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Nano-cell fabrication on InSb utilizing point defects behavior induced by focused ion beam

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ABSTRACT

In ion irradiated GaSb, InSb and Ge, the induced point defects form voids and these voids develop to the cells by further irradiation. The nano-fabrication technique utilizing this behavior is performed on (100) InSb by focused Ga^+ ion beam (FIB). Fabrication of nano-cell lattices with cell an interval of 30–300 nm are tried varying the acceleration voltage and the ion dose at room temperature, and the plan views and the cross-sectional views of the nano-cell structures are observed by scanning electron microscopy (SEM). The possible ranges of the cell interval, the cell diameter and the cell height are obtained from the results.

1. Introduction

Anomalous behaviors such as the surface elevation and the cellular structure formation, in some ion-irradiated semiconductors, have been observed very occasionally by several researchers since 1957 [1–3]. Nitta et al. found that the cellular structure is formed on the Sn^+-implanted GaSb surface at a low temperature and similar structures are also formed for InSb and Ge [4–6]. They also proposed a formation mechanism of the cellular structure on the basis of movement of the point defects and proved it experimentally [7]. Ion implantation induces a lot of Frenkel pairs (vacancies and interstitials) in the implanted region. These two kinds of point defects are much different in mobility; the vacancies will be immobile and the interstitials will be mobile at low temperatures around liquid N_2 temperature. While interstitials with a high mobility migrate far from the implanted layer, vacancies with a low mobility remain there. Consequently the vacancies increase in the implanted region, and the voids are formed from the oversaturated vacancies. In fact, Nitta et al. showed that the large voids with 20–30 nm diameters appeared in GaSb thin foils implanted at about 150 K [6]. In the case of the bulk sample, the created voids develop one-dimensionally absorbing the point defects induced by subsequent ion irradiation, resulting in formation of the fine cells, as examined in References [4–6]. These developed cells had about 30 nm diameter and 250 nm depth and they were partitioned by 5–10 nm thick walls. Because of this fineness, the authors designed a fabrication technique utilizing this phenomenon to form the ordered nano-cell structures [8] and tried it for GaSb by focused ion beam (FIB) [9,10]. This technique consists of two processes. The first process is to form the initial array of the voids orderly in the surface layer and the second is to develop the voids to the cells. The ion dose, ion acceleration voltage and substrate temperature are major parameters in this nano-cell fabrication. In the authors' work, both processes are performed in a FIB apparatus at room temperature. First an ordered initial pattern is fabricated on a wafer by ion irradiation using milling mode of FIB. The second step to develop the initial pattern is performed by ion irradiation using the imaging mode of FIB, when the ion dose is controlled by the scanning times. In the work on GaSb, an invisible initial pattern developed to a visible nano-cell structure by increasing scan in FIB secondary electron image. This change showed that the formation of the cellular structure is not caused by sputtering but by the self-organizational behavior of the point defects induced by irradiation. In addition, the authors' proposed nano-fabrication technique was verified to be promising.

In this work, nano-cell fabrication is performed for InSb, which is another III–V compound semiconductor revealing the cellular structure as well as GaSb. Varying the ion acceleration voltages and ion doses, the possible dimension range of the nano-cell is estimated and the factors dominating it are discussed.

2. Experiment

Two kinds of samples were fabricated for SEM top view and cross-sectional view. The procedure is described in the authors' previous work [11]. InSb with (100) surface orientation was irradiated in a Micrion 9500 FIB using Ga^+. For the top view, nano-cell patterns (10 μm × 10 μm) consisting of nine matrices (each matrix is a two-dimensional lattice of implanted dots at a constant interval (30, 50, 80, 100, 120, 150, 180, 240, and 300 nm)) were fabricated. For the cross-sectional view, five

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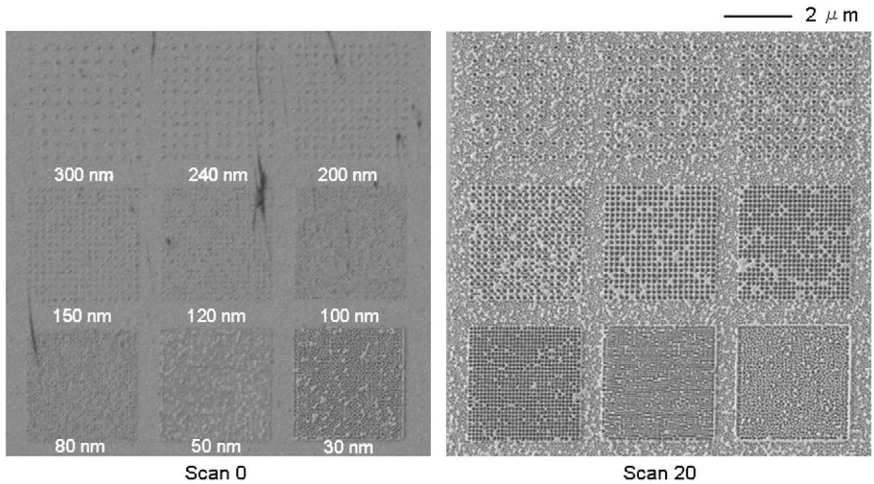

Fig. 1. SEM images of the initial pattern on InSb wafer where each dot was made by 2.25×10^4 of 30 keV Ga^+ and its developed pattern by 20 times image scanning.

35 μm × 35 μm large matrices with a 200 nm dot interval were fabricated on an InSb wafer and the wafer was cleaved.

The ion doses per one implanted dot are designed to be equal in all matrices of an initial pattern in order to create the same number of Frenkel pairs at every dot (they were different in the previous paper [7]). The second step to develop the initial pattern was performed by ion irradiation using the imaging mode of FIB, when the ion doses were determined by the number of scanning times. The ion dose per one scan was 1.04×10^{14} ions/cm^2 and the maximum number of scanning was 20 times. The top view was observed for every scanning times and the cross-sectional view for 0, 5, 10, 15 and 20 scanning times by a scanning electron microscope (SEM), JEOL JSM-7700F.

3. Results and discussion

Fig. 1 shows SEM images of the initial pattern on InSb wafer where each dot was made by 2.25×10^4 of 30 keV Ga^+ and its developed pattern by 20 times image scanning. This result is much different from that of GaSb whose initial pattern was made by the same ion dose. In the case of GaSb, the weak contrast of the initial structure in the matrices with a dot interval of 150 nm and over vanished by 5 times image scanning, that is, the nano-cell structure did not develop by the image scanning. The initial pattern of InSb developed in the matrices with dot intervals of 80–300 nm by scanning, though its contrast was also weak. The most ordered nano-cell structure is obtained at the dot intervals of 80, 100 and 120 nm, and the regularity is lost in the matrices with larger or smaller dot intervals than those. The matrix of 30 nm dot interval was not fabricated in the initial process, and the matrix of 50 nm dot interval lost the regularity by scans though its initial pattern had been clear. In the case of larger dot intervals than 120 nm, the initially created dots became cells by scanning, however, the newly created small holes between initial dots disturbed the regularity. The new small holes (about 50 nm diameter) appeared at the center of four neighboring initial dots (about 90 nm diameter at 20 scans) in the matrix of 150 nm dot interval. In the dot intervals of 200–300 nm, the small holes were created all over the scanned region. These secondary holes are considered to have been created by the vacancies being not absorbed by the initial voids.

Fig. 2 shows the initial pattern made by 2.25×10^5 of 30 keV Ga^+ per one dot and its 20 times image scanned pattern. The structures of the 30 and 50 nm dot intervals are already destroyed in the initial pattern. At all the dot intervals of 80 nm and over, the top surfaces of almost all the dots are removed and the clear cells with about 60–80 nm diameter are observed in the pattern. These cell structures were developed by image scanning, and the cell diameter reached at about 150 nm in the matrices of 200–300 nm dot intervals by 20 times

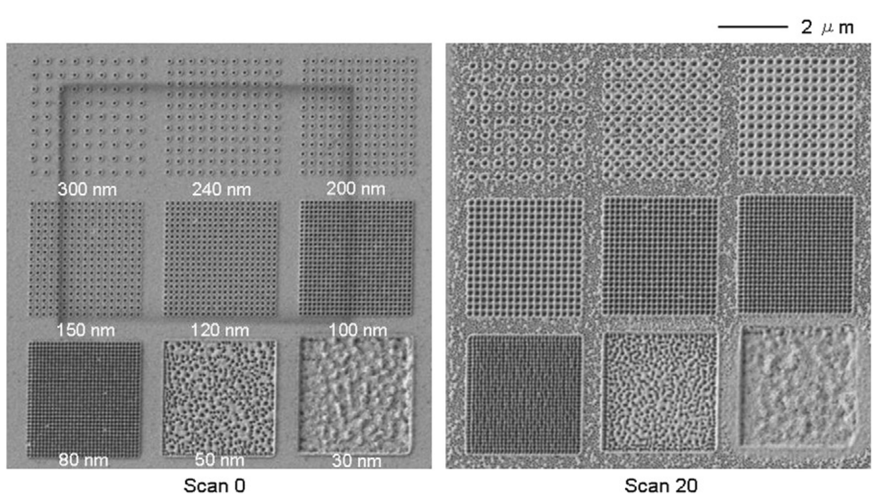

Fig. 2. SEM images of the initial pattern made by 2.25×10^5 of 30 keV Ga^+ per one dot and its 20 times image scanned pattern.