

# Molecular Beam Epitaxy of Low-Resistance Polycrystalline P-type GaSb

Yingda Dong, Dennis W. Scott, Yun Wei, Arthur C. Gossard, and Mark J. Rodwell

*Department of Electrical and Computer Engineering*

*University of California at Santa Barbara, Santa Barbara, CA 93106*

Phone: (805) 893-3812 Fax: (805) 893-8714 Email: yingda@ece.ucsb.edu

## Abstract:

We report, for the first time, the growth and electrical properties of low resistance carbon-doped polycrystalline GaSb (poly-GaSb) by molecular beam epitaxy using  $\text{CBr}_4$ . The resistivity of poly-GaSb has strong dependence on film thickness and the grain size of the polycrystalline film, particularly when the film thickness is comparable with the grain size. It is found that grain size is determined by growth temperature, while hole concentration is significantly affected by antimony to gallium beam flux ratio. With same doping level, grain size, and similar film thickness, the resistivity of carbon-doped poly-GaSb is more than one order of magnitude lower than that of carbon-doped poly-GaAs. This is attributed to GaSb's favorable surface Fermi-level pinning in the valence band and higher hole mobility. It is proposed that carbon-doped poly-GaSb be used as extrinsic base material in InP heterojunction bipolar transistor to improve the device's high-frequency performance.

## I. Introduction

In SiGe BJTs, growth of a polysilicon extrinsic base over a dielectric spacer reduces the capacitance between the base and the collector ( $C_{BC}$ )<sup>[1],[2]</sup>. In InP heterojunction bipolar transistors (HBTs), the same technique can be applied, with low resistivity polycrystalline material employed as the extrinsic base layer of an InP HBT with buried  $\text{SiO}_2/\text{SiN}$  surrounding a collector pedestal, as shown in Figure 1. With this structure,  $C_{BC}$  and  $R_B$  can be reduced simultaneously and both ECL logic speed and maximum oscillation frequency ( $f_{max}$ ) will be significantly improved.

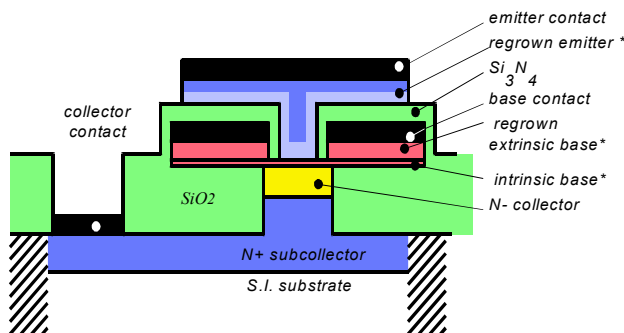


Figure 1. Proposed InP HBT structure with regrown base and emitter.

Polycrystalline materials are composed of small crystallites joined together at grain boundaries. At the grain boundaries between the crystallites, there exist a substantial number of traps that pin the surface Fermi level and greatly influence the bulk conductivity<sup>[3]</sup>. In our study, p-type polycrystalline GaSb (poly-GaSb) has been chosen as a potential candidate for the extrinsic base material because p-type GaSb has surface Fermi level pinned in the valence band<sup>[4]</sup>. As Figure 2 shows, this Fermi level pinning causes a band bending barrier much less than that of poly-GaAs or poly-InGaAs near the grain boundaries. Conduction between grains in poly-GaSb is therefore less limited and lower bulk resistivity can be achieved.

## II. Experimental Procedures and Results

Poly-GaSb samples were grown in a Varian Gen II system equipped with a valved and cracked Sb source. High purity carbon tetrabromide ( $\text{CBr}_4$ ) was delivered into the growth chamber through an ultra-high leak valve. A  $0.3\mu\text{m}$  thick  $\text{SiO}_2$  film was deposited on a semi-insulating (100) GaAs substrate by plasma-enhanced chemical vapor deposition (PECVD) and the sample was then cleaned prior to being loaded into the MBE chamber. The growth rate was  $0.2\mu\text{m/hr}$  and the  $\text{CBr}_4$  flux was fixed with the same leak valve setting.

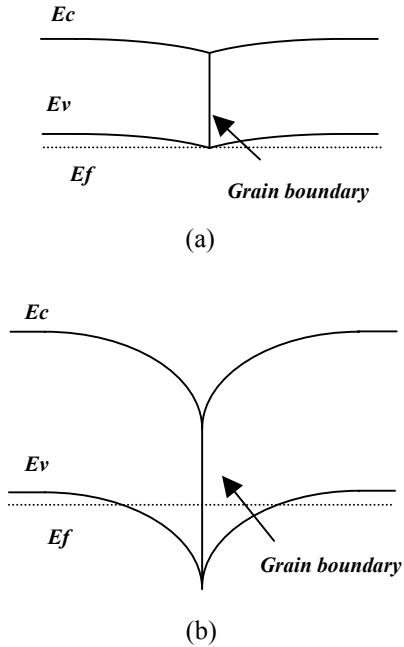


Figure 2. Schematic diagrams of suggested energy band structure near grain boundaries in p-type of (a) GaSb and (b) GaAs.

Three 1000Å poly-GaSb samples were grown at different substrate temperatures with fixed antimony to gallium beam flux ratio of 5. Figure 3 displays the dependence of hole concentration and mobility on growth temperature. It was found that the growth temperature had strong influence on the hole mobility, but not on the hole concentration. This behavior could be related to the grain size's temperature dependence, which is shown in Figure 4 together with the resistivity of the same poly-GaSb films. Figure 5 displays the SEM images of poly-GaSb grown at (a) 520°C and (b) 475°C.

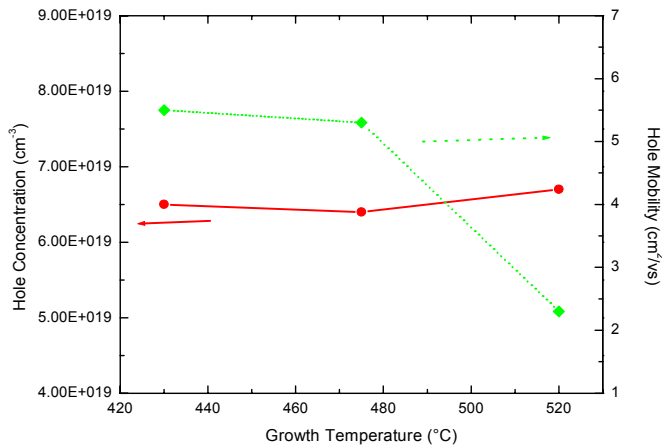


Figure 3. The dependence of hole concentration and mobility of poly-GaSb samples on growth temperature.

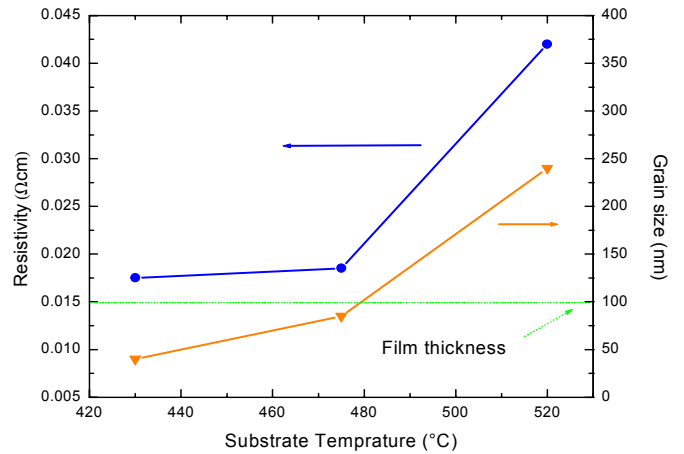


Figure 4. The dependence of resistivity and grain size of poly-GaSb samples on substrate temperature.

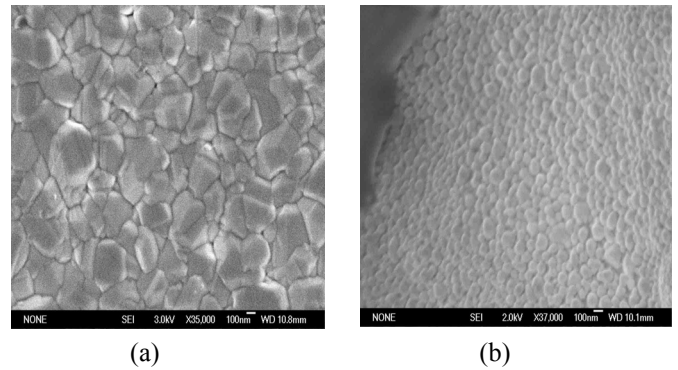


Figure 5. SEM images of poly-GaSb samples grown at (a) 520°C and (b) 475°C.

It can be seen from Figure 4 that the resistivity decreases rapidly with the substrate temperature decreasing from 520°C to 475°C but remains relatively constant at lower temperature. It can be found that for the 1000Å poly-GaSb film grown at 520°C, the film thickness is smaller than the average grain size. It is reasonable to assume that under this circumstance the grain boundary areas are substantially reduced, severely limiting the conduction. This may explain why the resistivity increased rapidly when the growth temperature was raised from 475°C to 520°C.

The second set of poly-GaSb samples were grown with varied antimony to gallium beam flux ratios at the same growth temperature of 440°C. Figure 6 shows the hole concentration

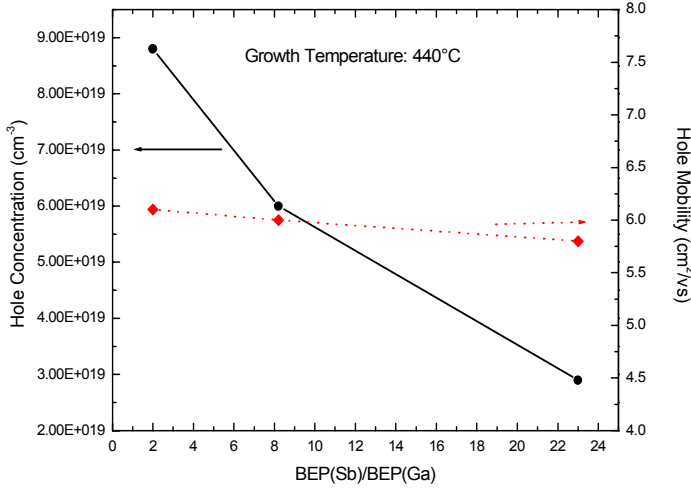


Figure 6. The hole concentration and mobility as a function of V/III beam flux ratio.

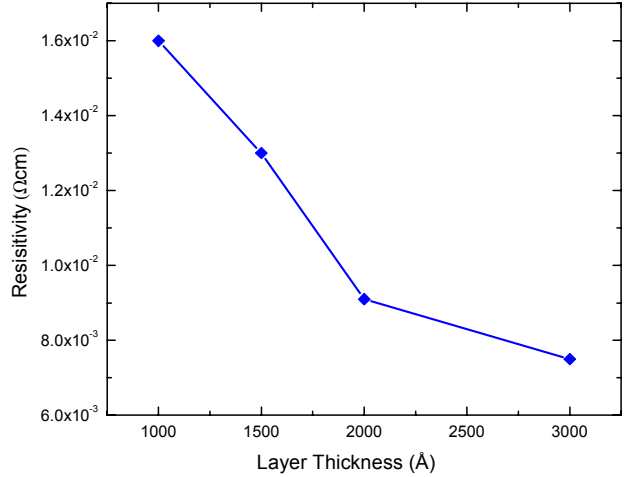


Figure 7. The dependence of poly-GaSb resistivity on film thickness.

and mobility of these samples as a function of the V/III beam flux ratio. The hole concentration shows a clear increasing trend for decreasing V/III ratio. This behavior could be explained by considering that carbon must displace Sb from its lattice site in order to behave as an effective p-type dopant. With lower Sb beam pressure, the chance of carbon being incorporated into the Sb sublattice will be larger and the hole concentration will therefore be increased. In this set of samples it was also found that the change of V/III flux ratio did not significantly affect the hole mobility. The dependence of the grain size on the V/III ratio was also weak.

The third set of poly-GaSb samples were grown with 1000Å, 1500Å, 2000Å and 3000 Å film thicknesses, all at 440°C. Figure 7 shows the resistivity of these four samples as a function of film thickness. The hole concentration, mobility, and sheet resistivity are listed in Table 1. It is clear that unlike monocrystalline material, the resistivity of poly-GaSb has a strong dependence on film thickness, with thicker films having lower resistivity. Consequently, the sheet resistivity is no longer proportional to the reciprocal of the film thickness; instead it increases very rapidly with decreasing film thickness.

The resistivity of the 3000Å poly-GaSb film is 7.5E-3 Ωcm, over one order of magnitude lower than that of polycrystalline GaAs having the same carbon doping level in a thicker 4000Å film<sup>5</sup>. This low resistivity is attributed to GaSb's favorable surface Fermi-level pinning in the valence band and higher hole mobility.

Poly GaSb Thicknesses (Å)	Hole Density $N_s$ ( $\text{cm}^{-3}$ )	Mobility $\mu$ ( $\text{cm}^2/\text{Vs}$ )	Bulk Resistivity $\rho$ ( $\Omega\text{cm}$ )	Sheet resistivity $\rho_s$ ( $\Omega/\square$ )
3000	8.2e19	10.2	7.5e-3	240
2000	8.0e19	8.6	9.1e-3	450
1500	8.1e19	5.8	1.3e-2	900
1000	7.8e19	5.1	1.6e-2	1550

Table 1. Electric properties of poly-GaSb samples with different film thicknesses.

### III. Conclusions

Low resistance poly-GaSb films can be achieved by MBE growth using  $\text{CBr}_4$  doping. The resistivity of poly-GaSb has strong dependence on film's thickness and grain size, particularly when the film thickness is comparable with the grain size. It has been found that growth temperature determines the grain size, but has little effect on hole concentration. The hole concentration, on the other hand, is significantly affected by the antimony to gallium beam flux ratio, with low V/III ratio helping the carbon incorporation. Low growth temperature and low V/III beam flux ratio are therefore the desirable growth conditions for achieving low resistivity poly-GaSb films. With same doping level ( $8 \times 10^{19} \text{cm}^{-3}$ ), grain size ( $\sim 100 \text{nm}$ ) and similar film thickness,

the resistivity of poly-GaSb is more than one order of magnitude lower than that of poly-GaAs. These results suggest that poly-GaSb is a good candidate for the use as an extrinsic base material in InP HBTs.

### References:

- [1] T. Nakamura, T. Miyazaki, S. Takahasji, T. Kure, T. Okabe, M. Nagata, IEEE Trans. Electron Devices ED-29 (1982) 596
- [2] T. H. Ning, R. Issac, P. Solomon, D. D. Tang, H. Yu, G. C. Feth, and S. Wiedmann, IEEE Trans. Electron Devices, ED-28 (1981) 1010
- [3] J.J.J. Yang, P.D. Dapkus, R.D. Dupuis, and R.D. Yingling, J. of Appl. Phys. 51 (1980) 3794
- [4] Spicer, W.E.; Chye, P.W.; Skeath, P.R.; Su, C.Y.; Lindau, J. of Vacuum Science and Technology, 16 (1979) 1422
- [5] N.Y. Li, C.W. Tu, Journal of Crystal Growth 188 (1998) 45