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Epitaxial GaAs for X-ray imaging

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ABSTRACT

To be used for X-ray imaging, semiconductor materials must exhibit good and uniform electronic properties. Epitaxial layers are therefore better adapted than bulk materials which contain dislocations, precipitates and point defects in variable concentrations depending on the growth mode and the nature of the material. However, they have to be thick enough to absorb photons efficiently. We produced thick epitaxial layers using a proprietary technique and made p/i/n (200–300 μm thick) diodes with this new material. These diodes are characterized by a large reverse current, which can originate from electron emission from deep level defects present in the depleted region or be a leakage current. In order to answer this question, we performed a characterization of the defects present in the material. Here, we describe results obtained from X-ray diffraction, X-ray topography, time resolved photoluminescence and resistivity measurements. We also investigated the possible effect of hydrogen. From these observations, we deduced that defects exhibiting an electrical role are in negligible concentration and concluded that the high reverse current observed is a leakage current.

1. Introduction

A detector is a diode, reverse biased at a voltage large enough to insure a depleted zone thick enough compared to the absorption depth of the particle to be detected. For X-rays in GaAs, the depleted zone should be around 100 μm in order to absorb 90% of 20 keV photons. This implies to apply a reverse bias of the order of 35 V when the material is doped at a level of 10^{13} cm^{-3}. The application of the reverse bias induces a reverse current associated with minority carrier emission from deep level defects located in the space charge region, eventually coupled to a leakage current along the edges of the mesa diode.

We are producing self-supported GaAs epilayers (by removing totally the substrate) of thicknesses ranging from 250 to 500 μm [1–3] and we make p/i/n structures as pixel detectors [4–6]. We have succeeded in making good detectors with 2 in. layers (see Ref. [7]). However, when using 4 in. layers, the reverse current of a detector is large and it is necessary to understand its origin in order to master and reduce it.

The aim of this work is to characterize these layers using methods allowing to evaluate the defects they contain and to correlate the presence of these defects with the amplitude of the reverse current. We used different techniques of characterization: X-ray diffraction (XRD) and synchrotron X-ray diffraction topography to characterize the crystalline structure and extended defects; time-resolved photoluminescence (TRPL), sensitive to point defects, which gives directly access to the defects which trap and emit minority carriers; deep level transient spectroscopy (DLTS) which provides a thermal spectroscopy of these deep defects; resistivity measurements which give information on the concentration of residual impurities which are not compensated by defects.

We performed these characterizations on two types of materials, originating from growth on 2 and 4 in. diameters substrates, for which the conditions of growth are similar but not identical.

2. Material characterization

The epilayers are grown on Czochralski (CZ) (1 0 0) GaAs wafers. The substrates, 650 μm thick, are completely removed by

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polishing before characterization. Polishing is made by mechanical grinding but in the future we expect to perform chemical etching with the use of etch-stop layers. Since the growth takes place in H_2 atmosphere, we first studied hydrogen exodiffusion to look for a possible interaction between defects and hydrogen. For this, the layers are heated in vacuum from room temperature to 760 °C. The quantity of emitted hydrogen is monitored using mass spectrometry and then converted into H_2 partial pressure. The variation of H_2 versus temperature is shown in Fig. 1. It indicates that hydrogen goes out of GaAs at 440 °C. The effects of the presence of hydrogen on the crystal structure before and after annealing at 450 °C is investigated in the next sections.

2.1. X-ray diffraction

The crystalline quality is characterised by XRD, the results are given in Fig. 2. We have made measurements on 2 and 4 in. layers and compared with Czochralski grown (1 0 0) GaAs wafer. For a 4 in. layer, we have performed measurements at different positions (centre and edge) of the layer to evaluate the uniformity as well as the effect of hydrogen exodiffusion. In all cases, the peaks associated with the (4 0 0) plane are in the range of 66.0530–66.0550° which correlate well with the theoretical value of 66.0518°. No differences are found between 2 and 4 in. layers, between different positions on a layer, before and after hydrogen removal. This indicates that all the layers have a good and uniform mono-crystalline structure. The hydrogen concentration is too small to induce any detectable change in the crystalline quality.

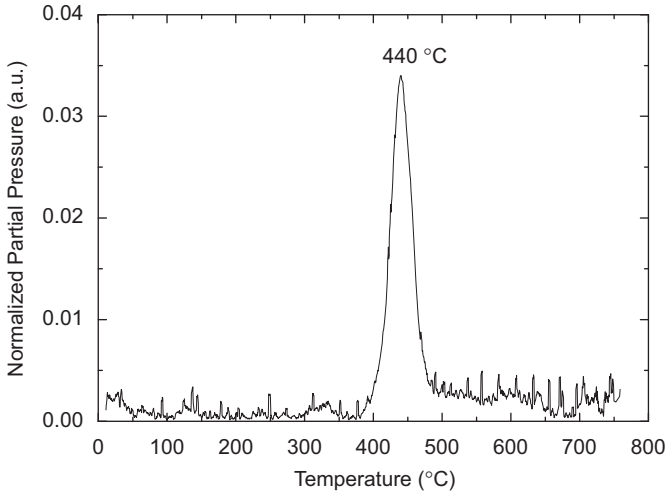

Fig. 1. Hydrogen exodiffusion in a 4 in. GaAs layer.

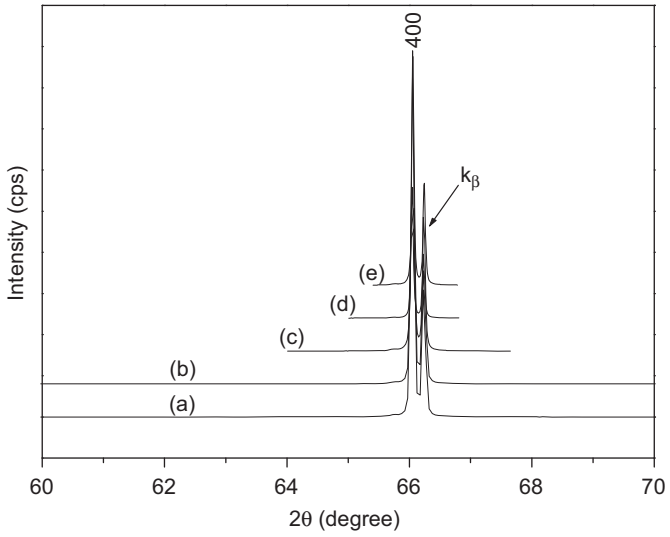

Fig. 2. XRD of GaAs layers characterized using a CuK_α X-ray source: (a) centre of a 4 in. layer, (b) edge of a 4 in. layer, (c) 4 in. layer after hydrogen exodiffusion, (d) 2 in. layer, and (e) CZ wafer.

2.2. Synchrotron X-ray diffraction topography

In order to obtain information on large defects, such as dislocations or precipitates, we used synchrotron X-ray diffraction topography imaging. The tests are performed in transmission geometry with a white light beam of 6 keV and a film detector.

The topographies (see typical ones in Fig. 3) reveal a set of uniformly distributed dark lines which we interpret as being associated with strains. No dislocations or precipitates are observed unlike the case of thick epilayers from another origin [8], i.e. grown by another method. The image taken at the centre of a 4 in. layer (Fig. 3(a)) is very similar to that taken on edge (Fig. 3(b)). The 2 in. layer (Fig. 3(e)) appears less strained than the 4 in. layer. This strain is not the consequence of crystal plane distortion induced by interstitial hydrogen atom since no effect of hydrogen exodiffusion on this strain (see the images of Fig. 3(c) and (d)) is observed consistent to the results of XRD. Hydrogen has no effect on the crystal structure. It is worthy to point out that a grown layer is thicker at the centre than on the edges resulting in bending of the substrate after growth. This difference of growth rate is attributed to the temperature gradient during the growth (the temperature being higher at the centre than on the edges). It is probably this temperature gradient during the cooling after growth which is responsible for the strain. The technique of growth should therefore be improved, by increasing the temperature uniformity.

2.3. Time-resolved photoluminescence

The system for time-resolved photoluminescence (TRPL) is composed of a Ti: sapphire laser pumped by a pulse laser (Verdi laser of 10 W), with a duration of pulse of 1 ps, a frequency of

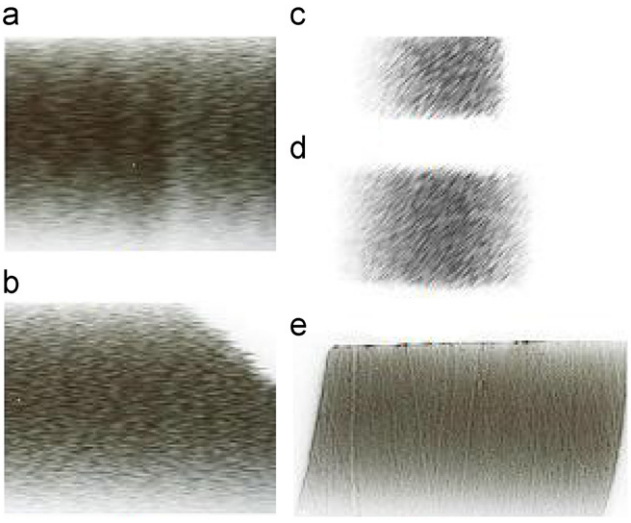

Fig. 3. X-ray diffraction topography of GaAs layers: (a) and (b) centre and edge of a 4 in. layer, (c) and (d) before and after hydrogen exodiffusion (1 h at 440 °C) of a 4 in. layer, and (e) a 2 in. layer.