Heterojunction Bipolar Transistor - Reliable, High Quality Solutions at a Very Low Cost

Heterojunction Bipolar Transistor (HBT) technology is an optimum solution for the demanding needs of today's commercial communication standards. Typical characteristics of HBT devices are high linearity and efficiencies, low phase noise, thermal ruggedness, and low cost. HBTs have a breakdown voltage greater than 20V which eliminates possible problems with overvoltage, making them ideal for battery operated applications. Their bipolar structure allows these devices to operate from a single positive supply. This lets the designer eliminate additional components, such as switching regulators, required by a dual supply operation typical of MESFET components. HBT devices are currently used in space applications as well as high volume commercial communications products in both the transmit and receive chains.

Yet even with such high acceptance, there are still some lingering perceived disadvantages associated with HBT. There are misperceptions that HBT devices have poor reliability, questionable performance repeatability in volume, and high device cost since the technology was initially intended for military use. To dispel these misperceptions the evolution of HBT must be understood.

During the early 1980s the US government approached manufacturers to develop a new technology for its military and space programs. GaAs/AlGaAs HBT technology was born. The initial crop of wafers appeared promising, demonstrating high gain. These devices were subjected to forward biased, accelerated life tests at high temperatures. The result of the bias/temperature stress on some devices was premature failure.

The failed devices experienced rapid DC current gain (β) degradation and increased turn on voltages (V_{BE}). Analysis revealed the failures were caused by a diffusion of positively charged interstitial beryllium, the p-type dopant, from the base into the base-emitter graded region where it could incorporate onto AlGaAs lattice sites. The β degradation was attributed to the creation of a potential spike in the conduction band at the emitter-base junction reducing electron injection. The increased V_{BE} was caused by an increase of the space charge region recombination and reverse hole injection as the beryllium approached the emitter. The findings were widely reported through a variety of articles published on the topic. HBT was labeled an unreliable technology with questionable repeatability. However, HBT research did not end here.

In the late 1980s TRW began to study methods of improving HBT reliability. Optimizing the structure and the wafer growth process became a primary focus. Several studies were conducted to understand methods for beryllium doping as well as ways to limit diffusion. TRW found that interstitial beryllium migration could be minimized through a combination of an increased As/Ga flux ratio and a reduction in the substrate temperature during growth of the wafer layers. The higher flux ratio reduces Be+ formation in a controlled method, lowering concentration and improving device stability. It was also determined that Molecular Beam Epitaxy (MBE) was the most ideal growth process. The MBE process is so precise that the wafer is grown one molecular layer at a time. The emitter, base, and collector layers are placed over the entire wafer evenly and at once. As a result no fine geometry photolithography is required to define the active region; requirements on mask alignment and optical resolution are greatly reduced. Utilizing this data, a new generation of high reliability, low cost HBT devices was born.

These new HBT devices are grown on a 3-inch semi-insulating substrate by using MBE. Silicon is used for the n-type dopant and beryllium for the p-type dopant. The devices are fabricated using a self-aligning ohmic metal process where a double photoresist liftoff technique aligns the base ohmic contact to within 0.15μm of the emitter mesa edge. The emitter and base mesa are formed by wet etch and boron implantation provides device isolation. An As/Ga flux ratio of 3:1 is utilized with a substrate temperature at approximately 570°C. The resulting profile is optimized for reliability.

This generation of HBT devices was subjected to accelerated life tests at high temperatures ranging from 220°C to 260°C. The failure criteria was established as 1dB degradation in gain from pre-lifetest levels. The devices grown using the TRW-defined method did not experience the failures of previous generations of HBT devices. A Mean Time to Failure (MTF) was calculated by Arrhenius's equation $MTF=Ce^{-Ea/kT}$, where C is a constant, Ea is the activation energy, k is Boltzmann's constant, and T is temperature in Kelvin. MTF was determined to be 4.6×10^7 hours at a junction temperature of 125°C, the equivalent of approximately

4,566 years. The devices proved that the method TRW developed for growing HBT wafers using MBE techniques yielded reliable and repeatable devices.

This same process produced the world's first space-qualified class "S" HBT components which are currently flying in space. It is a powerful testament to the reliability of these devices, as once an application is launched into space its components must function for decades in the harshest of environments. The same production line which fabricates the class "S' devices is utilized to fabricate commercial HBT devices.

Realizing the reliability issues an emerging HBT technology faced during its infancy 10 years ago had been solved, RF Micro Devices successfully transitioned HBT technology to the commercial marketplace. RF Micro Devices has used HBT technology to design components such as low noise amplifiers/mixers, quadrature modulators, demodulators, gain blocks, and power amplifiers with efficiencies up to 65%. For the past 4 years, these devices have logged over 1.5 million device hours under RF stress accelerated lifetests at junction temperatures of 250°C. In conjunction, TRW has been running accelerated DC lifetests which correlate with the RF stress test results. Today over 40 million hours MTF at 125°C junction temperature have been achieved.

HBT devices are currently used in hundreds of different applications ranging from cellular phones to wireless security systems to cable television system components. The list of applications grows every day as the benefits of this technology are discovered and utilized by the electronics industry. Since its introduction as a solution for the needs of wireless systems, GaAs/AlGaAs HBT technology has had a significant impact on communication systems designs. Through a powerful combination of high gain and efficiency that is best of any commercial solution currently available, HBT devices provide designers reliable, high quality solutions at a very low cost.