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Nano-cell fabrication on semiconductor utilizing self-organizational behavior of point defects induced by ion beam

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ABSTRACT

The nano-fabrication is based on the author's discovery that the cellular structure is formed on the ion implanted GaSb surface [[1] N. Nitta, M. Taniwaki, T. Suzuki, Y. Hayashi, Y. Satoh and T. Yoshiie, Mater. Trans. 43 (2002) 674]. In the present work the nano-fabrication is developed using focused ion beam technique. As the top–down procedure, a two-dimensional lattice of the voids is produced under GaSb surface by precise irradiation of focused ion beam. After that, the bottom–up procedure is performed using image scanning mode by which voids get developed to cells. The effects of the ion acceleration voltage and ion dose on the development of the cell structure are determined by observing plane and cross-sectional views in a scanning electron microscope. Using the technique, possible cell dimensions are discussed.

1. Introduction

The idea of the nano-fabrication performed in this article was derived from the authors' discovery that the cellular structure is formed on the ion implanted GaSb surface [1]. Generally ion implantation into semiconductors creates a damaged region on their implanted surface and further implantation changes the implanted layer into amorphous structure. However, in the case of GaSb when heavily ion-implanted at about 150 K, the characteristic structure was formed on the implanted surface. This structure consists of hollow cells with fine dimensions of about 30 nm diameter and 250 nm height (high aspect ratio) and these cells are partitioned by very thin wall (5–10 nm thickness). The authors consider that this structure is formed due to behavior of Frenkel pairs (vacancies and interstitials) induced by ion implantation. That is, some of induced vacancies which survived from recombination form the voids and these voids develop to the fine cells, as reported in reference [2].

The characteristics of the discovered cell structure, fineness, high aspect ratio and very thin partitioning wall, can be exploited in nano-device processing. Therefore, we proposed a new fabrication technique using focused ion beam (FIB) to form an ordered nano-cell structure and proved the validity of this idea by performing experiments [3,4]. In this article, the authors have further worked to investigate the effects of the ion acceleration voltage and the ion doses on the cell growth on GaSb by observing plan and cross-sectional views in a scanning electron microscope (SEM).

2. Experiments

Our proposed technique consists of two procedures, which correspond to the top–down process and the bottom–up process in nano-fabrication technology. The first step is to create an ordered initial pattern, and the second step is to develop the initial pattern into an ordered array of cells. In this work, both processes were performed by a Focused Ion Beam (FIB) system, Micrion 9500. First an ordered initial pattern was fabricated on a (100) GaSb wafer by ion irradiation using milling mode. The initial pattern consists of nine matrices of 2.4 µm × 2.4 µm. 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) as shown by Fig. 1. The ion doses per one dot are designed to be equal in all matrices of an initial pattern, in this work, in order to create the same number of Frenkel pairs in every dot (they were

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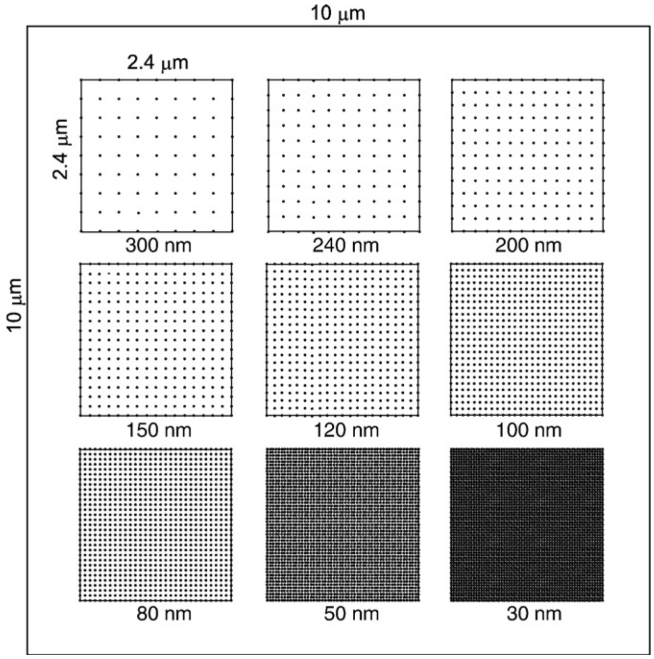

Fig. 1. Schematic diagram of the initial pattern fabricated by milling mode of FIB. The initial pattern consists of nine matrices of 2.4 μm × 2.4 μm, and each matrix is a two-dimensional lattice of implanted dots at a constant interval (30, 50, 80, 100, 120, 150, 180, 240, and 300 nm).

different in the previous paper [4]). The second step was performed by ion irradiation in the imaging mode of FIB, for which the ion dose was determined from the number of scans. The ion dose per scan was 8.39×10^{13} ions/cm^2 and the maximum number of scans was 20. The top views of these fabricated wafers were observed by a scanning electron microscope (SEM), JEOL JSM-7700F. The samples for cross-sectional view were prepared using the acceleration voltages of 30 and 50 kV. Aligned five 35 μm × 35 μm large matrices with a 200 nm dot interval were fabricated on a (100) GaSb wafer; one was the initial pattern obtained after the first step and other four matrices were developed patterns obtained after the second step (using 5, 10, 15 and 20 scans). The fabricated wafer was cleaved and its cross-section was observed by SEM.

3. Results and discussion

3.1. 15 kV irradiation

The SEM surface image of the initial pattern fabricated by 15 keV Ga^+ to a dose of 2.25×10^5 ions/dot did not show a distinct ordered structure, though voids might have been created under the surface, and the surface image did not change even after development by 20 scans. In this case, the projected ion range of 15 keV Ga is 13 nm and the number of Frenkel pairs created by 15 keV 2.25×10^5 Ga^+ is estimated to be 2.4×10^8 by TRIM code [5]. The ion range might be too shallow and the Frenkel pairs might be too insufficient to create voids by subsequent irradiation.

Fig. 2 shows a) the initial pattern fabricated by the dose of 1.13×10^6 ions/dot and b) after the second step developed by 20 scans. The ordered hollow arrays are formed in the matrices with a larger dot interval (I_d) than 100 nm in the initial pattern, and the regularity is significantly disturbed in the 100 nm interval dots array. It is noted that the secondary voids are created in the artificially fabricated voids even at $I_d \geq 100$ nm. Subsequent imaging scans develop the cells as shown typically by the 120 and 150 nm interval dots arrays. However, the formation of the secondary voids is also remarkable.

3.2. 30 kV irradiation

In the case of the initial pattern fabricated with 2.25×10^4 ions/dot, the matrices of $I_d \geq 120$ nm was visible in SEM photographs, but their contrast was weak. These structures were not developed at all by imaging mode scanning. Therefore, it is concluded that the ion dose smaller than 2.25×10^4 ions/one dot (4.85×10^7 Frenkel pairs per one dot are created) is too small for the ordered structure to develop by subsequent irradiation.

The SEM images of the initial pattern fabricated with 1.13×10^5 ions/dot showed that the dots were formed except for 30 nm and 50 nm matrices, but that they were not ordered. The ordered

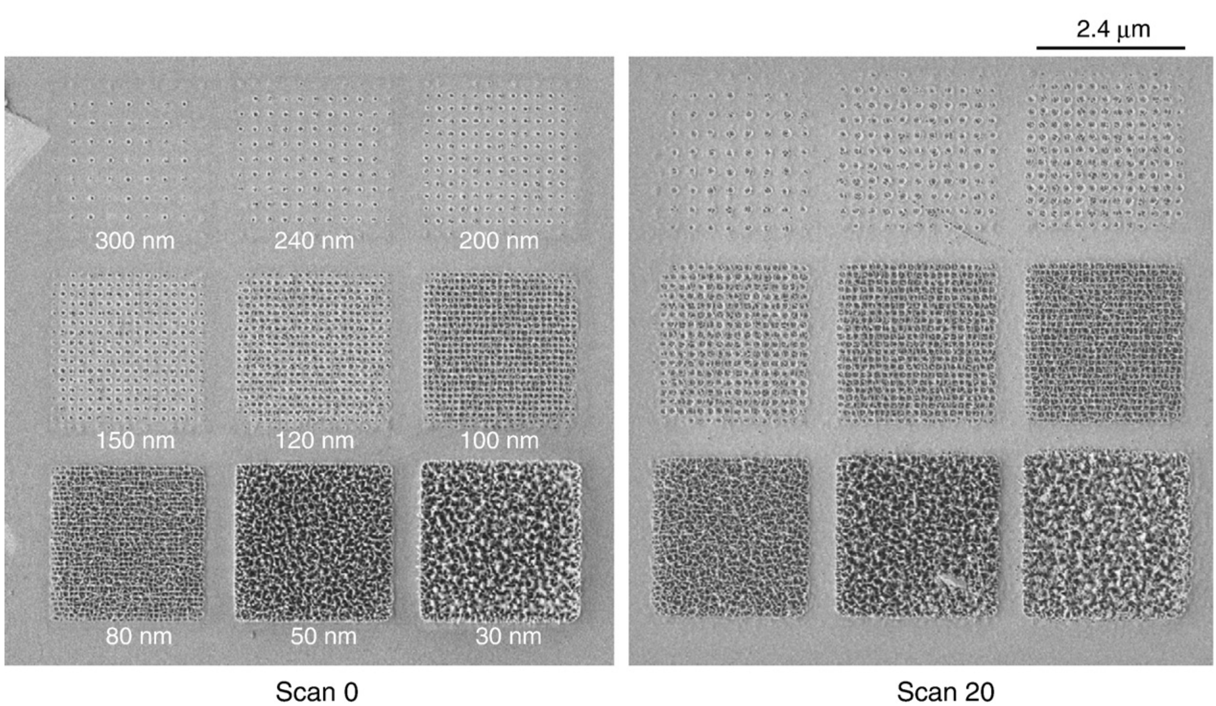

Fig. 2. SEM images of the initial pattern on GaSb surface fabricated by 15 keV Ga^+ to a dose of 1.13×10^6 ions/dot, and the pattern developed by subsequent 20 scans.