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THE PREPARATION OF InAsSb/InSb SLS AND InSb PHOTODIODES BY MOCVD

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ABSTRACT

Infrared absorption and photoluminescence have been demonstrated for $InAs_{1-x}Sb_x/InSb$ strained-layer superlattices (SLS's) in the 8-15 μm region for As content less than 20%. This extended infrared activity is due to the type II heterojunction band offset in these SLS's. The preparation of the first MOCVD grown p-n junction diode was achieved by using dimethyltellurium as an n-type dopant . Several factors, such as background doping and dopant profiles affect the performance of this device. InSb diodes have been prepared using tetraethyltin. The resulting current-voltage characteristics are improved over those of diodes grown previously using dimethyltellurium. Doping levels of $8x10^{15}$ to $5x10^{18}$ cm^{-3} and mobilities of $6.7x10^4$ to $1.1x10^4$ cm^2/Vs have been measured for Sn doped InSb. SLS diode structures have been prepared using Sn and Cd as the dopants. Structures prepared with p-type buffer layers are more reproducible.

INTRODUCTION

$InAs_{1-x}Sb_x/InSb$ strained-layer superlattices (SLS's) have been proposed for use as long wavelength detectors in the 8-15 micron range. The preparation of high quality materials was achieved by the minimization of cracks and dislocations in these $InAs_{1-x}Sb_x/InSb$ SLS's by using 2-3 μm thick, compositionally graded $InAs_{1-x}Sb_x$ buffer layers [1]. Infrared absorption and photoluminescence were determined for these high quality SLS's in the 8-12 μm region for As content less than 20% [2]. This extended infrared activity is due to the type II heterojunction band offset in these SLS's.

Fabrication of a photodiode is an important step in the development of a new infrared material. The preparation of the first MOCVD grown p-n junction diode was achieved by using dimethyltellurium as an n-type dopant [3]. The structure of the SLS used in this photodiode consisted of $InAs_{0.18}Sb_{0.82}/InSb$ layers with equal layer thicknesses, 13.0 nm. Several factors, such as background doping and dopant profiles, are believed to affect the performance of this device. Recently, a high detectivity, > $1x10^{10}$ $cmHz^{1/2}/W$ at 10 μm, InAsSb SLS photodiode was prepared by MBE [4]. The MBE InSb has a lower background carrier concentration than the MOCVD InSb and Se was the n-type dopant. This paper discusses the use of tetratethyltin as an n-type dopant and Cd as a p-type dopant. Current-voltage characteristics of an InSb diode prepared using tetraethyltin are presented and compared to the previously reported diode results. These measurements indicate that Sn is the preferred n-type dopant for InSb. The results of the growth of step-graded buffer layers using Cd or Sn as the dopant are also discussed.

EXPERIMENTAL

Studies investigating the use of tetraethyltin (TESn) and dimethylcadmium (DMCd) were carried out in a previously described horizontal, atmospheric pressure system [5]. The sources of In, Sb and As were trimethylindium (TMIn), trimethylantimony (TMSb) or triethylantimony (TESb) and arsine (AsH3). Tetraethyltin was used in its pure state in a bubbler at a variety of different flow rates and temperatures. Purified hydrogen was used as the carrier gas. The layers were grown at 470 C on (100) InSb substrates. The optimum growth conditions have been previously described [5]. At 470 C and a pressure of 630 torr, a V/III ratio of 2.4 and a growth rate of 0.5 μm/h were used. At 410 C and 630 torr, a V/IIIratio of 3.0 and a growth rate of 0.1 μm/h were necessary to obtain the same surface morphology. The buffer layers discussed in this paper were grown at low pressure, 200 torr, a V/III ratio that varied between 15 and 60, and 470 C. The InSb substrates were cleaned by degreasing in hot solvents and deionized water. They were then etched for two minutes in a 10 to 1 mixture of lactic acid and nitric acid, rinsed with deionized water and blown dry with filtered nitrogen.

Structures for Hall measurements were grown on compensated, Cd doped InSb with measured hole densities at 77 K of 10^{12}-10^{13} cm^{-3}. The general structure which was used for the Hall measurements consisted of a single layer of InSb 2 to 4 μm thick grown directly on the subst..ate. Hall measurements were made by standar'd van der Pauw techniques. The reported mobilities were determined with a magnetic field of 2.0 or 3.0 kG. The epitaxial layers were uniformly doped. The samples were examined by optical microscopy and a lapping technique to determine layer thicknesses.

The structure of the diode reported on in this paper consisted of an n-type substrate, N_D-N_A = 3×10^{17} cm^{-3}, a 1.6 μm Sn doped layer with N_D-N_A = 1×10^{16} cm^{-3}, and a final layer of undoped InSb with N_A-N_D = 1×10^{16} cm^{-3}. The p-doping in the final layer is the present background level of the InSb grown using TMIn and TMSb at 470 C. The diodes were mesa isolated with an area of 1.2×10^{-3} cm^2.

RESULTS AND DISSCUSSION

One of the major difficulties that has been encountered in the growth of InAsSb SLS photodiodes by MOCVD is the high background carrier concentration [3]. One approach to lower this background that has been investigated is the use of low pressure MOCVD. The use of low pressure MOCVD has resulted in a small improvement in the background carrier concentrations for the best samples and a slight improvement in mobilities. The carrier concentration improved from 7×10^{15} cm^{-3} to 5×10^{15} cm^{-3} and the mobility changed from 5000 to 7400 cm^2/Vs. However, in order to prepare a photodiode, a graded buffer layer and doped layers still need to be grown. The results of doping experiments which used TESn at both atmospheric and reduced pressure are illustrated in Fig. 1. The low pressure values for the mobility versus carrier concentration are very similar to the atmospheric pressure results.

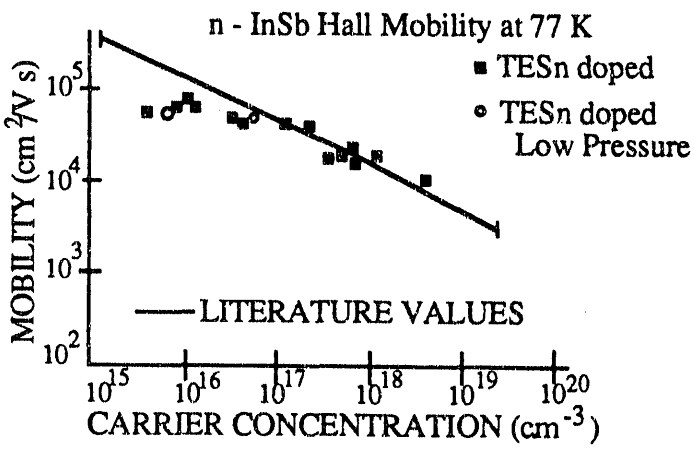

Figure 1. Mobility versus net carrier concentration at 77 K for uniformly doped epitaxial layers of InSb. The open circles are the data for InSb grown at 200 torr and the filled squares are for the samples grown at 630 torr.

The current-voltage characteristics of the photodiode grown using TESn and described above are shown in Fig. 2. The diode characteristic is typical of a narrow bandgap semiconductor [3]. This device exhibits considerably better diode behavior than the first diode reported which was grown using Te as the n-type dopant. The doping levels are also somewhat different than those of the Te diode. Also, the Te diode was grown in an SLS structure with a bandgap of about 10 μm compared to the bandgap of InSb of 5.5 μm. This could explain some of the difference in the I-V curve. The preparation of SLS diodes using Sn will determine if the use of Sn improves the device parameters for infrared detection. The background carrier concentration is still the same for the undoped InSb. Further improvements in this number are needed to enhance the photodiode behavior.

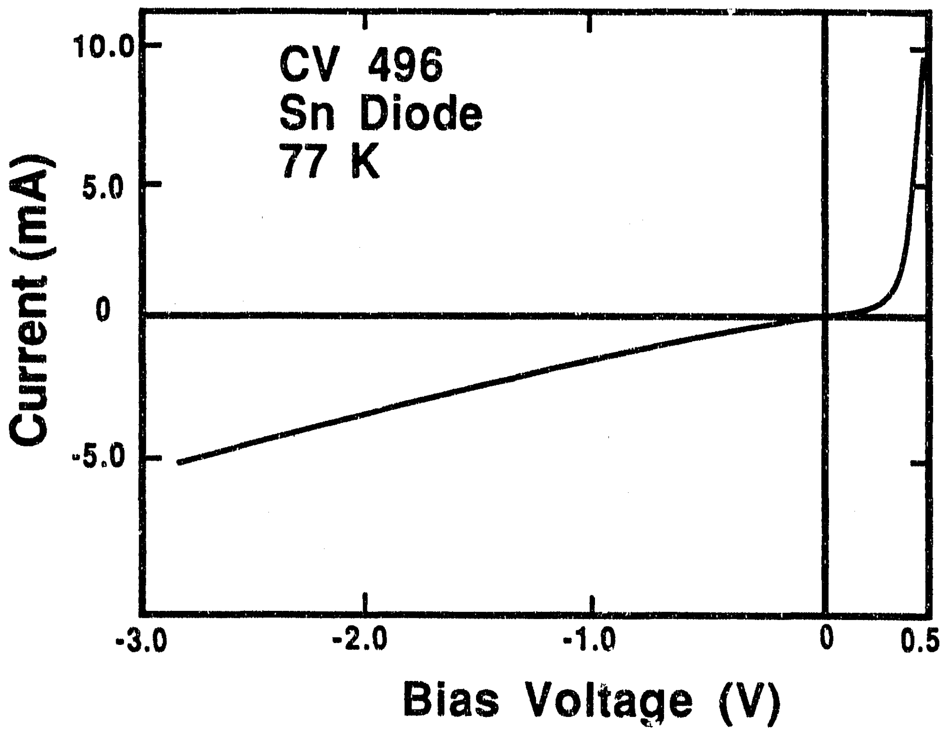

Figure 2. The current-voltage characteristics at 77 K for an unpassivated grown junction, InSb diode prepared using Sn as the n-type dopant and undoped InSb as the p-type material at 630 torr.

Initial attempts to grow the step-graded InAsSb buffer layer using Sn doping resulted in poor morphology as illustrated in the micrograph in the upper right hand corner of Fig. 3. The growth of an InAsSb/InSb SLS on top of these buffers resulted in poor morphology and cracks as illustrated by the micrograph in the upper left hand corner of Fig. 3. Attempts to prepare diodes from the Sn doped InAsSb step-graded buffer layers resulted in devices that exhibited no rectification. Since the initial photodiodes grown at atmospheric pressure were grown on p-type buffer layers, this structure was reproduced at low pressure using diethylcadmium as a source for Cd. The micrograph in the lower left hand corner of Fig. 3 shows the morphology of the Cd doped buffer layers. These p-type buffer layers have improved morphology and improved reproducibility over that of the n-type buffer layers. The result of the first attempt to grow an Sn doped SLS on top of the Cd-doped buffer layers resulted in very poor morphology. This is illustrated in the micrograph in the lower right hand corner of Fig. 3. A possible reason for this type of surface is the growth of an SLS with a large lattice mismatch to the substrate. However, the surface of this Sn doped layer is much worse than the surface of the SLS grown on the Sn doped buffer layers which was grown under identical conditions except for the dopants. This experiment will be reproduced in an attempt to confirm the observed effect.

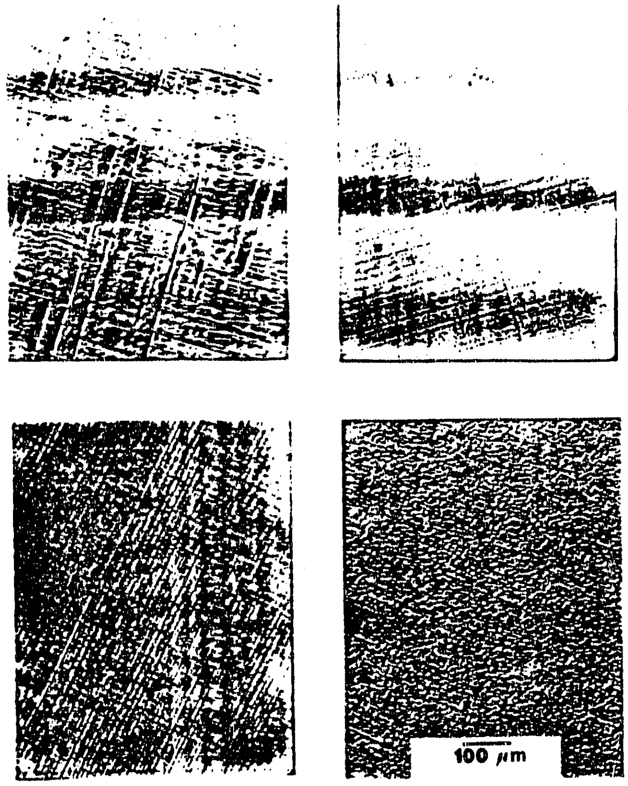

Figure 3. The surface morphology of InAsSb step-graded buffer layers grown using Sn and Cd as dopants and similar structures with InAsSb/InSb SLS's grown on top of them. See text for a detailed description.

The reproducibility of several MOCVD InAsSb growths is illustrated in Fig. 4 where the As composition of InAsSb as determined by x-ray diffraction is plotted against the arsine flow rate. The variation from run to run is approximately one percent. This type of mismatch is not sufficient to explain the extremely rough surface morphology that was observed for the Sn doped SLS grown on top of the Cd doped InAsSb step-graded buffer layer. Until an InAsSb/InSb SLS photodiode can be grown using Sn at low pressures, there is no way to know if the low pressure growth by MOCVD will yield improved electrical characteristics.

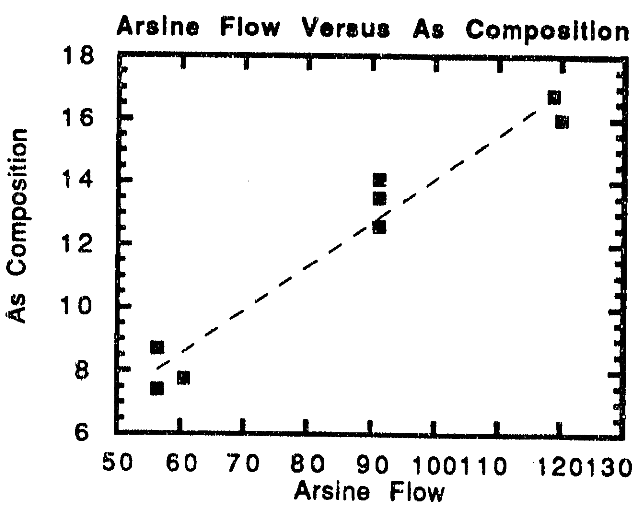

Figure 4. Arsine flow versus As composition in InAsSb grown at 200 torr and 470 C.

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