InP HBT Production Process

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Abstract

The need for higher performance electronics for space and defense applications has driven the development of InP heterojunction technologies. For the past 10 years, TRW has been developing InP HBT and HEMT technologies for mission critical applications [1–3]. Consistent and continuous improvements in the basic MBE structure and process technology have enhanced device and circuit performance, producibility, and reliability such that InP is being successfully used for many space and defense applications. At TRW we have established an InP HBT high yield and manufacturable production process. The production capability of InP technologies is dependent on three core capabilities: stable epitaxial material, stable frontside process, and stable backside process.

INTRODUCTION

The performance and cost advantages of Gallium Arsenide (GaAs) based Heterojunction Bipolar Transistor (HBT) and High Electron Mobility Transistor (HEMT) technology has enabled several high volume commercial applications. TRW is currently delivering over 4 million Molecular Beam Epitaxy (MBE) based GaAs HBT and HEMT integrated circuits per month for several commercial applications, and for high performance high reliability defense avionics, ground, and space applications.

Indium Phosphide (InP) based technology has numerous advantages over GaAs technologies for many applications. In addition, the ability to produce cost-efficient high-volume InP microelectronics enables a wide range of new insertion opportunities for InP HBT products for government and commercial applications. These applications include high performance power amplifier for cellular phones, ultra-efficient ultra-linear power amplifiers ideally suited for digital communication systems and satellite networks ICs, and highly integrated mixed signal and high-speed fiber-optic circuits. The rapidly expanding demand for broadband telecommunications provides a strong market pull for the enabling performance provided by InP microelectronics. Our InP HBT and HEMT technologies are in production with high line yields comparable to that of our GaAs production line. Overall process steps and cycle time are also comparable to the respective GaAs technologies.

InP HBT APPLICATIONS

Millimeter wave transceivers for local multi-point distribution systems (LMDS) will benefit from InP technologies. InP HBT technology provides both high efficiency and high linearity capability for these digital networks. Due to the value of bandwidth, these links will continue to increase in frequency where greater spectrum is available.

Cellular telephone power amplifiers have a combination of very stringent performance requirements including high power added efficiency (PAE), and low off leakage current for long talk time and standby time, high breakdown voltage for robust use, and low implementation cost. InP HBT offers improved performance over GaAs HBT technology. Demonstrated device measurements include PAE = 84% at 10 GHz and PAE = 90% at 2.4 GHz [4]. Comparable microwave power amplifiers have demonstrated greater linearity for an InP HBT implementation as compared to a GaAs HBT implementation [5-7].

InP HBT technology is particularly well suited for high-speed fiber-optic circuits including single channel SONET OC-768, 40 GBPS for Internet backbone broadband data transmission. InP HBTs have advantages for several key front-end component blocks including transimpedance amplification, gain control, clock and data recovery, modulator drivers, and high speed MUX/DMUX functions. A key parameter is digital clock frequency and we have demonstrated frequency dividers operating at 69 GHz [8] and, more recently, at 80 GHz with 100 mW power dissipation [9]. We also have demonstrated a fully functional direct digital synthesizer (DDS) chip operating at world record speeds [9]. This circuit is the most complex InP circuit demonstrated to date with over 3000 HBT devices.

In space applications, size, weight, and power efficiency performance advantages make InP technology a clear winner for several functions that have been traditionally produced using GaAs MMICs. Future broadband Ka-Band commercial telecommunication systems such as Astrolink, Spaceway, and Teledesic are proposing to use large phased arrays for transmission and reception of multi-beam signals. InP performance and cost advantages will make InP technology a natural choice for these systems.

MBE PRODUCTION

TRW pioneered the use of MBE for high-volume commercial GaAs production. Reproducible and reliable MBE growth techniques were initially developed for GaAs HBTs and HEMTs using single wafer MBE systems and these techniques were later transferred to multi-wafer MBE systems [10]. The capability to manufacture production quantities of reproducible and reliable MBE-grown InP HBT and HEMT material is key to the commercial viability of these technologies. MBE brings to the InP material system the same advantages of material reproducibility and uniformity that it brings to GaAs. Advanced calibration tools and non-contact materials analysis such as double crystal x-ray diffraction, photoluminescence, deep level trap spectroscopy, and photoreflectance allow precise control and lattice matching of the epitaxial layers using statistical process control (SPC) methodology. Figure 1 shows the uniformity of the Al fraction in a 1 µm thick InAlAs layer

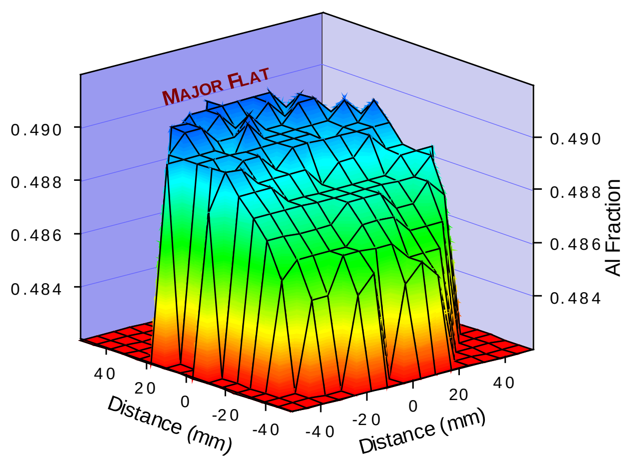

Figure 1. Al fraction in a 1µm thick InAlAs layer grown on a 4-inch wafer in a multi-wafer MBE production machine.

grown on a 4-inch wafer in a multi-wafer MBE production machine. Improved substrate quality combined with optimized growth conditions and techniques have resulted in excellent material quality and repeatability. InP substrate quality is rapidly improving and cost is coming down as volume ramps up, just as with GaAs.

PROCESS AND TECHNOLOGY

The InP HBT frontside process is very similar to TRW's flight-qualified one-micron GaAs HBT process, with minor metal and etch chemistry differences, and has essentially the same high yield.

We have developed and established a robust backside via with dry etch process with high yield. The baseline backside via process is identical for both InP HBT and InP HEMT processes.

The HBT structure is grown in a solid-source MBE system equipped with a valved phosphorus cracker [3]. The structure is grown on a semi-insulating InP substrate and consists of an n^+ InP sub-collector, an n^- InP collector, a linearly graded n^- InGaAlAs layer at the collector-base interface to minimize the current blocking due to the InGaAs/InP conduction band discontinuity, a p^+ InGaAlAs graded base, an n InAlAs Emitter, and an n^+ InGaAs cap layer. The fabrication process starts with the definition of the emitters, followed by a self-aligned base metal. Then, the base and the collector layers are etched sequentially with selective wet etching solutions. Then, the sub-collector is etched down to the substrate for device isolation. Next, the collector ohmic metal is evaporated and the devices are passivated. Finally, a thin film NiCr resistor and two layers of gold interconnect metal with airbridge crossovers are used to form the circuits. Figure 2 shows a flow diagram of the

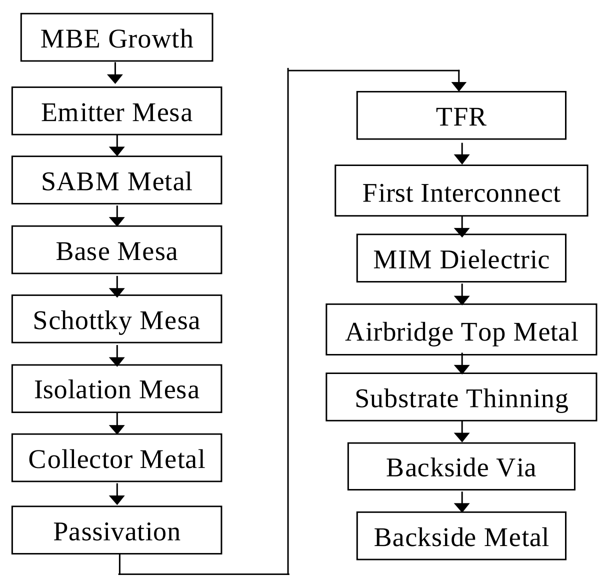

Figure 2. InP HBT process flow.

fabrication steps for our InP HBT production process and Figure 3 illustrate a cross-section of the InP HBT technology. The InP DHBT demonstrates high-speed RF performance and nearly ideal DC I-V characteristics. Figure 4 shows a representative measured output DC characteristic of a 1.5x10 μm^2 emitter area device.

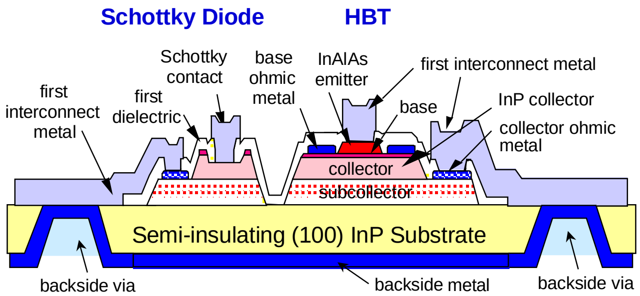

Figure 3. Cross-section of the InP HBT Technology

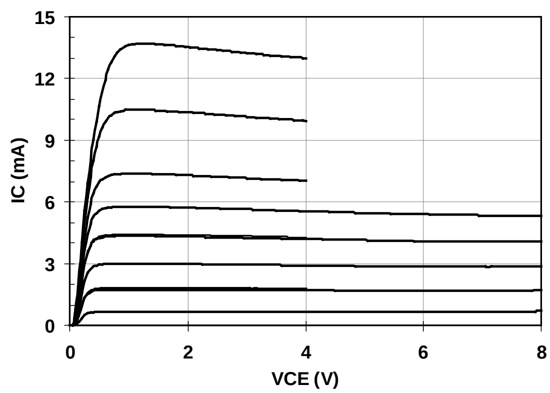

Figure 4. Output DC I-V characteristics of a high-speed 1.5X10 μm^2 InP HBT.

Reliability

The purpose of component and IC reliability characterization is to evaluate and qualify the advanced InP HBT technology for space, Class "K", and commercial chip fabrication. Early results of our full commercial and space qualification work for the InP HBT show excellent reliability. Figure 5 shows the initial reliability data of our InP HBT production process compared to published GaAs HBT reliability

Conclusions

The ability to produce cost-efficient high-volume InP microelectronics enables a wide range of insertion opportunities for InP HBT and HEMT products for government and commercial applications. We have developed an InP HBT production process that demonstrates yield and reliability comparable to our GaAs HBT process.

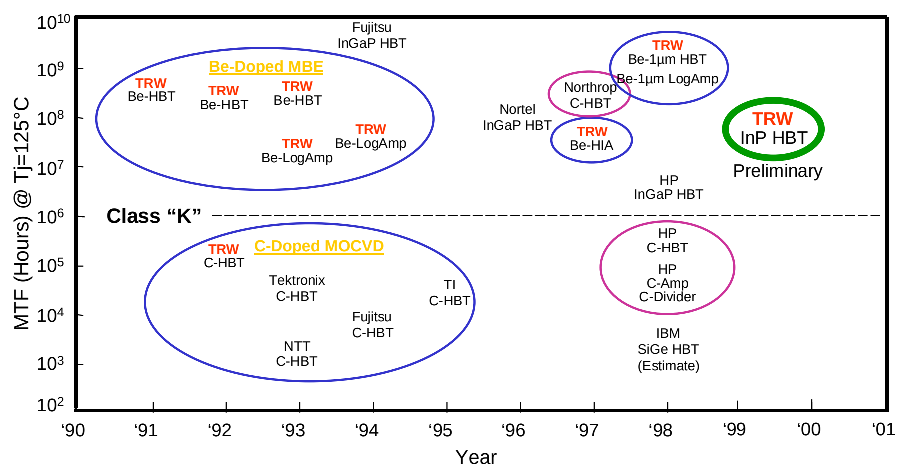

Figure 5. Preliminary InP HBT reliability compared to published GaAs HBT reliability

Acknowledgements

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