Study of p-n Junction Diodes Fabricated on Dilute Nitride of InSb

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Abstract- Bulk crystals of dilute nitride of InSb (InSb:N) are grown using Vertical Directional Solidification (VDS) Technique. Substrates of thickness 500 µm were cut from the crystal and polished to mirror finish. These wafers were found n type in nature using Hall measurements. Boron (B) atoms were diffused in the substrate using ion implantation. Range of Boron atoms in the InSb:N substrate was estimated using SRIM software and SIMS was conducted after ion implantation to verify the Boron incorporation. I-V characteristics of the p-n junctions formed due to implantation of boron indicated diode formation with ideality factor 1.2.

Index Terms- InSb, Dilute nitrides, p-n Junctions, Ideality factor

I. INTRODUCTION

The Indium Antimony has smallest band gap in III-V group semiconductors and very high mobility. It is an infra red sensitive material with advantages over other IR sensitive materials such as stability and uniformity of composition [1]. InSb is useful in infra red imaging and gas phase detection system, infrared sensors and filters. The band gap of InSb was modified by addition of nitrogen to make the material suitable for sensing in LWIR, 8-12 µm atmospheric transmission range [2]. The advantages of the bulk crystal growth by VDS are: detached growth of the crystal from ampoule wall and seedless unidirectional growth. The detachment of the ingot from ampoule wall results in lower stress between ampoule wall and the crystal and as a result the detached crystal has lower defect density compared to crystals grown attached to the ampoule wall [3]. Binary crystals of InSb and GaSb grown by this method have shown reduction in defect density while enhancing electrical properties. In case of bulk crystal of InSb:N, while bulk crystal was grown detached with incorporation of nitrogen carrier concentration was higher compared to undoped crystals. The bulk crystal of InSb:N grown by VDS technique was used for fabrication of devices.

The fabrication and characterization of p-n junction on p type InSb substrate grown by VDS was reported by D. B. Gadkari [4]. The leakage current in this case was very low and the diodes formed using ion implantation of tellurium atoms show rectifier like characteristics. The study of p-n junction diodes was also reported on thin film of InSb:N formed using molecular beam epitaxy where Carbon was used as p type dopant [5]. In another literature, nitrogen implantation to form InSb: N is reported [6]. In this study the diodes were formed on bulk substrate of InSb:N using ion implantation of Boron ions. Boron atoms were chosen for implantation as the Boron atoms are suitable as p type dopant and they are suitable for negative ion implantation.

II. EXPERIMENTAL DETAILS

The growth of bulk crystal of InSb:N was carried out using VDS technique. The 5N purity source materials were sealed in quartz tube with conical shape at lower end and it was filled with argon at pressure 200 torr. The temperature of the furnace was raised to 750^0C and quartz ampoule was held at this temperature for 5 hours to form uniform composition of melt. The ampoule was slowly lowered to 575^0C that is 50^0C above the melting point of InSb:N. From this point, the ampoule was lowered. The speed of downward motion of ampoule 3mm/hr and temperature gradient 17 ^{0}C/cm was optimized from previous growths [7]. The ampoule was continuously rotated with speed 10rpm. In this process seed crystal was not provided in ampoule. The ampoule was held at 350^0C for 3 hours for annealing. The ingot was found detached from the ampoule wall after growth. Three bulk crystals of dilute nitride of InSb (InSb:N) were grown using vertical directional solidification (VDS) technique. Wafers of thickness 1mm were cut and polished to mirror finish before using them for implantation. The carrier concentration of n type wafer of InSb:N was determined using hall measurements. The carrier concentration and resistivity of the wafers cut from InSb:N crystals were in range 3-8 E 17 cm^{-3} and 2-4 E -4 ohm-cm respectively. For the crystals with carrier concentration greater than 5 E 17 cm^{-3}, the wafers were annealed before implantation Annealing of the wafers reduced the carrier concentration [8].

The depth of implanted ions was estimated using software, The Stopping and Range of Ions in Matter (SRIM). The result of simulation generated for ion energy 100 keV is shown in Fig. 1. The simulation indicates ion range in InSb:N was 2014A where the atoms straggled about 950A for 100 keV. The distribution of ions is not uniform over depth for single stage ionization. Hence two step ion implantation was carried out where energy of ion beam used in second implantation was 50keV. The simulated range for 50keV was 1224A.

Boron implantation was carried out using negative ion acceleration. The beam size was 5mmX 6mm. The implantation dose of Boron ions was 1 E 17 /cm^3 and ion current was 300nA to 450nA. The as-implanted sample is used for measurements. The wafer is not annealed to avoid further boron diffusion in the wafer.

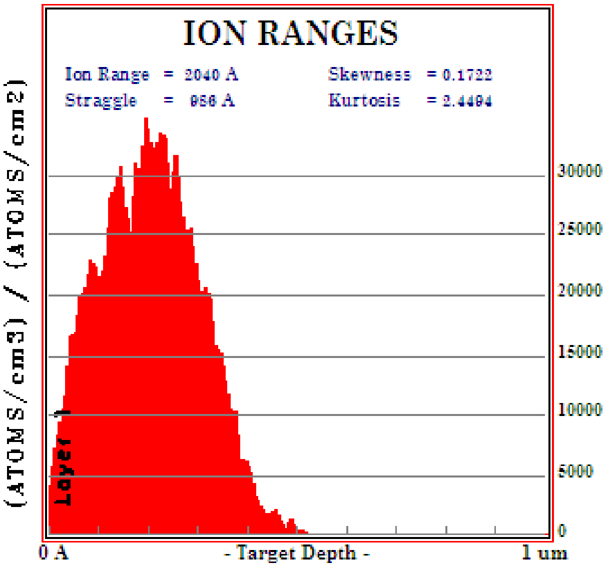

Fig.1 Simulation of Boron implantation using SRIM

III. RESULTS AND DISCUSSION

The depth profile of implanted wafer was generated using SIMS as shown in Fig. 2. The Cesium (Cs) beam was used for measurements. The depth profile of crater created by sputtering was measured using stylus profiler. The concentration of boron atoms reduced at 200nm which was in accordance with SRIM profile shown in Fig. 1. The incorporated Boron atoms have replaced In atoms which resulted in p type region near the surface. The presence of B-Sb bond indicated that these Boron atoms were active in the substrate. The count of In-N and In-Sb bonds in that area decreased due to presence of B-Sb bonds. The profile also shows incorporation of nitrogen throughout crystal. The presence of Sb-N bond was negligible.

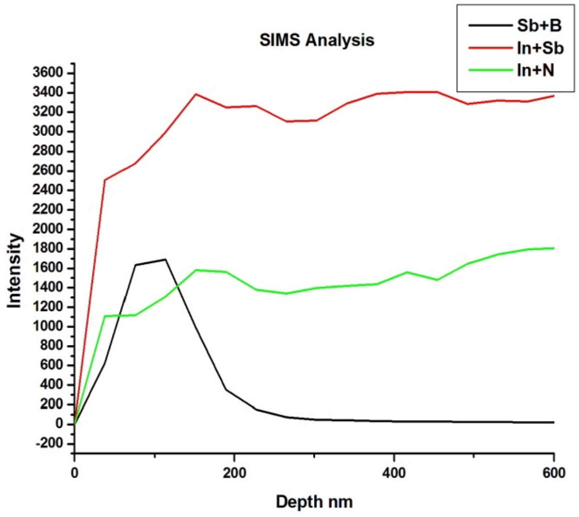

Fig. 2 SIMS profile of the ion implanted InSb:N wafer

The damage done by ion implantation was studied using Raman spectra as shown in Fig. 3. The bulk crystal of InSb:N has grown with preferential orientation [220]. The substrate of InSb:N showed forbidden LO peak along with TO phonon peak. After implantation intensity of forbidden peak increased indicating reduction in crystallinity of the substrate due to damage formed due to ion implantation.

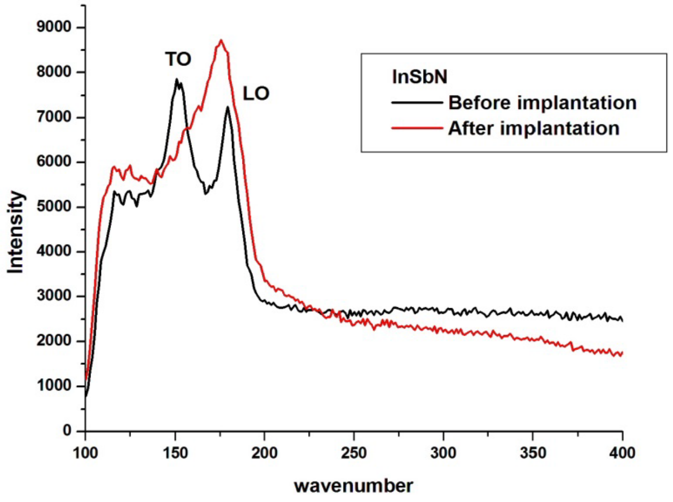

Fig. 3 Raman characteristics of InSb:N substrate before and after ion implantation

I-V characteristics of p-n junction diodes formed by ion implantation were carried out. Fig. 4 shows schematic of boron implanted region on the substrate of InSb:N. Indium dots were deposited used for ohmic contacts to determine I-V characteristics .

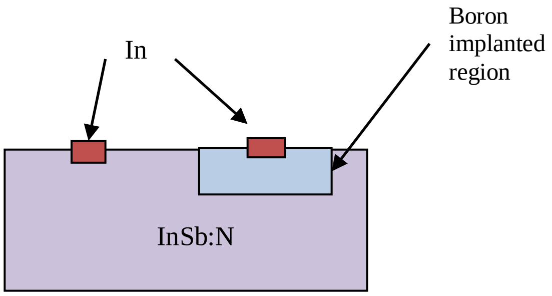

Fig. 4 Schematic of p-n junction formed on the InSb:N substrate where In dots were deposited for the purpose of ohmic contacts

The current I of a diode with saturation current density I_0 and diode ideality factor *n*, for biasing voltage *V* and at temperature *T* are related by [9]

$$I = I_0 \exp(qV/nkT) \quad (1)$$

Fig. 5 represents I-V characteristics of p-n junction formed by ion implantation of Boron on the substrate of InSb: N. The forward current increased at 1V. The leakage current by the Shockley-Read-Hall (SRH) and surface leakage current dominated reverse current. When diffusion current dominates ideality factor is one and when recombination current dominates ideality factor is 2. Forward current was limited by shunt resistance. Ideality factor in the region is 1.20. This diode shows increase in forward and reverse current when exposed to white light at room temperature as shown in Fig. 6.

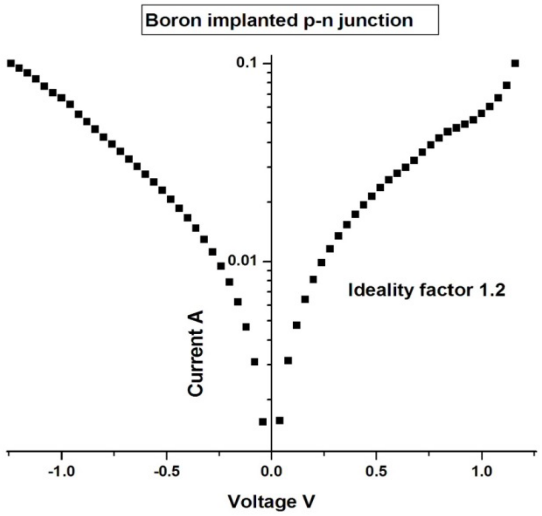

Fig. 5 IV characteristics of boron implanted p-n junction

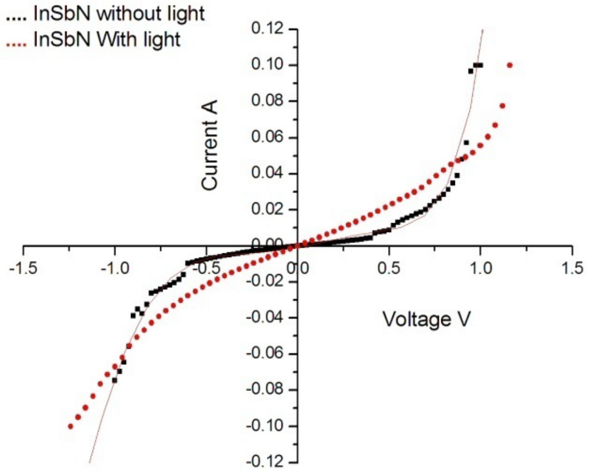

Fig. 6 Linear I-V characteristics of p-n unction formed by Boron implantation

IV. CONCLUSION

The diffusion of Boron in the substrate was simulated using SRIM and measured using SIMS. The estimated and measured ranges for Boron in InSb:N match. SIMS analysis indicated presence of bond formation of Sb-B. The incorporated Boron atoms were active. Nitrogen presence in the wafer was uniform. The ideality factor at room temperature was 1.20. The forward current was limited by shunt resistance. The p-n junction formed by boron implantation had photosensitive nature.

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