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B—6—1 (Invited) GaAs/(AlGa)As Heterojunction Bipolar Transistors

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The Heterojunction Bipolar Transistor (HBT) has long been recognized as possessing many advantages over other devices for high speed digital or analog signal processing applications. It is only recently, however, that the development of modern epitaxial technologies has made it possible to realize some of these advantages.

The concept of the HBT contains several inherent advantages over FET and homojunction bipolar transistor designs for high speed applications. Carrier transit times are very short because small dimensions can be grown vertically into the epitaxial layers far more easily than they can be deliniated laterally using optical or even e-beam lithography. The wide bandgap emitter provides high emitter injection efficiency, independent of the emitter and base dopings. This allows high base doping to be used, thus keeping base resistance low despite extremely thin layers. It may also be possible to achieve velocity overshoot of electrons in the base by using the step in the conduction band at the emitter-base interface as a "launching ramp" to inject high energy electrons into the base. Finally, the threshold voltage of the device is fixed by the bandgap of the emitter and base materials, and is not a process sensitive parameter which could vary across a wafer or from wafer to wafer. This is a very significant advantage for LSI circuits.

Growth of structures taking full advantage of these concepts requires the control afforded by modern epitaxial technologies such as MBE or MO-CVD. With heavily doped (10^{19}cm^{-3}) very thin (500Å) base layers, control over dopant density and dopant diffusion during and after epitaxial growth becomes important. The relatively high operating current densities require low emitter contact resistance. Multilayer contacts can be made to the (AlGa)As using heavily doped (10^{20}cm^{-3}) GaAs overlayers.

To achieve high frequency operation, processing techniques must be chosen carefully. Self-aligned base contacts using ion implantation can minimize base resistance. The use of semi-insulating GaAs substrates leads to small parasitic capacitance.

Modelling of HBS devices using realistic parameters yields very encouraging results. For 1 μm x 2 μm emitter areas and a base thickness of 1000Å, a switching time on the order of 20 pS (fan in = fan out = 1) is conservatively predicted, with a speed-power product per gate of about 70 fJ. These device calculations utilize parameters well within the reach of present technology, and should be realizable in the immediate future. Slightly further into the future, devices with 0.75 μm x 1 μm emitters and modest velocity overshoot should yield switching times below 10 pS and a speed-power product of about 20 fJ per gate.

Considerable progress has been made in the fabrication of HBT devices. High gain HBT's were demonstrated by Dumke et al and Konagai et al several years ago. Recently, refinements in lateral geometry have been introduced by various groups, including Beneking et al and Ankri et al. High frequency operation with f_T = 3 GHz has been reported. In all these efforts, LPE was used for materials technology. Recently, McLevige et al have made buried emitter HBT devices using a combination of MBE and ion implantation. Current gains up to 100 have been reported, and a ring oscillator has been made.

In our laboratory, HBT devices have been made using MBE material grown on n^+ substrates. Base thicknesses ranging from 500Å and 2000Å were used, with doping from $1 \times 10^{19}cm^{-3}$ to $2 \times 10^{18}cm^{-3}$. Heavily doped GaAs was used to facilitate emitter contacting. Device processing was done using two different techniques. Selective etching has been employed to make contact to the base in one method. The preferred technique, however, is to use implantation of Be. Proton or boron bombardment is used to achieve device isolation. Current gains of up to 190 have been observed. A cut-off frequency, f_T of up to 8 GHz has been deduced from S-parameter measurements on devices having 5 μm emitter finger width. The performance of these devices is limited by parasitic bonding pad capacitance from the n^+ substrate, lead inductance, and contact resistance. The use of semi-insulating substrates, better packaging, and more heavily doped layers for emitter contacting is expected to produce devices with considerably higher f_T.

The impressive predicted circuit performance and steady experimental progress demonstrated by (AlGa)As/GaAs HBT devices, suggest that they will play a major role in the next generation of high speed digital and analog integrated circuits.