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Study of focused ion beam response of GaSb

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Abstract

In this work, we present an experimental study of the morphological and chemical evolution of the (100) GaSb surface after 50 keV focused Ga^+ ion beam exposure using scanning electron microscopy, X-ray diffraction, Auger electron spectroscopy and room temperature raman measurements. A honeycomb-like structure consisting of many cells evolved under the GaSb surface implanted with 50 keV Ga^+ ions for ion fluences of 2.5×10^{15} ions/cm^2. The cell diameter and the thickness of the walls partitioning the cells were about 60 and 20 nm respectively. During further FIB implantation the subsurface cavities expanded in the surface direction and form a microtexture of filaments about 25 nm in diameter. Above a Ga fluence of 6.25×10^{16} ions/cm^2 the onset of nanofibers growth was observed taking place in close proximity to the FIB modified surface. The nanofibers are amorphous with remarkably uniform diameters in the range of about 25 nm incorporating GaSb nanocrystallites with cubic zinc blende structure. A growth model is proposed based on the idea of a catalytic vapour liquid solid nanowire growth mechanism.

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1. Introduction

The use of high energy focused ion beams (FIB) for maskless patterning is a well-established technique and well suited for device prototyping [1]. To keep up with the trend of devices to shrink in dimensions, the response of ion induced material modifications will have to be controlled on a nanometer scale. It is well known that under certain sputter conditions, i.e. generally under off-normal ion incidence, a periodic height modulation in the form of ripples and dots develops during ion bombardment on a submicron length scale as observed for semiconductor materials [2–5], metals [6–8], insulator surfaces [9] and others (e.g. graphite [10]). Particularly for some III/V compound semiconductors, such as InAs, GaAs or GaSb irradiated by energetic ions, anomalous behavior was observed [11–13].

Previous studies on ion implantation in GaSb have indicated swelling effects at the near-surface regions [14]. Facso et al. investigated low-energy normal incidence Ar^+ sputtering of GaSb (100) surfaces and observed that, as erosion proceeds, self-organized nanoscale islands appear on the surface [15]. Homma observed filament-like microtextures on GaSb implanted with Cs ions at low energy [16] and Nitta and Taniwaki observed an anomalous structure on GaSb and InSb surface implanted with 60 keV Sn^+ at low temperatures [17]. Nitta et al. examined this effect in detail and proposed a defect formation mechanism, based on movement of the point defects induced by ion implantation [18].

The aim of this work is to give a contribution to the basic research in the FIB pattern characteristic of the

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III–V compound semiconductor GaSb, which was chosen due to its technological importance. GaSb with a band gap of 0.7 eV, which falls into the infrared spectral range, is gaining increasing importance for optoelectronic devices [19]. In this paper we show for the first time that the proposed defect formation mechanism, based on movement of the point defects might be active in the initial stage of FIB milling but later on a new Ga catalyzed mechanism is responsible for the anomalous behavior of GaSb under FIB exposure.

2. Experimental

All machining experiments were carried out using the Micrion twin lens FIB system (model 2500) equipped with a Ga liquid metal ion source. To investigate the morphological evolution, squares of $(50 \times 50)\ \mu m^2$ were irradiated on pieces of mirror polished GaSb (1 0 0) with various ion fluences. For patterning, the 50 keV Ga^+ ion beam with a beam current of 2 nA is scanned in discrete steps across the GaSb surface at normal incidence. If not mentioned in particular, the processing was done in the single scan mode, thereby each pixel is irradiated only once and the fluence is adjusted by the dwell time the beam remained on each single spot. The pixel spacing was adjusted to guaranty a beam overlap of more than 80%, thereby a nearly uniform ion fluence distribution is obtained [20].

The pattern evolution was observed by top-view and cross-sectional secondary electron microscopy (SEM) of cleaved samples, high resolution transmission electron microscopy (HRTEM). The chemical composition of the pattern was evaluated by auger electron spectroscopy (AES) using a VG Microlab 310F system and electron dispersive X-ray (EDX) analysis. X-ray powder diffraction (XRPD) was carried out on an X'Pert powder diffraction goniometer (Philips). Raman spectra were obtained using a Nd:YAG laser with 532 nm line with an incident laser power of 2 mW to excite the samples in the backscattering geometry.

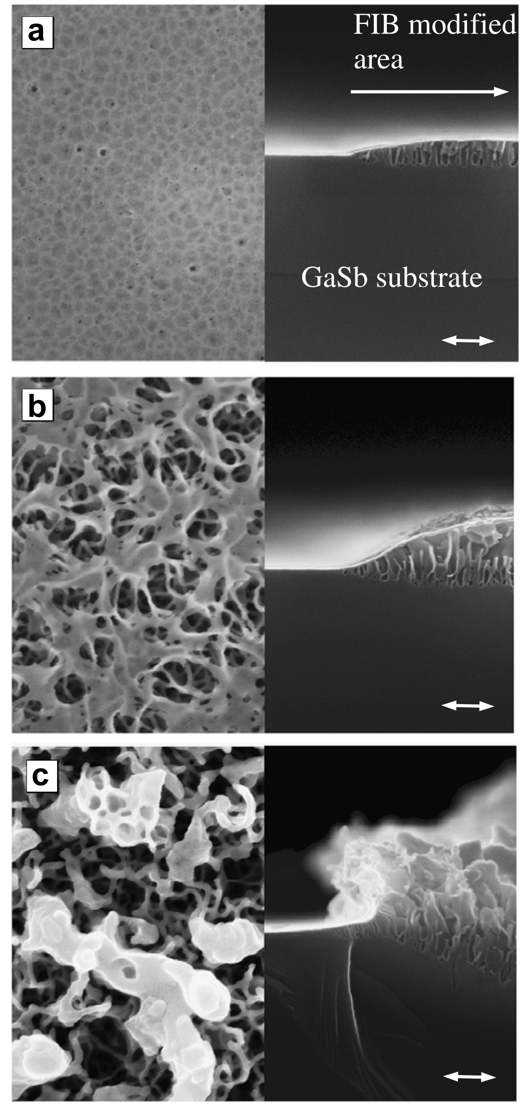

Fig. 1. Top view SEM images of the GaSb surface and cross-sectional SEM images of the cleaved samples after 50 keV FIB exposure with ion fluences of (a) 2.5×10^{15}, (b) 7.5×10^{15} and (c) 6.25×10^{16} ions/cm^2. Scale bar, 200 nm.

3. Results and discussion

The SEM images in Fig. 1 show the evolution of the GaSb surface after 50 keV FIB exposure with ion fluences of (a) 2.5×10^{15}, (b) 7.5×10^{15} and (c) 6.25×10^{16} ions/cm^2. The images on the right side show the respective crossections of the boundary region between the FIB bombarded area and undisturbed GaSb. For the lowest ion fluence we observed the formation of a subsurface cavity structure (Fig. 1(a)). The cavity diameters and the thickness of the walls partitioning the cavities were about 60 and 20 nm, respectively.

One can clearly see the swelling effects at the near-surface regions which were already reported in previous studies on ion implantation in GaSb [21]. Nitta et al. proposed a mechanism for the cavity formation based on movement of point defects induced by ion implantation [18]. According to TRIM calculations, one Ga^+ ion accelerated by 50 kV creates about 3000 vacancies and the same number of interstitials in the GaSb. Due to the difference in mobility, interstitials migrate out of the implanted region, whereas vacancies escape from recombination. In spite of the poor mobility of vacancies at low temperatures, after they accumulated over a critical concentration they coalesce forming voids. These voids absorb vacancies generated by subsequent implantation and extend to the surface direction. Fig. 1(b) shows the filament microtextures about 20 nm in diameter that are developed on the surface bombarded by a fluence of 7.5×10^{15} ions/cm^2. During this self-organizational formation of a cellular structure most of the structures reach to the surface and the depth of the structures increased to 200 nm. In the optical microscope the exposed box showed a black soot-like appearance, which is attributed to a decrease in scattered light due to a closely spaced texture.