An abstract submitted to *the 2014 CS MANTECH: May 2014*, Denver, USA

Npn GaN/InGaN Heterojunction Bipolar Transistors Using a Palladium-Based Contact Scheme

Yi-Che Lee, Tsung-Ting Kao, Jeomoh Kim, Mi-Hee Ji, Theeradetch Detchphrom, Russell D. Dupuis and Shyh-Chiang Shen*

Center for Compound Semiconductors, School of Electrical and Computer Engineering
Georgia Institute of Technology, 777 Atlantic Drive NW, Atlanta, GA 30332-0250
POC: Phone: 404-894-1884; shensc@ece.gatech.edu

III-nitride (III-N) materials system and related transistors offer greatly increased power-switching performance and a dramatic theoretical advantage in the standard Figures of Merit. Although extensive efforts were spent on the development of III-N unipolar devices such as heterojunction field effect transistors, recent developments of III-N heterojunction bipolar transistors (HBTs), in particular GaN/InGaN HBTs, have shown that III-N bipolar transistors could able be suitable for next-generation high-power switching and amplification. We have previously reported *npn* GaN/$In_{0.03}Ga_{0.97}N$ HBTs with high current gain (h_{fe} > 100) and high current density (J_C > 20 kA/cm^2) for devices grown on sapphire substrates [1,2,3]. The microwave performance of InGaN/GaN HBTs with f_T = 8GHz were also reported [4]. However, these devices were prone to degradation under a high current stressing condition and the achievable J_C and the d.c. power density ($P_{d.c.}$) were limited for GaN/InGaN HBTs grown on sapphire. In this paper, we report on a drastic InGaN HBT performance improvement using a palladium-based metallization for the base layer contact. When compared to a typical nickel-based metallization, the Pd-based contact demonstrated a much improved contact stability and is less susceptible to the high-current-stressing related device degradation. The fabricated GaN/InGaN HBTs using the newly developed metal scheme also shows a record J_C > 94 kA/cm^2 and $P_{d.c.}$ > 1.3 MW/cm^2 for a device with an emitter area (A_E) of 11.7 μm^2. To the best of our knowledge, the results represent the highest current and power handling performance achievable for III-N HBTs grown on sapphire substrates to date.

The layer structures of the *npn* GaN/$In_{0.03}Ga_{0.97}N$ HBTs were grown in a Thomas–Swam metal–organic chemical vapor deposition (MOCVD) reactor and typical device fabrication processing steps include three mesa-etching steps, followed by n-metal deposition for the collector and the emitter contact, respectively. For performance comparison purposes, either Ni-based or the Pd-based *p*-type contact were deposited on two samples with the same HBT layer structures, respectively. Figure 1 show a voltage stressing test by monitoring the change of the base-emitter voltage (V_{BE}) on two InGaN HBTs with the same device designs but different p-type base metal compositions (i.e., Ni-based contact v.s. Pd-based contact). The devices were stressed at a constant I_B of 100 μA and V_{CE} of 10 V. It is shown that V_{BE} of the HBT with Ni-based contact not only becomes unstable for $t_{stressing}$ > 10 min. but also shows large amount of voltage drop before the device degrades. Further study indicates that the device degradation also led to a leaky BC junction after the current stress, possibly due to the electro-migration of the metal species into the etched *p*-type base layer. On the other hand, a HBT with Pd-based base contact seems thermally stable (ΔV_{BE} < 17 mV over a 1-hour constant I_B stressing) and a much lower series resistance in the base contact was also achieved. The stable base contact may be attributed to the low diffusion coefficient of Pd in the p-type InGaN layer [5]. A Gummel plot of a InGaN HBT using a Pd-based p-type contact with A_E = 11.7 μm^2 is shown in Figure 2. A maximal h_{fe} of 76 was measured at V_{BE} = 8V. Figure 3 shows the common–emitter family curves of the same InGaN HBT measured in a quasi-static pulsed measurement mode. The achievable stable operation with J_C > 95 kA/cm^2 and V_{CE} > 15 V, corresponding to a $P_{d.c.}$ of > 1.3MW/cm^2, was demonstrated. The results suggest that InGaN HBTs are capable of achieving ultra-high-power d.c. handling capability even on poor thermal conducting substrates like sapphire.

In summary, we report significant GaN/InGaN HBT performance improvement by using a new Pd-based contact scheme for devices grown and fabricated on sapphire substrates. The improved metal contact stability enables a state-of-the-art high-power-density performance demonstration of InGaN HBTs. Details on the device performance and processing improvements will be discussed in the conference.

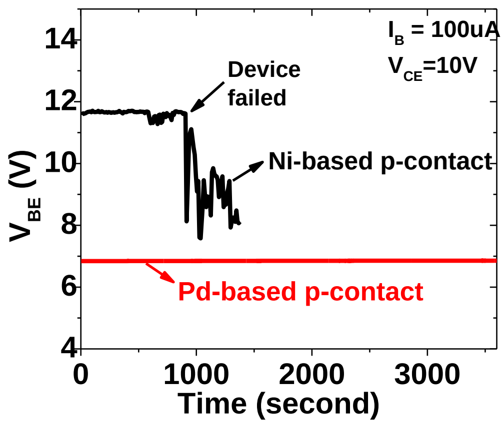

Figure 1. A chart showing the evolution of V_{BE} under a constant I_B stressing condition in the forward active mode. The devices under test have $A_E = 20 \times 20\ \mu m^2$ and $I_B = 100\ \mu A$ at $V_{CE} = 10$ V.

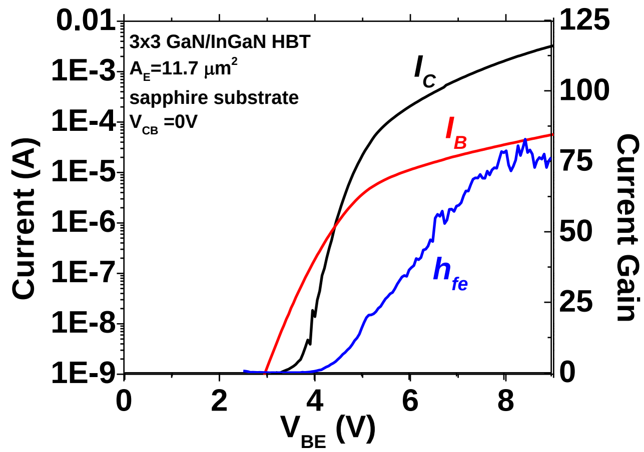

Figure 2. The Gummel plot of a GaN/InGaN HBT using the Pd-based contact scheme.

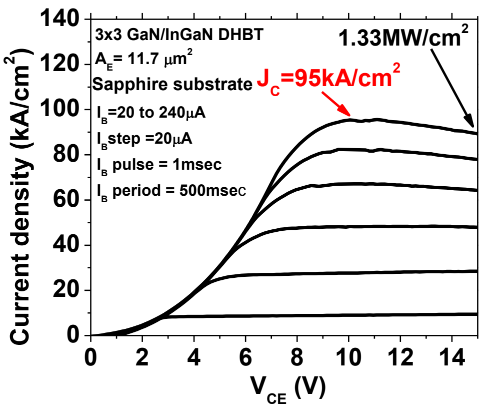

Figure 3 The quasi-static common-emitter family curves of a GaN/InGaN HBT using a Pd-based p-type base contact scheme.

References:

[1] S.-C. Shen, *et al.*, "GaN/InGaN Heterojunction Bipolar Transistors with fT > 5 GHz," *IEEE Electron Device Letters*, vol. 32, no. 8, pp. 1065-1067, August 2011.

[2] Y.-C. Lee, *et al.*, "GaN/InGaN heterojunction bipolar transistors with ultra-high d.c. power density (>3MW/cm^2)," *Phys. Status Solidi A*, vol.209, no. 3, pp.497, 2012

[3] Yun Zhang, *et al.*, "High- performance GaN/ InGaN double heterojunction bipolar transistors with power density >240 kW/cm^2, " *Phys. Status Solidi C*, vol. 8, no. 7–8, pp. 2451–2453, 2011

[4] R. D. Dupuis, *et.,al.*, "III-N High-Power Bipolar Transistors," in *ECS Transactions*, vol. 58, no. 4, pp. 261-267, 2013

[5] H.K. Cho, *et al.*, "Characterization of Pd/Ni/Au ohmic contacts on p-GaN," *Solid-State Electron.* vol. 49, pp. 774–778, 2005