REVIEW OF HETEROJUNCTION BIPOLAR TRANSISTOR STRUCTURE, APPLICATIONS, AND RELIABILITY

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INTRODUCTION :

Heterojunction Bipolar Transistors (HBTs) are increasingly employed in high frequency, high linearity, and high efficiency applications. As the utilization of these devices becomes more widespread, their operation will be viewed with more scrutiny. Advances are being made in the growth of heterojunctions and other structures conducive to the development of HBTs. improvements in performance. are expected in the near future, but at this point in the development of HBT technology, it appears appropriate to survey the present condition of the technology.

The structure of an HBT (Fig. 1) is totally accountable for its uncommon capabilities and is equally responsible for its vulnerability to failure mechanisms. An examination of this structure is followed by a review of some applications. Although this technology has matured quickly to its present development, reliability data on its performance are sparse. From available data it is becoming apparent that HBTs show great promise when steps are taken to eliminate prevalent failure mechanisms.

STRUCTURE:

In order to maintain a high emitter injection efficiency in homojunction BJTs it is necessary to use lightly doped material for the base region and heavily doped material for the emitter region[1,2]. These conditions unfavorably affect the base resistance and emitter capacitance. Another mechanism for controlling emitter injection efficiency must be employed in order to improve forward gain characteristics without sacrificing high frequency performance. Through the use of deposition systems with epitaxial capabilities, (such as MBE, MOCVD, etc.), heterojunction approaches to bipolar devices have been implemented. These systems have provided interfaces between dissimilar materials virtually free of imperfections,

Through the use of abrupt and graded junctions, HBTs have been developed employing both Si

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*NASA/ASEE Faculty Fellow from North Carolina A&T State University and 11 I-V technology. Only 11 I-V technology will be considered as part of the present review, Two systems dominate III-V HBT heterostructure designs. GaAlAs/GaAs and InGaAs HBTs are lattice matched to GaAs and InP substrates respectively.

PNP devices have been fabricated utilizing Si as the base dopant, but ultra-thin bases are necessary in order to offset poor hole mobility [2], NPN lnGaAs HBTs are capable of exceptional high frequency performance at the expense of a heavily doped base, making them vulnerable to base-dopant diffusion, unless preventive measures are taken. GaAlAs/GaAs HBT reliability studies focus mainly on mechanisms directly affected by high emitter current densities in NPN devices[3-8].

HBTs are especially suited for microwave applications, when considering their high cutoff frequency, low phase noise, high linearity and high efficiency in comparison to other technologies. In order to optimize the realizable power-added efficiency and to minimize any delay in carrier transport brought on by capacitances in the collector base junction, high emitter currents are charactcristic[9]. NPN GaAlAs/GaAs HBT reliability studies have been surveyed more extensive y due to their availability y.

APPLICATIONS:

HBTs have demonstrated superior capabilities in applications requiring high values of power gain at high frequencies, such as MMIC technology. The easy dimensional control, during device processing, makes parasitic capacitances suppressible, thereby increasing f, and reducing logic propagation delay time[9]. These attributes make HBTs inherently suited for high speed digital applications.

GaAlAs/GaAs HBTs have enjoyed the most widespread use of any HBT material system and is a relative] y mature technology by heterostructure standards. InGaAs HBTs are preferable to GaAlAs/GaAs HBTs for high power, high sped applications due to higher electron mobility, lower bandgaps, and higher substrate thermal conductivity. InGaAs HBTs are well suited to some optoelectronic applications due to their direct compatibility with sources and detectors for 1.3 micron radiation, an important wavelength for fiber-optic communication[2].

RELIABILITY:

In recent DC life tests of NPN GaAlAs/GaAs HBTs, the most prevalent failure. mechanism limiting NPN device lifetimes is the field-aided diffusion of dopants out of the base into the. wider bandgap emitter. For the most part, this involves Be diffusion as it is the p-dopant of choice. The effect of this diffusion is the degradation of the forward current gain (h(t), an increase in the base-emitter turn-on voltage (V_{BE}) and the emitter resistance (R_E). The increase in V_{BE} is attributed to a deviation in the location of the junction and the hetero-interface increasing the potential barrier against electron injection [3-8]. Evidence suggests that devices with abnormally high values of V_{BE} and R_E, possibly due to Be diffusion during growth, are more susceptible to dopant diffusion across the base-emitter junction and the subsequent DC parameter degradation[3].

It is suggested that the Be diffusion is enhanced in ion-implanted devices around the junction edge due to its proximity to a defect-rich region, The implication of this finding is that some type of mesa-etched isolation for the emitter would be advantageous over ion-implanted isolation[6]. Another approach to reducing Be diffusion from the base into the emitter is the use of a graded superlattice between the base and emitter[3-5, 10]. The superlattice(Fig. 2), reportedly, blocks the movement of any interstitial Be from the base into the emitter. Carbon, as an alternative base dopant to beryllium, is less likel y to diffuse into the emitter, although current gain is generally in ferior[4,5 ,8,9]. A thin high-bandgap AlGaAs surface passivation layer on the surface of the base adjacent to the emitter forms a barrier to holes and reduces the surface recombination current. 'I'his layer apparentl y increases h_{fe} and reduces its drift, This effect has been attributed to a slowing of the trap creation process and h_{fe} desensitization to the concentration of traps[8].

When Be diffusion from the base into the emitter was eliminated as the prevalent failure mechanism in an InGaAs HBT by the utilization of a graded superlattice structure between the base and emitter, degradation of the base-collector junction became the dominant failure mechanism in a DC life test. "l'he parameters associated with base-emitter junction degradation were stable during the DC life test, but the leakage current for the base-collector junction(I_{CB}) as well as V_{CE}(offset) both increased. The physical origins of this junction degradation have not been speculated upon[1 O]. Another investigation of InGaAs HBTs produced degradations of I_{CB} and V_{CE}(offset) during a storage life test. In this study median times to failure decreased with base widths and were dependent upon the particular metallization profile of a device. SIMS and Auger analyses support the claim that this degradation was caused by sinking of the base metal into the GaInAs collector. Non-alloyed Au/Pt/Ti contacts were made to the emitter, base, and collector of the devices in this particular study. The conclusion is drawn that lifetimes could be increased with the use of a sputtered refractory metal such as TiW or evaporated AuBe as the base metal[11].

CONCLUSION:

As HBTs undergo more widespread application, the need for reliability testing increases. Lifetesting of NPN GaAlAs/GaAs HBTs has been active for the longest period and points to diffusion of base dopants as the prevalent failure mechanism involved. Among the preventive measures taken to alleviate this mechanism are (1) a graded superlattice between the base and emitter, (2) the utilization of carbon as an alternative base dopant to beryllium, and (3) a thin high-bandgap AlGaAs surface passivation layer.

NPN InGaAs HBTs have been lifetested for degradation of the base-collector junction. Although all tests were not conclusive, at least one source attributed the degradation to sinking of the base metal into the GaInAs collector. The usc of a sputtered refractory metal such as TiW or evaporated AuBe as the base metal is identi tied as the appropriate preventive measure.

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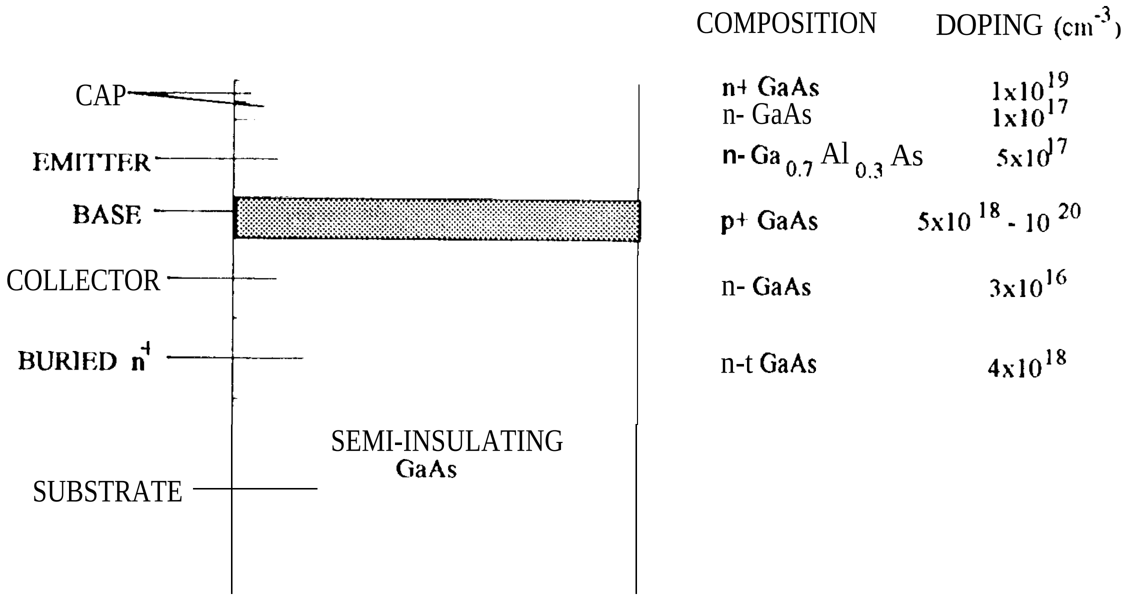

Figure 1. Device Layer Structure for GaAlAs/GaAs HBT [2],

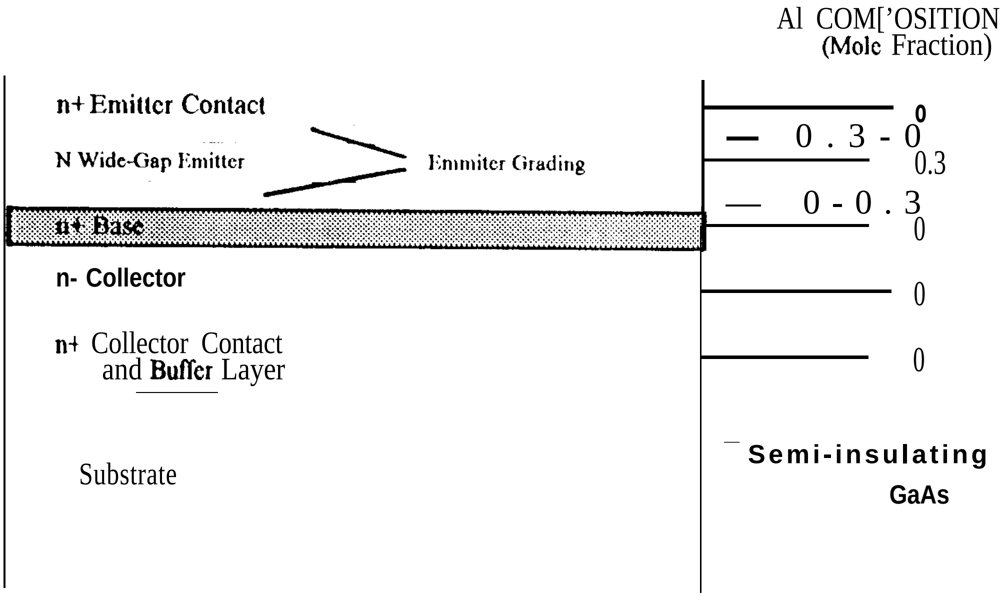

Figure 2. Graded Layer Structure for GaAlAs/GaAs HBT [5].