) at 1050 °C for 25 s in nitrogen ambient was adopted in order to perform the post-annealing treatments. The as-implanted results revealed that the longitudinal optical (LO) phonon Raman peak (indicating the crystalline silicon phase) exhibited a decrease in peak intensity, peak position, and peak area but an increase in full-width at half-maximum (FWHM) of the peak as ion fluence increased or substrate temperature decreased. However, the transverse optical (TO) phonon Raman peak (indicating the amorphous silicon phase) decreased in peak position and FWHM of the peak but increased in peak intensity and peak area when ion fluence increased or substrate temperature decreased. The amount of implantation-induced damage in the LT specimens is greater than it is in the RT ones. However, the as-annealed results revealed that the amount of residual damage in the LT specimens is slightly smaller than it is in the RT ones and the difference widens as ion fluence increases.

1. Introduction

The recent growing interest in increasingly scaled-down micro-electronic devices has led to stricter guidelines in the formation of shallow junctions. The BGe molecular ion implantation method has gained much attention due to its attractive advantages including: (1) implanting boron ions at a lower effective energy level with a higher beam current; and (2) implanting germanium ions to enhance amorphization without inducing undesirable chemical, electrical, or physical effects [1–5]. In essence, junction depth and sheet resistance are pivotal factors in determining the performance of shallow junctions in micro-electronic devices [6] and both are closely related to implantation-induced damage behavior. Implantation-induced damage is also influenced by substrate temperature because of the occurrence of *in situ* annealing during ion implantation [7,8], which may affect the amount of damage incurred. Also, the implantation damage induced by molecular ions is not (and is basically greater than) a linear superposition of the implantation damage induced by the constituents in each ion. This is due to the fact that molecular ion implantation causes high-density irradiation of incident atoms via local energy deposition and multiple collisions in the substrate. Subsequently, the effects of damage overlapping may convert temporary damage into permanent damage. This is known as the non-linear damage effect [9–11]. Therefore, an in-depth investigation of the damage induced by BGe molecular ion implantation is essential before it is used in industrial applications. Unfortunately, few experimental studies have thus far been conducted examining the characterization of damage induced by BGe molecular ion implantation. However, Raman scattering spectroscopy (RSS) is widely-accepted as a highly effective method used in distinguishing between crystalline and disorder structures [12,13]. Hence, the objective of the present study is to examine the feasibility of using RSS to probe the damage induced by 77 keV BGe molecular ion implantation. Additionally, the substrate-temperature-dependent damage behavior in the low-temperature region is explored by comparing liquid nitrogen temperature (LT) and room temperature (RT). Finally, the influences of ion fluence and post-annealing treatment on damage behavior are also studied at great length.

* Corresponding author. Institute of Nuclear Engineering and Science, National Tsing Hua University, Hsinchu 300, Taiwan, ROC. Tel.: +886 3 5714661; fax: +886 3 5720724.
E-mail address: jhliang@ess.nthu.edu.tw (J.H. Liang).

0042-207X/$ – see front matter © 2011 Published by Elsevier Ltd.
doi:10.1016/j.vacuum.2011.11.018

2. Experimental details

The specimens employed in the present study were prepared from Czochralski-grown phosphorous-doped <100> silicon wafers with a resistivity of 1–10 Ω-cm. These were cut into 2 cm × 2 cm squares and deliberately clamped on to a specimen holder in order to ensure good thermal contact when implanting. The 77 keV BGe molecular ion implantations along with various ion influences were carried out with a NEC 9SDH-2 3 MV tandem accelerator. The implanted areas on the specimen were 1.5 cm in diameter and the ion beam current was measured directly from the specimens. A copper grid was employed in order to minimize interference from secondary electrons in charge integration when determining ion fluence. In the case of the LT implantations, the specimens were cooled by passing liquid nitrogen beneath the specimen holder. The temperature was monitored by a thermocouple placed on the backside of the specimen holder. As for the RT implantations, no cooling was applied to the specimens. During implantation, the normal axis of the specimen surface was inclined 7° off relative to the incident-ion beam axis in order to minimize channeling effects. Furthermore, the incident-ion beam current density was maintained between 30 and 50 nA in order to prevent the specimens from overheating. The as-annealed specimens were prepared by chemically cleaning the as-implanted specimens before they underwent a one-step annealing treatment in a Heatpulse 610i RTA system at 1050 °C for a duration of 25 s.

All of the non-implanted, as-implanted, and as-annealed specimens were measured using RSS in order to compare damage behavior. The RSS spectra of the specimens were room-temperature recorded using a micro-Raman spectrometer together with a triple grating monochromator (TRIAX 550) in backscattering geometry. An argon laser beam with a single-line wavelength of 514.5 nm was utilized to inject the specimens with a spot approximately 1–2 μm in diameter. The laser power was kept low (1–2 MW) in order to minimize the undesired beam heating effects. Notice that both the spot size and laser power were also kept constants during the measurements for comparative purposes. A thermoelectrically-cooled charge-coupled device (CCD 3000) detection system was employed to collect the scattered light signals that passed through the monochromator. These light signals were then integrated for 180 s with a wavenumber step size of 1.2 cm^{-1}.

3. Results and discussion

Fig. 1 displays the SRIM [14] Monte-Carlo simulation in the depth profiles of boron atoms and total defects (interstitials plus vacancies) of the 77 keV BGe implant at an ion fluence of 5×10^{14} cm^{-2}. Since SRIM is only applicable for monomer ion implantations, this study approximates the 77 keV BGe implant using a linear superposition of the 10 keV B and 67 keV Ge implants. Ref. [15] contains all of the required input data for the SRIM computations. The figure clearly shows that the depth profile of total defects skews more highly toward to the specimen surface than does that of the boron atoms. The projected range and longitudinal range straggling of ion-implanted boron in silicon are 39.2 and 17.9 nm, respectively. In addition, the SRIM-calculated threshold ion fluence Φ_{th}^{calc} necessary to cause amorphization in the specimen is defined as the ion fluence at which the maximum concentration of total defects overcomes the concentration of silicon atoms in the non-implanted specimen or the atomic number density of silicon [3] and is determined to be 9.1×10^{13} cm^{-2}. Taking an ion fluence of 5×10^{14} cm^{-2} as an example, the SRIM-calculated amorphous layer extends from the specimen surface to $x = 73.9$ nm. That is, the thickness of the amorphous layer is 73.9 nm. Also, the optical penetration depth of the 514.5 nm argon

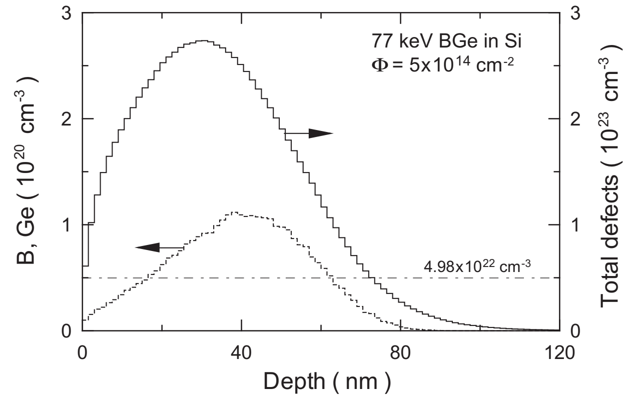

Fig. 1. SRIM-calculated depth profiles of boron atoms and total defects in the 77 keV BGe implant with an ion fluence of 5×10^{14} cm^{-2}. The atomic number density of silicon is also indicated in the figure.

laser beam into silicon substrate ranges from 500 to 1000 nm [16–18] depending on the crystalline and temperature status of the silicon substrate. Hence, the detection signals obtained from RSS include information regarding the entire implanted layer as well as, to some extent, the bulk silicon.

Fig. 2 illustrates the as-implanted RSS spectra under various ion fluences due to the 77 keV BGe implants at LT and RT, where I denotes intensity and k represents wavenumber or the so-called Raman shift. The RSS spectrum of the non-implanted specimen is also shown in the figure for comparative purposes. As can be seen, all the RSS spectra show a prominent sharp peak at approximately 520 cm^{-1}, which is attributed to the LO phonon in the crystalline silicon (c-Si) phase [19], the so-called first-order peak of crystalline silicon (1O). In addition, there is a broad peak at approximately 470 cm^{-1} when ion fluence exceeds some threshold ion fluence. This broad peak is due to the TO phonon in the amorphous silicon (a-Si) phase [20] and is usually used to indicate an amorphous

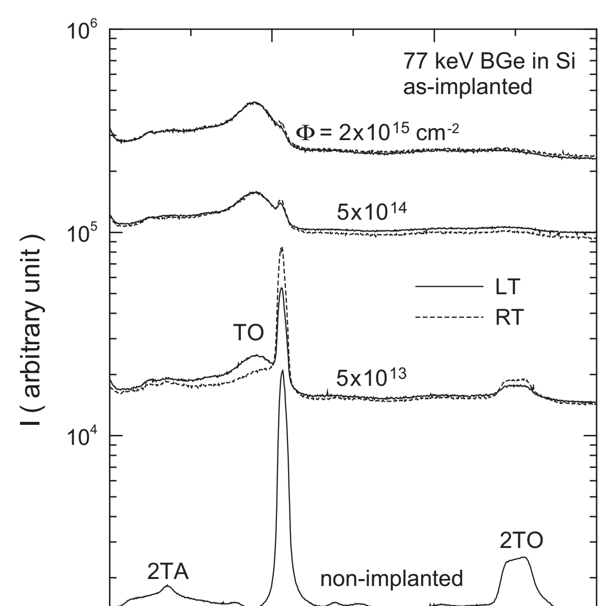

Fig. 2. As-implanted RSS spectra and Raman characteristic peaks for various ion fluences in the 77 keV BGe implants at LT and RT.