View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by AMS Acta

InP based double heterojunction bipolar transistor with carbon doped GaAsSb:C base grown by LP-MOVPE

S. Neumann, W. Prost, F.-J. Tegude

Solid State Electronics Department, University Duisburg-Essen, Lotharstrasse 55,
ZHO, 47048 Duisburg, Germany, email: neumann@hlt.uni-duisburg.de
Phone: ++49 (0)208 379-3879, Fax: ++49 (0)208 379-3400

Abstract — **We present the growth of highly carbon doped GaAsSb on InP substrate with LP-MOVPE and nitrogen carrier gas. Carbon doped GaAsSb lattice matched on InP are of pronounced interest for high speed double heterostructure bipolar transistors (DHBTs). We observed a significant effect of the nitrogen carrier gas on the growth behaviour which results in lower distribution coefficients. A linear doping behaviour with small CBr_4 flows up to p=4 x 10^{19} cm-^{3} can be observed and first realized DHBT structures shown f_T and f_{max} values of 100 GHz and 60GHz, respectively.**

I. INTRODUCTION

Highly p-type doped $GaAs_{1-x}Sb_x$ is a suitable candidate as a base layer in InP based npn double heterostructure bipolar transistors (DHBTs). $GaAs_{1-x}Sb_x$ can be grown at x = 0.49 lattice matched to InP and forms a type-II staggered heterojunction line up at the InP interface [1]. This enables the use of InP as collector layer without the current blocking effect.

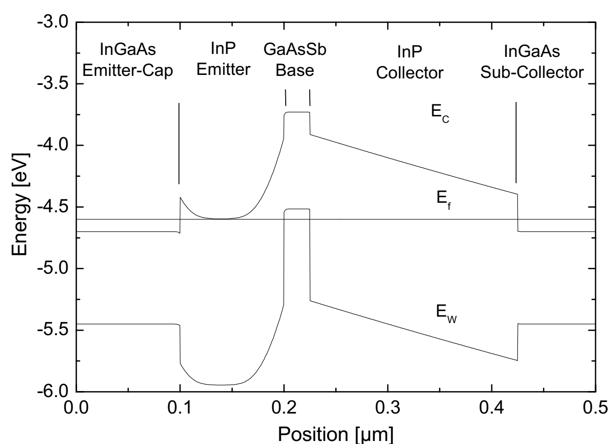

Fig. 1: Energy band diagram of an DHBT with carbon doped GaAsSb base layer

In Figure 1 the energy band diagram is given. The GaAsSb:C base layer is inserted between two InP layers forming a double heterostructure bipolar transistor. This device shows very high breakdown and low turn on voltage [2]. The very high p-type doping capability of this material system using carbon enables further small base layer resistance. In addition, the high saturation drift velocity of the electrons in the InP collector results in very high f_T and f_{MAX} values up to 300 GHz [3]. The ternary III/V semiconductor $GaAs_{1-x}Sb_x$ has a solid phase miscibility gap ranging from x = 0.2 to 0.8 [4]. With MOVPE, the metastable growth of GaAsSb lattice matched on InP has been demonstrated. In addition, the limited growth temperatures required for high p-type doping and the etching effect of the carbon sources like CBr_4 or CCl_4 resulted in substantial efforts in order to control sticking coefficients of As and Sb and the limited decomposition of the Ga source. It is well known from previous studies using the InGaAs:C base layer that nitrogen carrier gas instead of hydrogen may relax the growth difficulties while enabling higher growth temperatures for the same C-doping density [4]. In this work we present a novel growth mode for the growth of p-GaAsSb:C on InP uisng nitrogen carrier gas and an all liquid source configuration. On the basis of first realized DHBT structures the Sb segragation and take up both in following layers and growth runs is studied by X-ray diffraction analysing carefully the impact for the production of GaAsSb/InP DHBT. In addition, a comparsion to the standard InGaAs/InP HBT or DHBT system is stressed.

II. EXPERIMENTAL SETUP

The experiments were done on semi insulating, exactly oriented (001) InP substrate in a AIX 200 reactor with RF heating. With purified nitrogen (N_2) as carrier gas a reactor pressure of p_{tot}= 50 mbar and a total flow of Q_{tot}= 3.4 slm were adjusted. Hydrogen was connected only to the source gas line. We used a complete non gaseous source configuration with tertiarybutylphosphine (TBP) / tertiarybutylarsine (TBAs) / trimethylantimony (TMSb) as group V sources, ditertiarybutylsilane (DitBuSi) / carbon tetrabromide (CBr_4) as group IV doping sources and the metal-organic sources trimethylindium (TMIn) / triethylgallium (TEGa). The group-V to group-III ratios (V/III) and also the group-IV to group-III ratios (IV/III) were calculated from the ratio of the partial

pressures of the precursors involved by the assumption of 100% source efficiency. For the determination of the antimony (Sb) concentration in the partial highly strained GaAsSb layers and for the non destructive characterisation of the HBT layers high resolution x-ray diffractometry (HRXRD) was used. The integrity of the layer structures is proven by HRXRD measurements in the vicinity of the 004 and 002-reflection in a coupled Θ-2Θ-mode using a double monochromator setup. The recorded reflection curves are compared to simulations using a commercial software. The carrier concentration of the p^+-$GaAs_{1-x}Sb_x$:C layers were determined at room temperature by van der Pauw Hall measurements. For this, we used alloyed indium ohmic contacts. Device fabrication is done by wet chemical etching and optical lithography. The on-wafer S-parameter measurements were performed using an HP8510C network analyser in the frequency range from 45 MHz to 40 GHz.

III. Results

The solid composition of the $GaAs_{1-x}Sb_x$ depends on the vapour phase composition Sb/V [= p_{TMSb} / (p_{TMSb} + p_{TBAs})] and additionally on the V/III ratio [4]. We observed that under excess group-III (V/III<1) the Sb incorporation increases to a range, which is relevant for DHBT applications while under excess group-V (V/III>1) the Sb incorporation decrease. For p-type doping CBr_4 is used and a linear increase of dopant density with CBr_4/Ga ratio (IV/III) up to p= 4 x 10^{19} cm^{-3} is observed. The influence of the CBr_4 flow on the solid composition is a well-known etching effect in general for III/V semiconductors. The increasing CBr_4 flow leads in the GaAsSb-system to a reduction of Ga atoms in the gas phase and consequently to higher V/III ratio, thus causes a lower Sb incorporation in the solid phase [6]. Based on this results the growth of p-GaAsSb single layers, superlattices and final DHBT layers is performed using nitrogen carrier gas. We observe a strong memory effect of the Sb with up to 8% Sb up-take in the following growth process. Dependent on the history of the liner and susceptor of the MOVPE system and the Sb contamination, the memory effect can be reduced to values lower 1% which have no impact on HBT properties. Further details about the growth of GaAsSb using nitrogen carrier gas are presented in [6].

Layer	Material	Thickness [nm]	Doping [cm^{-3}]
Emitter cap	n^+-InGaAs	100	1 x 10^{19}
Emitter	n-InP	70	5 x 10^{17}
Spacer	nid-InP	10	undoped
Base	p^+GaAsSb	20	4 x 10^{19}
Collector	nid-InP	300	undoped
Subcollector	n^+-InGaAs	300	1 x 10^{19}

Table 1: Epitaxial layer structure parameters of fabricated InGaAs/InP/GaAsSb DHBT

We have grown first DHBT structures with a carbon doped GaAsSb base layer. The parameters of the layer structure are listed in Table 1.

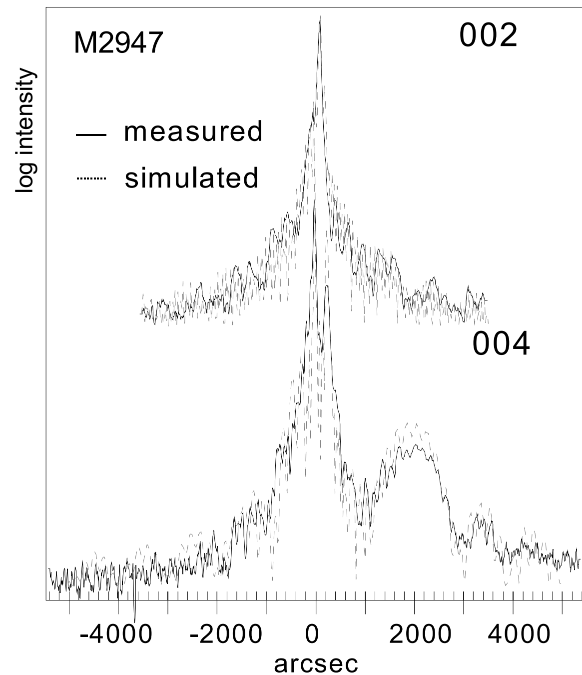

Fig. 2: Measured and simulated high resolution x-ray curve for the (004) and (002) reflection of the DHBT layer structure.

Figure 2 shows the high resolution x-ray diffraction curves in the vicinity of the (004) and (002) reflection of the DHBT layer stack. We simulate both reflexes with one parameter set. Equal layers which are grown with same growth conditions are coupled to minimize the number of free parameters. Thus enables us to determine the composition an the layer thickness of each layer. The period of the fringes can be associated to singel layers of the HBT. The determined values of composition and
thickness (layer parameter) is in good agreement with the intended data. The composition of the strained GaAsSb base can be determined from the right hand peak in figure 2. The simulation of the x-ray data of this layer stack shows an excellent agreement with the measured curves.

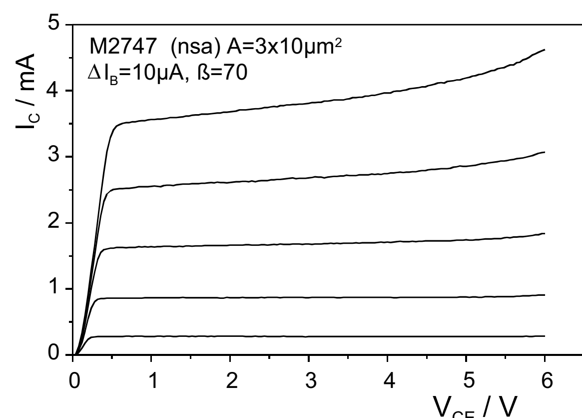

Fig. 3: Common emitter output characteristic for an InP/GaAsSb/InP DHBT.

Device fabrication is done by wet chemical etching and optical lithography. Fig. 3 shows the room temperature I-V characteristic for a non self aligned DHBT with 3 x 10 μm^2 emitter area. We observe a current gain of ß=70 with a breakdown voltage greater 6V and a offset voltage of 38 mV.

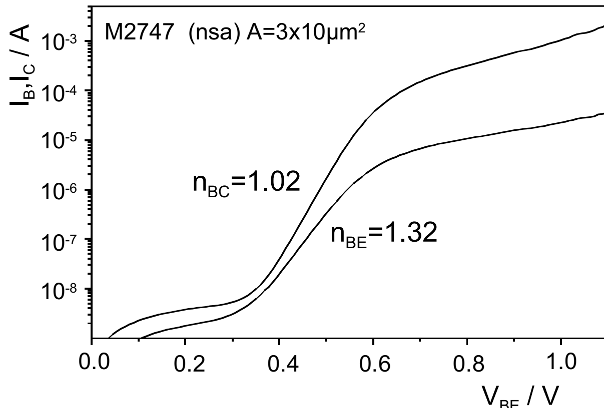

Fig. 4: The Gummel plot of the fabricated InP/InGaSb DHBT (V_{BC} = 0).

The base collector diode shows ideal behaviour with a ideality factor of about n_{BC}=1.02. The first devices with an emitter area of 1x5 µm² exhibit a preliminary but encouraging high frequency performance. The non-deembedded cutoff frequency (f_T) of 100 GHz and maximum oscillation frequency (f_{max}) of 60 GHz were estimated by extrapolating the current gain and Masons`s unilateral power gain with a slope of 20 dB/decade at V_{CE} of 1.0 V.

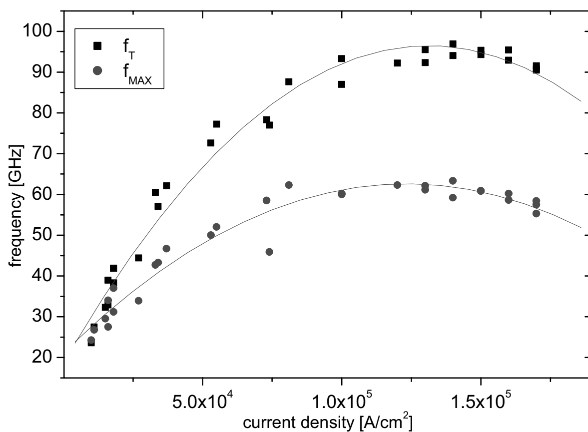

Fig. 5: Evolution of f_T and f_{max} with the current density. The Peak f_T and f_{MAX} is reached at J_C=1.3 x 10^5 A/cm².

Figure 5 shows the evolution of f_T and f_{max} with current density J_C. A peak f_T and f_{max} is obtained at J_C=1.3 x 10^5 A/cm². Comparing these results with standard HBTs realized with the same mask set [7], the GaAsSb DHBT have the advantages of a high breakdown voltage such as InP/InGaAs DHBTs with composite collector and a equal or even lower turn on voltage as InP/InGaAs SHBT. As well the high frequency results shows no disadvantage compared to the other structures.

IV. Conclusions

A novel growth mode for the fabrication of GaAsSb/InP DHBT has been elaborated. It has been demonstrated that the problems related to the segregations and up-take of Sb is controllable. These effects are suppressed to a degree where no disadvantages for device fabrication can be found. In comparison to InGaAs/InP HBT there is a fundamental advantage of higher growth temperatures for the same p-type doping level. This is all important for stable MOVPE growth conditions and giving rise to further device improvements in terms of higher doping levels and/or better crystal layer quality.

Acknowledgement

Support and helpful discussions with Eric Major (AKZO NOBEL, High Purity Metalorganics) are gratefully acknowledged. Also private communication with Prof. S.P. Watkins (Simon Fraser University, Canada) concerning GaAsSb growth and carbon doping are gratefully acknowledged.

V. References

[1] R. Bhat, W-P. Hong, C. Caneau, M. A. Koza, C-K. Nguyen, S. Goswami , "InP/ InGaAsSb/ InP and InP/ GaAsSb/ InGaAsP double heterojunction bipolar transistors with carbon-doped base grown by organometallic chemical vapor deposition", *Appl. Phys. Lett*, Vol. 68 (7), 1996

[2] C. R. Bolognesi, N. Matine, X.G. Xu, G. Soerensen, S. Watkins, "InP/$GaAs_{0.51}Sb_{0.49}$/ InP fully self-aligned double heterojunction bipolar transistor with a C-doped base: a preliminary reliability study" *Microelectronics Reliability,* 39 (1999) 1833-1838

[3] W. Dvorak, C.R. Bolognesi, O.J. Pitts, S.P. Watkins; "300 GHZ InP/GaAsSb/InP Double HBTs with High Current Capability and BVCeo>6V", IEEE Electron Device Letters, Vol. 22, No.8, 2001

[4] M. J. Cherng, R. M. Cohen, G. B. Stringfellow, "$GaAs_{1-x}Sb_x$ Growth by OMVPE", J. of Electronic Materials, Vol. 13, No. 5, 1984

[5] D.Keiper, P.Velling, W.Prost, M.Agethen, F.J.Tegude, G.Landgren, Jpn.J.Appl. Phys. vol. 39, 2000.

[6] S.Neumann, W.Prost, F.-J. Tegude,"Growth of highly p-type doped GaAsSb:C for HBT application", in Proceedings of the Indium Phosphide and Related Materials (IPRM), Santa Barbara, California, USA May 2003

[7] P. Velling, "A comparative study of GaAs- and InP-based HBT growth by means of LP-MOVPE using conventional and non gaseous sources", *Progress in Crystal Growth and Characterization of Materials* (2000) 85-13 1