Journal of
Applied Sciences

ISSN 1812-5654

ANSInet
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http://ansinet.com

Journal of Applied Sciences 10 (14): 1489-1491, 2010
ISSN 1812-5654

Growth and Characterization of p-type InSb on n-type (111) and (110) InSb Substrates using Molecular Beam Epitaxy

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Abstract: In this study, Molecular Beam Epitaxy (MBE) has been used to grow p-type InSb layers on both n^+(111) and n(110) InSb substrates. Reflection High Energy Electron Diffraction (RHEED) studies along with electro-chemical Capacitance Voltage (CV) profiling system shows reasonable crystal quality on both cases as well as excellent depth impurity profile. Subsequently, using data from C-V profiling, I-V characteristics of these structures were simulated.

Key words: MBE, IR detectors, InSb, RHEED, narrow-gap semiconductors, photo detectors

INTRODUCTION

InSb amongst other narrow band gap III-V semiconductors are potentially important for use as Infrared (IR) radiation detectors sensitive in the 5-7 μm range, where the lower wavelength is related to liquid nitrogen temperature and the 7 μm at around room temperature range (Ashley *et al*., 2000; Johnson, 1999; Norieka and Francombe, 1981; Williams *et al*., 1988). Furthermore polar surface InSb (111) substrates (Lebedev *et al*., 2007) are widely used for epitaxial growth, whereas (110) InSb is very little used.

The growth of GaAs based multilayer and quantum well structures using MBE has been the subject of our previous study within this laboratory (Mohades-Kassai *et al*., 1989; Mohammadkhani *et al*., 2010; Mohades-Kassai, 2000, Kassai and Soufi, 2000; Samkan *et al*., 2001; Ziabari *et al*., 2008a, b).

In this study we used both (110) and (111) orientations to grow epitaxial layers of InSb on them to examine whether their I-V characteristics and consequently their detectivity would show major difference.

EXPERIMENTAL PROCEDURES

In this study, InSb layers were grown in a computer-controlled V80H system, where the background pressure with shroud cooled with liquid nitrogen and all the cells on standby was measured to around 10^{-10} Torr.

The polished n^+-type InSb (111) substrate for layer No. 50 and n-type InSb (110) substrate for layer No. 51, separately and successively mounted on a preheated molybdenum sample-holder using molten Ga as solder and loaded in the load-lock of the MBE system.

After a pump-down, the substrates were individually transferred to the growth chamber where they were heated to about 420°C under Sb flux. The oxide layers of both samples were desorbed and surface reconstructed as was observed on the RHEED screen (Fig. 1a).

After 5 min outgassing at ~420°C, the substrate temperature was lowered to ~400°C. These temperatures were measured with thermocouples mounted near the surface and had previously been calibrated with actual temperatures. The ratio of Sb to In beam equivalent pressures, measured with an ion gauge was kept near 2-3:1. The growth rate for both layers was 3.5 μm h^{-1} as calibrated previously.

The In Sb and Be shutters were then opened to start growth with intended Be doping level of 1×10^{19} cm^{-3}. Use was made of a calibration of these cells at lower temperatures together with extrapolated vapor pressure data. Conventional outgassing of the cells was carried out immediately prior to growth.

After growing for 1 h and 40 min, a p-type InSb layer with a thickness of 5.5 μm was grown on n^+-type InSb (111) substrate (layer No. 50) and after a duration of 2 h, a similar p-type InSb layer with a thickness of 7.0 μm was grown on an n-type InSb (110) substrate (layer No. 51), respectively. During the entire growth period, streaky and bright RHEED patterns were monitored and occasionally photographed (Fig. 1b, c).

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After the above mentioned periods, both growths were terminated and substrates were removed and divided into samples for carrier concentration measurement versus depth using Bio-Rad Electro-Chemical C-V profiling system.

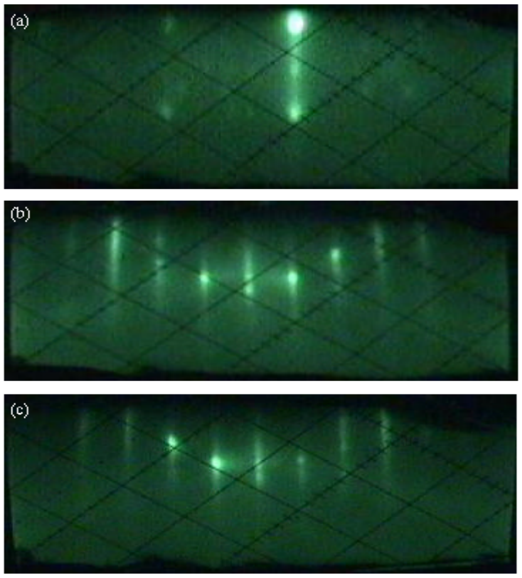

Fig. 1: RHEED patterns, (a) after oxide desorption, during growth for (b) layer No. 50 and (c) layer No. 51

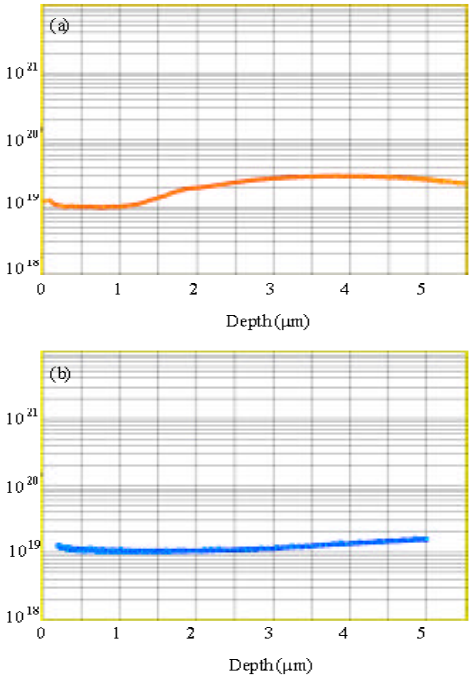

Fig. 2: (a, b) Etch profile for P-layer and substrate

Figure 2a and b show the etch Profile of the layers No. 50 and 51.

RESULTS AND DISCUSSION

Simulation of the Current-Voltage behavior (I-V) of the grown p-n junction was then performed using numerical solution of the Poisson equation. For simplicity, the layer thickness and the thickness of the ohmic contacts were assumed to be 2 μm for p-region, 4 μm for n-region and 50 nm for the ohmic contacts, respectively. Acceptors in the p-region with an energy level of E_a some 50 meV from the valance band and the donors with energy level of 0.7 meV from the conduction band were assumed.

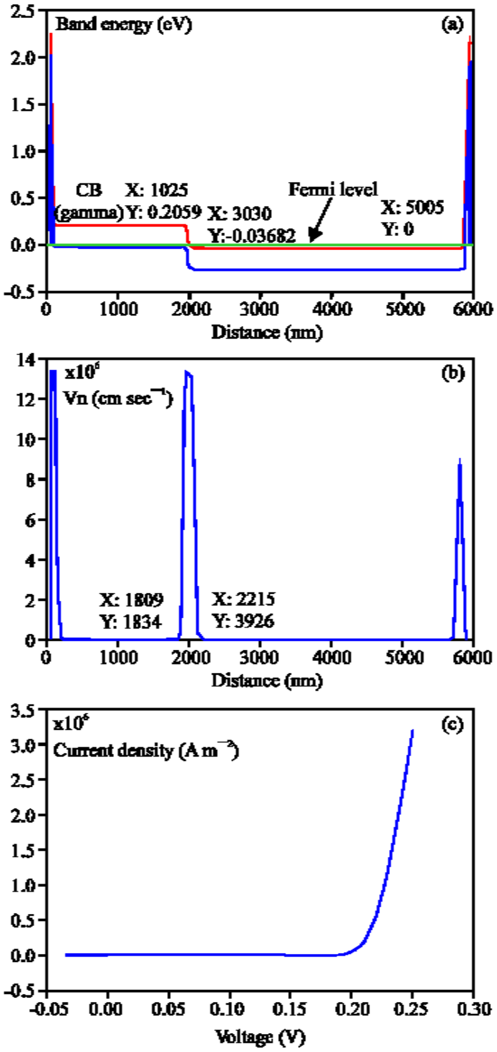

Fig. 3: (a) Simulated energy band diagram with the relevant Fermi level, (b) dimulated drift velocity showing width of the depletion region and (c) simulated I-V characteristic for 77°K

Figure 3a shows the energy band diagram with the relevant Fermi level, 36.82 meV above the conduction band and 21.38 meV above the valance band. This position of the Fermi level with respect to the conduction band and valance band is in accordance with the donors and acceptors of $N_d = 10^{19}$ cm^{-3} and $N_a = 3\times10^{19}$ cm^{-3}; respectively, as measured by the depth profiler (Fig. 2). The width of the depletion region as shown in Fig. 3a is 400 nm.

Furthermore, Fig. 3b represents drift velocity of the electrons within the depletion region where the electric field is at maximum. It can be seen that the drift velocity peaks within the 400 nm region which is the verification of the depletion region even further.

In analyzing the results however, one would assume that 400 nm is wider than necessary conditions for carriers to tunnel through. This assumption enables us to use classical calculation rather than quantum approach in I-V characterization. Figure 3c shows simulated I-V characteristics for this junction at 77°K, based on the numerical data obtained from the measured etch profile.

CONCLUSIONS

In conclusion, we have grown high quality p-type InSb on two different orientations of (111) and (110) InSb substrates by molecular beam epitaxy. The RHEED patterns indicate that the grown layers are of acceptable quality and since the long, streaky and bright patterns persists throughout the growth period, we could conclude that the crystal quality of our layers were standard. This was further verified by measuring the impurity profile in the depth of the layer. The uniformity of the depth profile as shown in Fig. 2 indicate the appropriate incorporation of Be impurity atoms on In sub-lattice sites which in turn suggests that our layers would posses reasonable mobilities.

The other conclusion that one could draw from the above is that the growth temperature was optimum or very near the optimized value.

Finally, the simulation results suggest that although the width of the depletion region is not wide enough for a highly responsive IR detector, nonetheless the p-n junction is configured and if we could grow a π region sandwiched between the two regions, we should in principle be able to obtain a reasonable IR detector. Along the same argument, the other conclusion that we could draw according to the results obtained in this work is that the substrate orientation does not play a major role in the final product.

REFERENCES

Ashley, T., I.M. Baker, T.M. Burker, D.T. Dutton and J.A. Haigh *et al*., 2000. InSb focal plane arrays (FPAs) grown by molecular beam epitaxy (MBE). Proc. SPIE, 4028: 398-403.

Johnson, A.D., 1999. High performance InSb/$In_{1-x}Al_xSb$ focal plane detector arrays grown by MBE. Proc. SPIE., 3629: 288-297.

Kassai, A.M. and H.R. Soufi, 2000. Design and fabrication of high accuracy GaAs hall effect sensor grown by molecular beam epitaxy. Proceedings of the 12th International Conference on Microelectronics, Nov. 31-Oct. 2, Tehran, Iran, pp: 345-348.

Lebedev, M.V., M. Shimomura and Y. Fukuda, 2007. Reconstruction of the InSb (111) in surface as a result of sulfur adsorption. Semiconductors, 41: 521-525.

Mohades-Kassai, A., 2000. Compensation in MBE grown GaAs doped with silicon and beryllium. Proceedings of the 12th International Conference on Microelectronics, (ICM'02), Tehran, Iran, pp: 341-344.

Mohades-Kassai, A., M.R. Brozel, R. Murray and R.C. Newman, 1989. Compensation in MBE grown GaAs dopedwith silicon and beryllium. Proceedings of the 16th International Symposium on GaAs and Related Compounds, Sept. 25-29, Institute of Physics, Karuizawa, Japan, pp: 471-476.

Mohammadkhani, M., M. Samkan and A.M. Kassai, 2010. Electron mobility enhancement in GaAs using in as a dopant in molecular beam epitaxy. Proceedings of the 9th Iranian Conference on Electrical Engineering, (ICEE'01), Tehran, Iran, p: 1-35.

Norieka, A.J. and M.H. Francombe, 1981. Growth of Sb and Insb by molecular beam epitaxy. J. Applied Phys., 52: 7416-7420.

Samkan, M., M. Mohammadkhani, H. Hamidi and A.M. Kassai, 2001. Design and fabrication of a schottky diode with GaAs semiconductor and al-expitaxially grown as metal contact. Proceedings of the 9th Iranian Conference on Electrical Engineering, May 01, Tehran, Iran, pp: 44-49.

Williams, G.M., C.R. Whitehouse, C.F. McConville, A.G. Cullis, T. Ashley, S.J. Courtney and C.T. Elliott, 1988. Heteroepitaxial Growth of InSb on (100) GaAs using molecular beam epitaxy. Applied Phys. Lett., 53: 1189-1191.

Ziabari, M., A.M. Kassai, A. Ziabari and S.E. Maklavani, 2008a. Designing a hamming coder/decoder using QCAs. J. Applied Sci., 8: 2569-2576.

Ziabari, M., K.M. Ahmad, E.M. Shahin and Z. Amirkoushyar, 2008b. A prospect for future generation of quantum dots in computers. J. Applied Sci., 8: 1841-1849.