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EXAFS comparison of crystalline/continuous and amorphous/porous GaSb

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Abstract

Ion irradiation of GaSb yields not only amorphization but also causes the material to become porous. For this report, GaSb has been irradiated to a dose sufficient to yield a porous network comprised of 15 nm wide rods. The local structure has been determined by EXAFS and compared with that of a polycrystalline standard. Significant Ga_2O_3 formation is observed along with Sb–Sb bonding far in excess of the homopolar bonding observed in other amorphous III–V semiconductors.

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Keywords: GaSb; Ion implantation; Amorphisation; Porous semiconductors; EXAFS

1. Introduction

GaSb is a direct bandgap semiconductor suitable for fabricating high-frequency electronic devices and optoelectronic devices operating in the 2–4 μm wavelength region [1]. Ion implantation is commonly used in device fabrication and can cause amorphization. Certain semiconductors, for example, GaSb and InSb, can also be rendered porous by irradiation [2–4]. Extended X-ray absorption fine structure (EXAFS) spectroscopy has been employed previously to investigate the ion-irradiation-induced amorphous phase in a number of III–V semiconductors [5–8]. It has provided evidence of homopolar bonding and a reduction in coordination number in the amorphous phase. In addition, an increase in the heteropolar bondlength has been observed and a Debye–

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Waller factor higher than in the crystalline material indicates increased disorder. Like InAs, GaSb is well suited for an EXAFS study as the *K*-edges of both components are accessible in the hard X-ray region and are well separated in energy. EXAFS investigations have been performed on bulk amorphous GaSb subjected to high pressure [9] and both high pressure and high temperature [10].

For this report, we have performed EXAFS on polycrystalline and ion-irradiated GaSb to determine the local structure in the material that is both porous and amorphous.

2. Experimental

Single crystalline GaSb was implanted at room temperature with positive ^{69}Ga ions using a series of implants at energies from 300 keV to 6.5 MeV. SRIM simulations [11] were used to select appropriate implant conditions[1] to create uniform vacancy production throughout the implanted depth of 2.5 μm. The implanted material was analyzed using scanning electron microscopy (SEM), which was performed on a cross section after cleaving the wafers. Transmission EXAFS was carried out at 10 K on beamline 20 B, at the Photon Factory in Japan. Absorption spectra were recorded at the Ga (10.367 keV) and the Sb (30.491 keV) *K*-edges. Samples were produced by removing the porous material ultrasonically in ethanol, and then filtering and collecting the material in a polyvinylidene fluoride membrane. Sufficient material was collected to yield $\mu x \sim 1$, where μ is the absorption coefficient and x is the GaSb thickness. Unimplanted polycrystalline references were prepared by finely crushing the crystalline material and mixing it with a BN binder to achieve similar GaSb thicknesses to the implanted samples. The EXAFS data from the Ga and Sb edges was Fourier transformed over the range $k = 4$–18 Å^{-1} and $k = 4$–16 Å^{-1}, respectively. The photoelectron scattering-path amplitudes were calculated ab initio using FEFF6 [12] for a GaSb zinc-blende structure with a first nearest neighbour distance of 2.6492 Å. Analysis was performed using FEFFIT [13]. The amplitude reduction factor (S_0^2) was determined from the polycrystalline sample and held constant during structural refinement.

3. Results and discussion

The effect of implantation on the microstructure can be seen in Fig. 1. The implanted layer, initially 2.5 μm thick and continuous, has expanded to 80 μm and been transformed into a network consisting of long (of the order of 100 nm) straight rods ∼15–20 nm in diameter. TEM analysis reveals the presence of a ∼2–3 nm thick amorphous layer on the surface of the rods (as shown in the inset in Fig. 1). Energy dispersive X-ray analysis indicates that the material has a significant oxygen content, which suggests that the amorphous layer is a surface oxide. It has been reported that oxidation of the implanted layer occurs when it is exposed to air, and is a consequence of, rather than the cause of, the porosity [14].

The k^3-weighted EXAFS spectra for the Ga and Sb *K*-edges are shown in Figs. 2(a) and 3(a) respectively. The corresponding non-phase-corrected

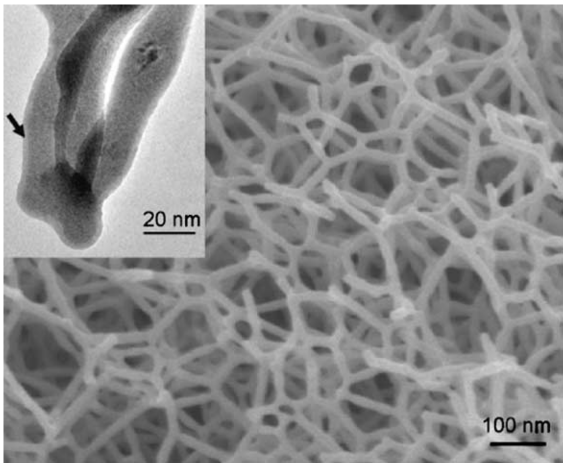

Fig. 1. SEM image of network structure of porous GaSb resulting from ion irradiation at room temperature. The inset shows a TEM image of GaSb after irradiation and exposure to air.

[1] 1.0×10^{16} at 6.5 MeV; 3.4×10^{15} at. cm^{-2} at 3.4 MeV; 2.7×10^{15} at. cm^{-2} at 1.8 MeV; 1.7×10^{15} at. cm^{-2} at 0.8 MeV, and 1.8×10^{15} at. cm^{-2} at 0.3 MeV.