Electroluminescence Characterization of Base Layers with In and N Incorporation in InGaP/InGaAsN HBTs

Robert Fitch, Fritz Schuermeyer, Roger Welser*, Thomas Jenkins, Ross Dettmer, James Gillespie, James Sewell, Ken Nakano, Chris Bozada, Dave Via, Ryan Welch
Air Force Research Laboratory, Sensors Directorate, Wright-Patterson AFB, OH 45433
*Kopin Corporation, 695 Myles Standish Boulevard, Taunton, MA 02780

In this paper, we will present characterization results on GaAs-based HBTs with quaternary base layers. Specifically, In and N were incorporated into the C-doped base layer during MOCVD growth. The aim of the effort is to reduce the base layer bandgap, thereby decreasing the base-emitter turn-on voltage and minimizing hole injection from the base into the emitter and collector.1)

Figure 1 presents the photoluminescence (PL) spectra of two wafers. These wafers had InGaP emitters, GaAs collectors, and the indicated base layers. PL emission from the GaAs collector layer, was observed at a photon energy of 1.507 eV. The emission from the C-doped base layer, for both wafers, was observed at lower photon energies than the GaAs collector due to bandgap narrowing caused by the high C concentration. The graph indicates that the bandgap narrowing due to the In and N content in the GaInAsN sample was 47 meV. Also the signal magnitudes of the two wafers were different. The larger base signal was due to the reduced base bandgap, increasing the electron confinement in the base layer.

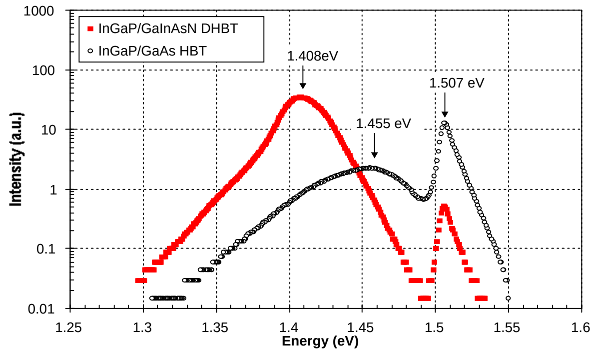

Figure 1. Photoluminescence spectra of two HBT wafers, obtained at liquid nitrogen temperature.

Electroluminescence emitted from fully fabricated HBTs can be used to obtain bandgap information on the heterostructure material.2) Figure 2 shows the base spectra of two HBTs. The peak energy of the In and N containing device was approximately 45 meV lower than the device with the GaAs base layer. These data were obtained under common-emitter operation with a positive bias at the collector terminal to minimize or eliminate base-to-collector hole injection. Under the chosen operating condition, electrons from the emitter traverse the base and reach the collector. Some of the electrons recombine in the base, leading to the base luminescence signal. The measurements were performed at room temperature and low power to minimize heating of the device. The observed shift in peak energy agrees well with the PL data. The full widths at half maximum (FWHM) were 87 and 92 meV for the GaInAsN and the GaAs devices, respectively, indicating improved quality of the GaInAsN device due to improved lattice matching.

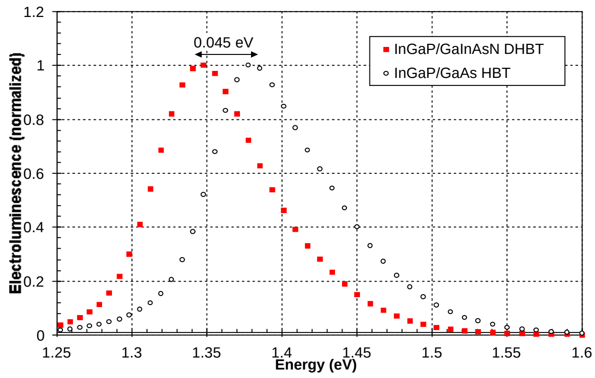

Figure 2. Room temperature base spectra for two HBTs with GaAs and GaInAsN base layers.

Figure 3 shows the spectra obtained under a forward bias applied to the base-collector junction with floating emitter terminal for the two HBTs. Hole injection from the base into the collector results in the ‘collector emission’ and electron injection from the collector into the base produces the ‘base emission’.2) As expected, one observes that the collector signals for the two devices coincide since the highly pure GaAs material emits this luminescence signal. The FWHM were approximately 62 meV, significantly narrower than the base signals of Figure 2. The magnitudes of the base signals under this bias condition were different for the two devices. This finding is expected since the ratios of hole to electron injections are different for the two devices.

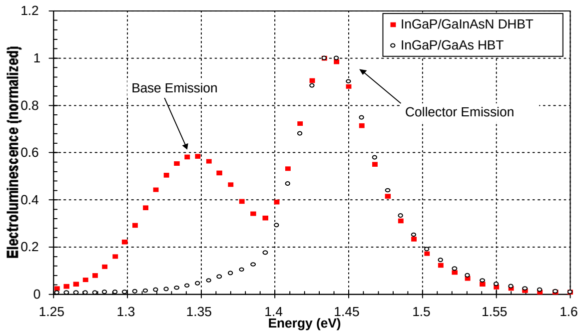

Figure 3. Normalized electroluminescence spectra for two devices under forward base-collector bias. Base and collector emissions are indicated.

Figure 4 presents the measured base peak energies versus Vbe for four samples with different In and N concentrations. A close correlation exists between the base-emitter voltage, required for a 100 μA collector current, and the electroluminescence peak energy.

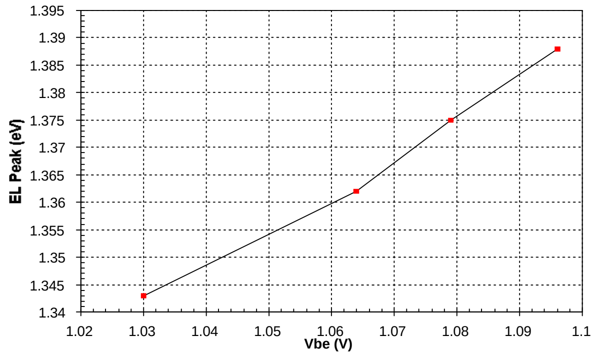

Figure 4. EL peak energy vs. Vbe.

These findings confirm that the bandgaps of the base layers were successfully reduced by incorporation of In and N into the base layer. The smaller bandgap led to the desired reduction in turn-on voltage of the transistors.

---

1) R. E. Welser and N. Pan, Topical Workshop on Heterostructure Microelectronics, Kyoto, Japan, August 20 to 23, 2000.

2) Robert Fitch et al., “Topical Workshop on Heterostructure Microelectronics, Kyoto, Japan, August 20 to 23, 2000.