Second International Conference on Indium Phosphide and Related Materials

Second International Conference

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POSTER SESSION

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Post Deadline Session

MONDAY, APRIL 23

InP-based Heterojunction Bipolar Transistors: Performance Status and Circuit Applications

P.M. Asbeck, C.W. Farley, M.F. Chang, K.C.Wang and W.J. Ho
Rockwell International Science Center
Thousand Oaks, CA 91360

Abstract

Present status and prospects of heterojunction bipolar transistors configured with InP, InGaAs and/or InAlAs on InP substrates are reviewed. Importance of ultrahigh electron velocity is highlighted. Self-aligned fabrication techniques are described, and devices with wide bandgap collectors for microwave power applications and with low turn-on voltage V_{be} for digital applications are presented. Frequency dividers configured with these devices have operated to 17GHz.

Introduction

The recent achievement of ultrashort (sub-picosecond) transit times in InP-based HBTs has been the source of considerable excitement [1]. At present, InP-based HBTs are being vigorously developed for microwave, digital and optoelectronic applications. This paper reviews the present status of device technology, and describes future prospects for InP-based HBTs.

The HBT structure has inherent advantages for a variety of applications.

1) Ultrahigh f_t and f_{max} can be obtained as a result of short transit times for carriers. The relevant dimensions are controlled by epitaxial growth and can be made very short even with simple processing with conventional lithography.
2) HBTs provide very high transconductance and high current handling capability per unit chip area.
3) Device turn-on ("threshold") voltage is very well controlled and uniform.
4) HBTs do not suffer from backgating or trapping effects, and leakage currents through substrates are absent. These issues are of significant concern in FET technologies.
5) Breakdown voltage is directly controllable by transistor design (collector structure).

InP-based materials provide a significant number of advantages over competing materials for HBT implementation:

1) Electron mobility is very high on a steady-state basis at low electric fields and velocity can be high under nonequilibrium conditions at high fields (velocity overshoot).
2) Material combinations are available which offer large bandgap differences (for the convenient implementation of wide bandgap emitters and collectors) and can be doped controllably over a wide range (above 10^{20} cm^{-3}).
3) Surface recombination velocity is lower than for GaAs.
4) Low bandgap materials are available for use in the base region (InGaAs), which can provide low Vbe value for digital circuit operation.
5) Substrate thermal conductivity is high (0.7 W/cmC for InP compared with 0.46W/cmC for GaAs).
6) Devices utilize the same substrate as sources and detectors of 1.3-1.55μm radiation, simplifying the fabrication of optoelectronic integrated circuits.

HBT Structure

Highest speed performance has been obtained from Npn HBT structures whose band diagram in the direction of electron travel is shown in fig. 1. Emitters of InP or AlInAs have been employed. Base regions and typically collector regions consist of InGaAs. Upon traversing the base-emitter junction, electrons are given high kinetic energy as a result of the conduction band step

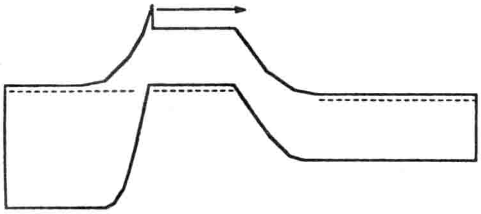

Fig. 1. Schematic band diagram of InP HBT with hot electron injection into base

(which amounts to dEc=0.23eV for InP/InGaAs junctions, and dEc=0.55eV for AlInAs/InGaAs junctions). For sufficiently thin base regions (<500A) most of the electron forward momentum is retained as the electrons cross the base. In the base-collector depletion region, electrons are driven to very high velocity by the electric field . This velocity can be maintained if the voltage drop is kept sufficiently small that the electrons do not scatter from the gamma minimum to satellite valleys, which requires small values of applied voltage (since the separation of gamma and X minima is 0.55eV in GaInAs).

HBTs utilize high acceptor doping level in the base. For solid or gas-source MBE, concentrations up to 1-5 x 10^{20} cm^{-3} have been obtained using Be doping. Dopant redistribution has been retarded by growth at low temperatures (down to 350C). MOCVD growth has been used with Zn or Be doping. For both materials, hole mobility as been relatively low (50-75 cm^2/Vsec) at the highest concentrations. The subcollector region and emitter contact regions make use of heavily doped n-type material. Concentrations of 6-8x$10^{19}$$cm^{-3}$ have been used, with Si doping. The associated contact resistances are extremely low (<1-2x10^{-7}ohm cm^2).

For a variety of applications, it is desirable to establish a graded composition between wide band gap and narrow bandgap device regions. For InP-based materials, continuous grading requires quaternary intermediate compositions which must be precisely controlled in order to maintain lattice match. An alternative method is to employ short period superlattices composed of the ternary materials, whose composition is accurately controlled. In the work at Rockwell the superlattice period is kept constant at 12A and the duty factor of the materials is varied across a number of intermediate ratios as illustrated in fig. 2.

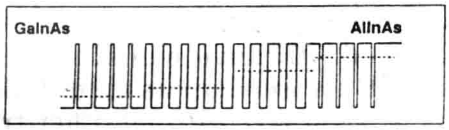

Fig. 2. Short period superlattice technique for grading effective composition.

For highest speed performance, device layout and processing must succeed in minimizing the separation between emitter and base contacts, and minimizing the area of the base-collector junction. Self-aligned approaches have been developed for this purpose [3]. Isolation is typically accomplished by mesa etching down to the semi-insulating InP substrate. Planarization is subsequently needed in order to facilitate interconnects. Fig. 3 illustrates the structure used at Rockwell for InP-based ICs. The structure is a derivative of the "dual-liftoff" technique described for GaAs HBT circuits [4]. Planarization based on SiOx and polyimide is utilized. The top view of a fabricated HBT is shown in fig. 4.

InP HBTs typically feature current gain on the order of 50-100, relatively independent of bias current (since base and collector current ideality factors are both near unity) and independent of emitter size (since the emitter edge recombination component of base current is typically low). The f_t obtained for the devices is typically higher than for comparable GaAs HBTs, and has reached the value of 165GHz at room temperature, and 244 GHz at 77K [1]. The associated value of f_{max} was 100 GHz. The estimated average velocity of electrons traversing the base and collector depletion regions was 3.5 x 10^7 cm/S. The high velocity is of particular significance. With bipolar structures, it is relatively convenient to minimize the distance over which electrons travel, and as a result high f_t can be obtained in numerous material systems. In SiGe/Si HBTs, f_t of 75 GHz has recently been reported [5].

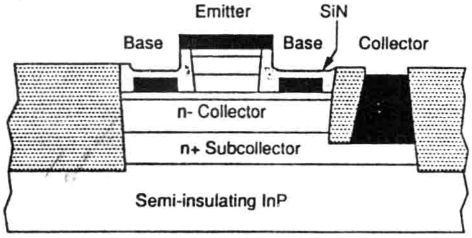

Fig. 3. Schematic cross-section of self-aligned HBTs fabricated at Rockwell.