High-speed Performance of *NpN* InGaAsN-*based* Double Heterojunction Bipolar Transistors

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Abstract

By incorporating simultaneously a proper amount of N and In into GaAs, a quaternary $In_xGa_{1-x}As_yN_{1-y}$ material lattice-matched to GaAs can be obtained with a significant reduction of the energy band-gap E_G. Progress in (In,Ga)(As,N) material quality has motivated the development of new heterojunction bipolar transistors (HBTs) with the use of this novel small band-gap material in the base for an advantageous lower turn-on voltage V_{ON} to produce cost-effective low-power devices.

Previous work on InGaAsN *Npn* HBT's has been concentrated on large area devices and initial DC results exhibited advantageous turn-on voltage reduction over the conventional InGaP/GaAs counterpart [1]. This work reports DC and RF characteristics of small-area *NpN* InGaP/InGaAsN/GaAs Double HBT's (DHBT's) grown by metal organic chemical vapor deposition. The basic structure consists of a 500 Å *n*-InGaP emitter followed by a 700 Å p^+-InGaAsN base and a 5000 Å *n*-GaAs collector. The $In_{0.03}Ga_{0.97}As_{0.99}N_{0.01}$ material is lattice-matched to GaAs with an E_G of approximately 1.2 eV. The large conduction band offset (ΔE_C ~ 0.32 eV) at the base-emitter heterojunction gives rise to more energetic electron injection into the base but will also result in increasing the turn-on voltage of the transistor. A 0.2 eV conduction band offset at the base-collector heterojunction blocks the electron flow and prevents electron from being injected in the collector. For all these reasons, interfaces have been properly designed with the use of step grading and delta-doping layers to reduce the effect of the conduction band spikes on the electron transport at both heterojunctions. Self-aligned DHBT's were fabricated using a regular triple-mesa technology process. Pt/Ti/Pt/Au and Ge/Au/Ni/Au were e-beam evaporated to form the base and collector contacts while sputtered WSi served as the emitter metal.

Devices with an active emitter area of 3x5 μm^2 exhibit a DC current gain of 10. Despite recent progress in InGaAsN material quality, difficulties in producing base InGaAsN electron mobility and lifetime values comparable to the GaAs counterpart lead to non-optimized base transit time and increasing base current for a reduced DC current gain. The collector ideality factor is 1.05 and the base ideality factor is 1.31, indicating high-quality InGaP/InGaAsN and InGaAsN/GaAs heterojunctions. The turn-on voltage (defined as the base-emitter voltage required to exceed a determined output collector current) of the *NpN* InGaAsN-*based* DHBT's is about 0.26 V lower than in a conventional *Npn* InGaP/GaAs HBT. The low turn-on voltage as well as advantageous offset voltage V_{OFFSET} ~ 0.12 V and knee voltage V_{KNEE} ~ 0.3 V provides an initial experimental indicator of the potential this novel technology can have for reducing power dissipation in GaAs-based transistors. Preliminary RF characteristics have been measured (see Figure 1). Self-aligned devices exhibit a cut-off frequency f_T = 32 GHz currently limited by the base transport parameters. Despite a base sheet resistance around 1000 Ω/ , a maximum oscillation frequency f_{MAX} as high as 60 GHz is reported from the *NpN* InGaAsN DHBT. These promising high frequency characteristics have been demonstrated using a straightforward epitaxial design. Improvements are expected with particular consideration given to enhanced base transit time and reduced collector capacitance.

In summary, microwave measurements from 3x5 μm^2 self-aligned *NpN* InGaAsN DHBT devices indicate that this low band gap material system can be successfully implemented in a GaAs-*based* HBT structure for lowering the turn-on voltage while attaining high-speed performances.

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References

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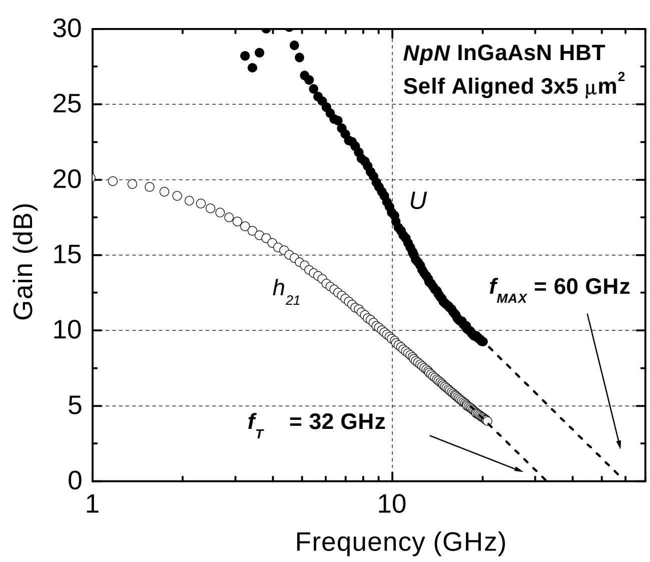

Figure.1 Measured high-frequency response of a 3x5 μm^2 InGaAsN-*based* NpN transistor at V_{CE} = 2.5 V and I_C = 21 mA.