Available online at www.sciencedirect.com
ScienceDirect
Journal of Crystal Growth 310 (2008) 1590–1594
JOURNAL OF CRYSTAL GROWTH
www.elsevier.com/locate/jcrysgro

Fabrication and passivation of GaSb photodiodes

Sujatha Sridaran, Ashonita Chavan, Partha S. Dutta*

Rensselaer Polytechnic Institute, Troy, NY 12180, USA

Available online 3 December 2007

Abstract

A novel Zn diffusion technique in n-GaSb substrate from a low temperature chemical bath deposited ZnS layer has been developed to obtain high breakdown voltages. Junctions formed by this technique have breakdown voltages of ~18.5 V, low reverse leakage current (0.01–0.03 A/cm^2 at −3 V), excellent reverse current saturation and ideality factor of ~1.3. The high breakdown voltages obtained are due to the co-doping of zinc and sulfur from the ZnS film. Sulfur forms shallow and deep levels that compensate the p-doping of zinc. The non-linear relation of the inverse of the zero-bias resistance area product ($1/R_0A$) versus perimeter to area ratio (P/A) in these diodes indicates surface leakage is the dominant leakage mechanism. CdS has been used to passivate the mesa photodiodes. After passivation, the $1/R_0A$ product reduces from 0.3 to 0.02 Ω^{-1} cm^{-2} for a 150 μm diameter device. The $1/R_0A$ product is also independent of the diode dimension confirming effective passivation. ZnS surface passivation on the mesa walls is not effective and is found to increase the leakage current.

PACS: 81.05.Ea; 68.35.Fx; 81.15.−z; 61.72.Vv; 85.60.Dw

Keywords: A1. Diffusion; A1. Doping; A1. Semiconducting III–V materials; A3. Chemical bath deposition; B1. Gallium antimonide; B1. Zinc sulfide; B3. Photodiodes

1. Introduction

Gallium antimonide (GaSb) based semiconductor materials are very attractive for high speed electronic and optoelectronic applications in the near to mid-infrared wavelength region [1]. There has been continuous research in the materials and device aspect of GaSb, though not as rigorously as other III–V compounds such as GaAs, InP or GaN. The slow maturity in the antimonide based device technology can be attributed to the high leakage currents and low breakdown voltages of GaSb devices. To obtain high breakdown voltages low doping concentrations are essential near the metallurgical junction to support a high electric field. Undoped as-grown GaSb is always p-type in nature with a residual acceptor concentration of ~10^{17} cm^{-3} [1]. Though Pino et al. [2] have reported net donor concentration of 1.16×10^{16} cm^{-3} at 300 K in GaSb, bulk growth of tellurium (Te) compensated GaSb to obtain high resistivity samples still remains a technical challenge. Lower doping levels (5×10^{14}–5×10^{15} cm^{-3}) can be achieved using growth from non-stoichiometric melts by liquid phase epitaxy at low temperatures or by compensation using Te doped GaSb in the growth solution [3,4]. Formation of p–n junction by Zn diffusion from vapor source always results in highly doped p-region [5,6]. Heinz [7] has demonstrated a low doped p-region (5×10^{15} cm^{-3}) by Zn diffusion from spin-on solid source.

In this work, we have demonstrated high breakdown voltages by co-doping Zn and S from a low temperature chemical bath deposited ZnS layer. The ZnS layer protects the GaSb surface during the high temperature diffusion step from the evaporating Sb, in addition to being a source of Zn for diffusion. CdS and ZnS layers have also been employed as a passivation layer on these devices, and its impact on the surface leakage has been evaluated. The simple co-doping technique developed in this work, circumvents the need to incorporate complex epi-layer or bulk growth in the fabrication process to obtain high breakdown voltage GaSb devices.

*Corresponding author.
E-mail address: duttap@rpi.edu (P.S. Dutta).

0022-0248/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jcrysgro.2007.11.186

2. Experimental details

The experimental details of the chemical bath deposition of ZnS, sealed tube diffusion followed by the device fabrication is as follows [8]. The substrates used in this work were single crystal Te-doped n-GaSb with carrier concentrations $\sim 3-5\times 10^{17}\,cm^{-3}$. Prior to all processing, the samples were degreased with hot xylene, acetone and methanol (XAM cleaning) followed by a 1 min etch in warm hydrochloric acid (HCl) to remove the native oxide. To form the p–n homojunction photodiode Zn diffusion was carried out from a low temperature chemical bath deposited ZnS layer of thickness ~1000 Å. The cleaned samples were immersed vertically in the chemical bath containing 0.001 M zinc chloride ($ZnCl_2$), 0.02 M ammonium chloride (NH_4Cl), 0.002 M thiourea (N_2H_4CS) in 50 ml of deionized water. The pH and the temperature of the bath were maintained at 10.3 and 85 °C, respectively. The bath was stirred continuously at ~200 rpm using a magnetic stirrer. Deposition was carried out for 45 min to obtain thickness of ~1000 Å. The film thickness was measured using a Dektak 8 surface profiler after etching regions of the ZnS film. Simultaneous depositions were carried on glass slides and the optical energy gap measured using a Varian Cary 500 UV-Vis-NIR spectrometer was found to be ~3.6 eV.

The ZnS deposited samples were sealed in an evacuated quartz tube ($\sim 10^{-6}$ torr) and diffusion was performed at 500 °C for 10 h. The secondary ion mass spectrometry (SIMS) analysis of the Zn and S profiles after the diffusion is shown in Fig. 1. It is important to note that ~50 nm of the SIMS profile from the surface is arbitrary and not considered for evaluation. The sheet resistance of the p-region measured using the four point probe was found to be ~198 Ω/sq. Hall measurements were performed on the p-region by forming ohmic contacts with indium (In). Extreme caution was exercised during contact formation to ensure that the p–n junction does not get shorted. Hall measurements result in a carrier concentration of $\sim 5\times 10^{18}$–$2\times 10^{19}\,cm^{-3}$ and carrier mobility of ~165–300 $cm^2/V\,s$. After the diffusion, the ZnS layer on the GaSb surface was removed by rinsing in warm HCl for 2 min. ZnS diffuses on both the front and the back sides of the wafer. Therefore, to enable ohmic contact formation to the n-GaSb substrate, the p-region from the backside is removed by etching for 30 s in chromic oxide solution (Cr_2O_3:H_2O:HF as 32 g:120 ml:10 ml) after protecting the front side with Apiezon-W wax. Ohmic contacts on n-GaSb were provided by the electron beam (E-beam) evaporation of 200 Å of tin and 1000 Å of gold followed by a rapid thermal annealing (RTA) at 350 °C for 15 s. Ohmic contacts on p-GaSb were provided by E-beam evaporation of 200 Å of titanium and 1000 Å of gold after patterning and lift-off. The front side was further patterned and mesa etched using sodium potassium tartrate, HCl and H_2O_2 (12 g:33 ml:9 ml diluted in 500 ml of deionized water) [9] for 10 min to define diodes of diameter varying from 150 to 500 μm. The schematic of the fabricated device is shown in Fig. 2.

3. Results and discussions

I–V characterization of diodes was carried out at room temperature using HP 4140B *I–V* meter. Standard pin probes were used to make connection to the top metal. The bottom metal was in contact with the metallic chuck, which was grounded. The large metal chuck also acted as a heat sink to keep the temperature of the device constant during the measurements. Dark *I–V* characteristics were obtained when the probe station was enclosed in a dark chamber to prevent any ambient incident radiation.

A representative plot of the dark *I–V* characteristics of the ZnS diffused mesa photodiodes with varying diode area is shown in Fig. 3. Diodes varying in diameter from 150 to 500 μm were tested. In the forward bias regime, all diodes exhibit a turn-on voltage of ~0.3 V, typical of GaSb devices [3]. The measured reverse saturation current density varies from 4.15×10^{-4} to $7.57\times 10^{-5}\,A/cm^2$ and the ideality factor varies from 1.30 to 1.35 across diodes with diameters between 150 and 500 μm.

In the reverse bias region, all diodes exhibit high breakdown voltage and low leakage current as seen in

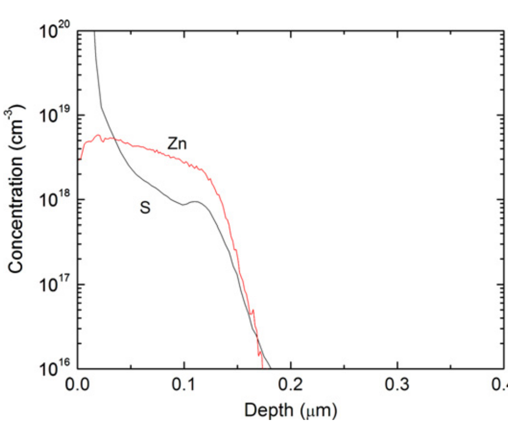

Fig. 1. Secondary ion mass spectrometry analysis of Zn and S profile diffused from ZnS thin film in n-GaSb.

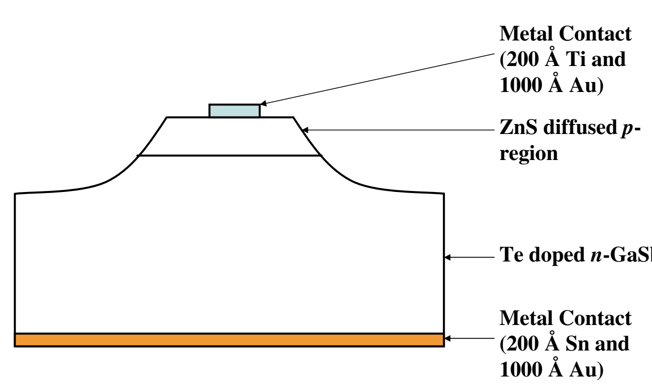

Fig. 2. Schematic of the cross section of mesa p–n homojunction photodiode.