Material and Processing Technology for Manufacturing of High Speed, High Reliability GaInP/GaAs HBT based IC's

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Abstract

High quality material and processing technology is reported for high speed and high reliability GaInP/GaAs HBTs. GaInP/GaAs HBT materials grown by CBE with non-toxic precursors showed low defect densities and acceptable mobility characteristics for high speed device applications. To reduce the base-collector capacitance (C_{BC}), all wet-based, simple Lateral Etching Undercut (LEU) technology was applied. The 20% reduction of C_{BC} using LEU technology resulted in 25% improvement of maximum oscillation frequency (f_{max}=100GHz). Reliability tests of passivated GaInP/GaAs HBTs with PECVD SiO_2 showed ~2% current gain degradation over a period of 800hrs under high current density (40KA/cm^2) stress condition. Finally, a transimpedance amplifier having a S_{21} gain of 12dB with a bandwidth of 19GHz was fabricated using the reported technology.

1. Introduction

GaInP/GaAs HBTs are becoming a good alternative to AlGaAs/GaAs HBT for manufacturing microwave and communication components. The advantages of GaInP/GaAs-based HBT technology over AlGaAs/ GaAs have been demonstrated by several groups [1]-[4]. They include among other improved processing due to material etching selectivity and high injection efficiency due to the large valence band discontinuity. Several attempts have been reported in the past for reducing the base-collector capacitance (C_{BC}) for improvement of the HBT performance and various technologies such as ion-implantation, polycrystal isolation and buried SiO_2 have been used for this purpose [5]-[6]. There is also evidence of improved reliability characteristics which combined with the other features makes GaInP HBT technology very suitable for manufacturing. For example, GaInP does not suffer from the oxygen related impurities which are easily incorporated during the epitaxy of AlGaAs. As a result, GaInP HBTs have achieved a mean time to failure (MIF) of 10^6 hours which is adequate for the 25-year lifetime requirement of practical systems [7]. This paper addresses material and processing approaches used to advance GaInP/GaAs HBT manufacturing technology. Chemical Beam Epitaxy (CBE) and simple Lateral Etching Undercut (LEU) technology were used for this purpose. The process also included SiO_2 passivation for high stability of device characteristics.

2. Material Growth and Characteristics

The HBT layers were grown by non-toxic precursors and proved to be of high quality as demonstrated by material and device characteristics [8]. Group III atoms were provided by TEGa and TMIn. Precracked tertiarybuthylarsine and phosphine (TBA, TBP) and uncracked trisdimethylaminoarsine (tDMAAs) were employed as Group V sources. The employed growth approach resulted in very high level of reproducibility of growth parameters and low defect density of 10 def/cm^2. Fig 1 shows room temperature Hall mobility data as a function of hole concentration. Data reported by others using arsine are also included in this figure for comparison. All layers grown by TBAs demonstrate slightly higher mobility than those grown by arsine.

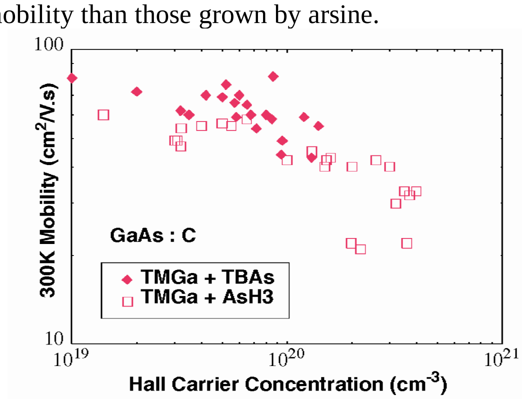


Fig. 1 300K mobility of carbon doped GaAs layers grown by CBE using TMGa and TBAs as a function of carbon concentration.

Good base quality could therefore be obtained even for carbon doping levels up to $2x10^{20}cm^{-3}$.

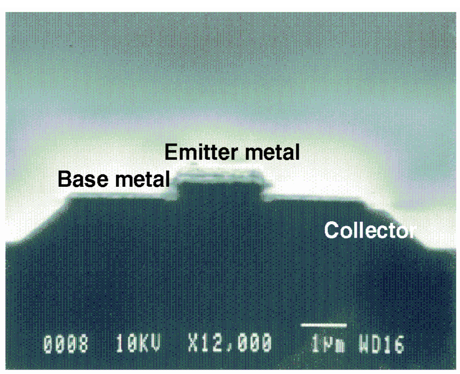
Typical HBT structures used in this work consist of a 300Å InGaAs emitter contact doped n+ ($1x10^{19}cm^{-3}$), 1100Å GaAs emitter cap doped n+ ($1x10^{19}cm^{-3}$), 2000Å GaAs emitter doped n ($2x10^{17}cm^{-3}$), 300Å GaInP emitter doped n ($4.5x10^{17}cm^{-3}$), 600Å GaAs base doped p+ ($4x10^{19}cm^{-3}$), and 7000Å GaAs collector n- ($1.5x10^{16}cm^{-3}$). A thin 100Å GaInP etching stop layer is inserted between GaAs collector and subcollector layer(n+ $1x10^{19}cm^{-3}$) to reduce base collector capacitance (C_{BC}) by using the Laterally Etching Undercut (LEU) technology discussed in next section.

3. HBT Technology and Device Performance

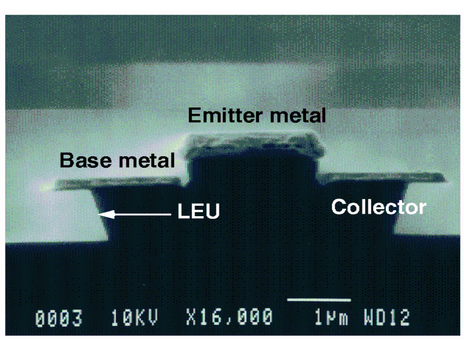
Self-aligned GaInP/GaAs single HBTs were fabricated using simple all wet based chemical etching which minimized layer damage and device degradation. Ti/Pt/Au non-alloyed metal was deposited to emitter and collector layers while Pt/Ti/Pt/Au was used as the base metal. Laterally Etched undercut (LEU) was developed and applied between the base and collector region to reduce base-collector capacitance (C_{BC}) while avoiding base resistance degradation. Typical DC characteristics of 2 x 30μm² single emitter HBT device include DC gain of 40, base ideality factor of 1.32 and collector ideality factor of 1.12 and a collector-emitter breakdown voltage of ~ 13.5V.

Fig. 2 shows the SEM cross section pictures of the fabricated HBT without (a) and with (b) LEU technology. 2 x 30μm² single emitter HBTs were measured using a network analyzer from 0.5 to 25.5 GHz. A reduction of C_{BC} from 470fF to 380fF by lateral etching of about 6000Å leads to higher maximum oscillation frequency which leads to 10% gain improvement at 10GHz as shown in Fig. 3. The most commonly used approach for minimizing C_{BC} is based on ion-implantation through the active base layer. The process analyzed here is based on LEU of the collector layer and offers therefore simplicity and a very effective way of reducing C_{BC}.

The key in this technology step is the incorporation of a thin ($1x10^{19}cm^{-3}$ doped) GaInP layer between the n^+ and n^- GaAs collector which provides selectivity in etching and determines the etching profile below the base. The resulting profile was found to manifest stability upon all remaining processing steps and device testing. 2x30μm² single emitter HBTs fabricated using LEU technology demonstrated an f_T of 58GHz and f_{max} of 100GHz at I_C=20mA, V_{CE}=2.5V. This corresponds to an f_T increase of 11% and f_{max} increase of 25% as a result of using LEU technology as shown in Fig. 3 which compares the comparison of gain-frequency characteristics with and without the LEU technique. The microwave performance of the investigated GaInP/GaAs HBTs shows only slight change with bias and permits therefore robust circuit design.



(a)



(b)

Fig. 2 Cross section SEM pictures of the self-aligned GaInP/GaAs HBT without(a) and with(b) LEU technology.

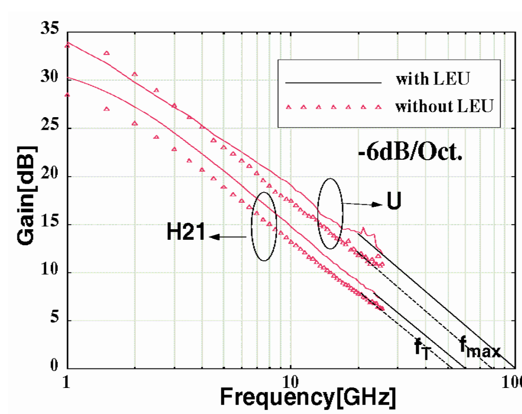


Fig. 3 Microwave performance of 2 x 30μm2 single emitter HBT with and without LEU technology at V_{CE}=2.5V, I_C=20mA.

4. Passivation and Reliability Test

Passivation is another important issue and has also been investigated in this work. GaInP/GaAs HBTs with and without passivation were compared in terms of DC and rf performance. Passivated HBT devices fabricated with LEU process were obtained by SiO_2 (4500Å) PECVD thin film deposition at 300°C. Fig 4 shows the cross section SEM photograph of passivated GaInP/ GaAs HBT. The DC and rf performance of HBTs before and after passivation were evaluated to investigate the influence of passivation. After passivation, the DC gain was found decrease slightly. The microwave performance on the other hand is almost the same before and after passivation except in the low frequency region (around 1GHz) which is dictated primarily by DC gain characteristics as shown in Fig. 5. Passivated GaInP/ GaAs HBTs were also subjected to reliability tests. A collector current density (J_C) of 40kA/cm^2 was chosen for performing such reliability tests for passivated 2 finger 5x10µm^2 emitter HBTs made by LEU process.

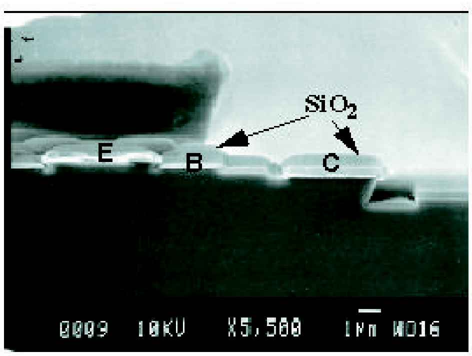


Fig. 4 Cross section of passivated GaInP/GaAs HBTs with PECVD SiO2.(4500Å)

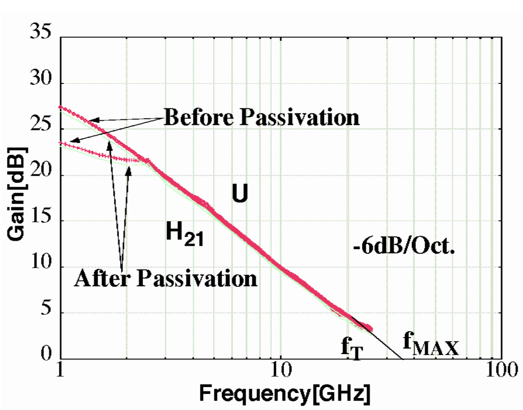


Fig. 5 Comparison of the microwave performance before and after passivation for a 2x10µm^2 single emitter device

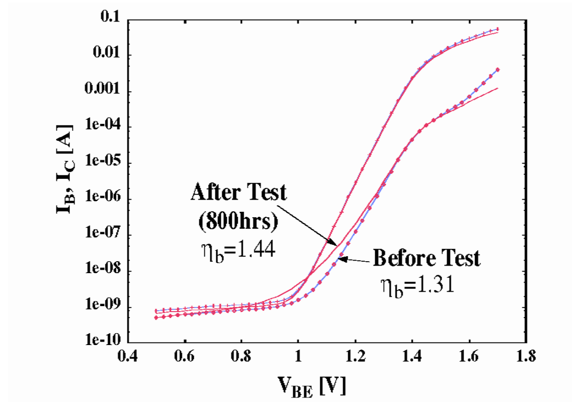


Fig. 6 Gummel plot of passivated 2 finger 5x10µm2 emitter HBTs before and after long term reliability tests.

Fig. 6 shows such long term reliability tests for passivated HBTs subjected to a current density of 40kA/cm^2. The devices were found to operate with a smaller than 2% current gain degradation over an initial testing period of 800hrs despite the high current density used. The Gummel plot of the passivated GaInP/GaAs HBTs before and after the reliability stress test. These results suggest that the current gain at medium to high collector current is not affected by the stress. At low collector currents, higher recombination current due to activation of recombination centers in the base increases the base current.

Finally, using the above described manufacturing technology, a transimpedance amplifier was designed and fabricated with coplanar wave guide transmission lines [9]. The design of the transimpedance amplifiers was carried out using the small and large signal equivalent circuits of HBTs. The technology used to fabricate these circuits is identical to that described for discrete devices in the previous section and employs Ni-Cr thin metal film for monolithic resistors and Al_2O_3 film as the insulator for high-Q MIM monolithic capacitors. The chip size for the circuit was 1125x800µm^2. A S_{21} gain of 12dB with a bandwidth of 19GHz has been measured using an on-wafer probe measurement technique. The associated transimpedance gain was 47dBΩ.

Another high-gain (18.8dB, 52dBΩ), high-bandwidth (13.5GHz) transimpedance amplifier was designed and fabricated using the same LEU technology [10]. This amplifier showed 118GHz of gain-bandwidth product with input and output matching of less than -8dB. The gain-bandwidth product of this amplifier is the highest reported figure for GaInP/GaAs HBT technology.

5. Summary

The material and processing manufacturing technology of GaInP/GaAs HBT is reported. The benefits obtained by employing CBE growth materials, LEU etching and SiO_2 passivation are demonstrated. The employed growth approach resulted in very high level of reproducibility of growth parameters and low defect density. Moreover, LEU technology resulted in 20% reduction of C_{BC} and leads to 25% improvement of maximum oscillation frequency (f_{max}=100GHz). Discrete HBTs and ICs built with this technology showed reliable and high speed performance. The technology is in the process of being introduced in a manufacturing line of HBTs and MMICs.

Acknowledgment

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