An InGaP/GaAs DHBT with an Integrated Wide-Tuning-Range Varactor for Broad Band Monolithic VCO Applications

Yuefei Yang, Dave Wang, Wing Yau, Bryan Lee, Dave Rasbot, Hau Tan, and Daniel Hou

Global Communication Semiconductors, LLC
23155 Kashiwa Court, Torrance, CA 90505
Phone: (310) 530 7274, Fax; (310) 530 7279, Email: yfyang@gcsincorp.com

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InGaP/GaAs HBT is an ideal candidate for low phase noise VCO applications because of its low 1/f noise due to its low surface recombination and free of DX center in the InGaP ledge layer. Low phase noise monolithic VCOs using InGaP/GaAs HBT and its base-collector junction as varactor have been demonstrated in mid 1990's [1], and have been mass produced at GCS for over 10 years. However, the base-collector junction varactor's tuning range is narrow due to the conventional uniform collector doping. To make wide tuning range varactors, a hyperabrupt doping profile in collector is required. Wide tuning range GaAs varactors with hyperabrupt doping profiles have been reported [2] and are available as catalog items. However, there are two problems in using hyperabrupt doping profile in the GaAs HBT collector: 1. High doping is required near the base-collector junction, which reduces the HBT breakdown voltage; 2. The collector thickness has to be increased in order to get wide varactor tuning range, which would greatly degrade the HBT's RF performance. The current solution for wideband VCOs employs a hybrid approach by using separate HBTs or BJTs and wide-tuning-range varactor devices. In this paper we report a novel InGaP/GaAs Double Heterojunction HBT (DHBT), which has an integrated wide-tuning-range varactor and a high performance HBT.

The InGaP/GaAs DHBT material structure grown by MOCVD includes an InGaAs/GaAs emitter cap layer, an InGaP emitter layer, a C-doped GaAs base layer, a thin n^- GaAs collector setback layer, an n-InGaP collector with hyperabrupt doping, and an n^+ GaAs sub-collector layer. The doping profile was carefully designed to have wide range and linear frequency tuning feature while keeping high breakdown voltage. Fig. 1 shows the DHBT schematic layer structure. A conventional InGaP/GaAs Single Heterojunction HBT (SHBT) with uniform collector doping was also fabricated for comparison. The collector thickness for both DHBT and SHBT were designed to be the same. The devices were fabricated using a two-mesa structure and ion implantation for sub-collector isolation. The varactors were fabricated using base-collector junction diode as the HBT base and collector contacts were formed.

Fig 2 shows the C-V curves of the base-collector junctions of the DHBT and SHBT. The DHBT's Gamma number is close to 2, and its capacitance tuning range C(0V)/C(17V) is 7:1. For comparison, the maximum tuning range of the SHBT is only 2.7:1. Fig. 3 shows the normalized oscillation frequency defined as Sqrt(C(0V)/C(V)) versus varactor tuning voltage. The tuning linearity of DHBT is quite good in the entire tuning voltage region. Fig. 4 shows the IV curves of the DHBT and SHBT. The electron blocking effect in the DHBT was effectively eliminated due to the high doping in InGaP near the GaAs setback layer. The DHBT has low Vce-offset voltage as expected. It shows slightly higher on-resistance and knee voltage due to lower electron mobility in InGaP. Fig. 5 shows almost identical 1/f noise spectra for DHBT and SHBT. Table 1 summarizes the key parameters of HBTs and varactors. It is noted that the BVcbo of DHBT is much higher than that of SHBT, but BVceo of both devices are the same due to the high collector doping near the base-collector junction for the DHBT. f_T and f_{max} of DHBT are lower than that of SHBT due to lower electron saturation velocity and higher base-collector junction capacitance, but the DHBT performance is still good enough for VCO application with oscillation frequency of up to ~15GHz.

In summary, we have demonstrated an InGaP/GaAs DHBT with a hyperabrupt doping profile in InGaP collector. Wide tuning range of 7:1 with high breakdown voltage of 28V has been obtained with good HBT performance, which is suitable for wide-band monolithic VCO applications.

[1] U. Guttich et al, 1994 IEEE MTT-S Digest, p.131.
[2] C. Huang, et al, IEEE EDL 2010 Vol.30 (2), p.108

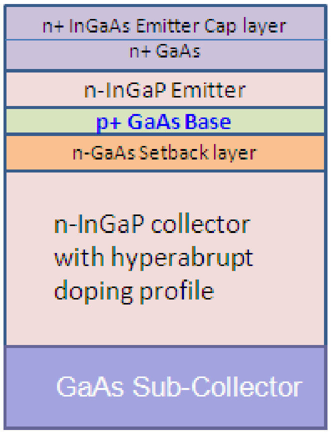

Fig. 1. InGaP/GaAs DHBT layer Structure

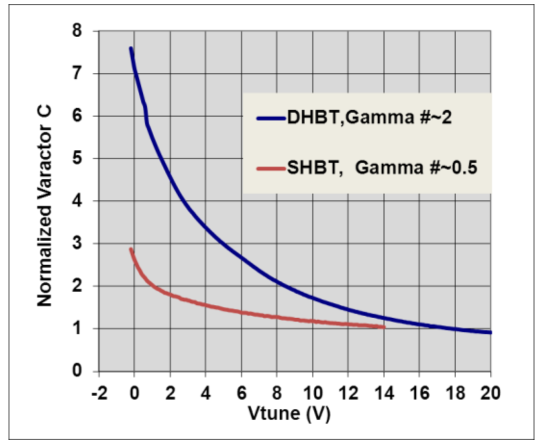

Fig. 2. Base-collector junction varactor C-V.

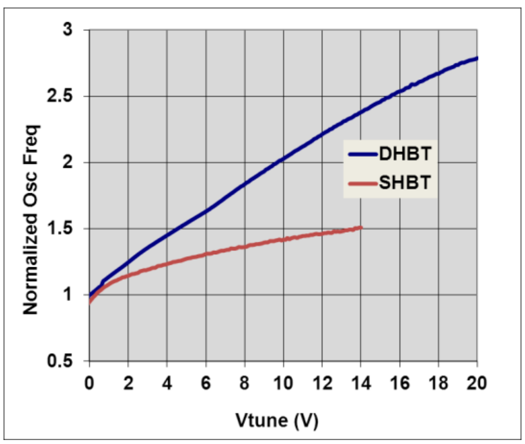

Fig. 3. Normalized oscillation frequency versus varactor tuning voltage.

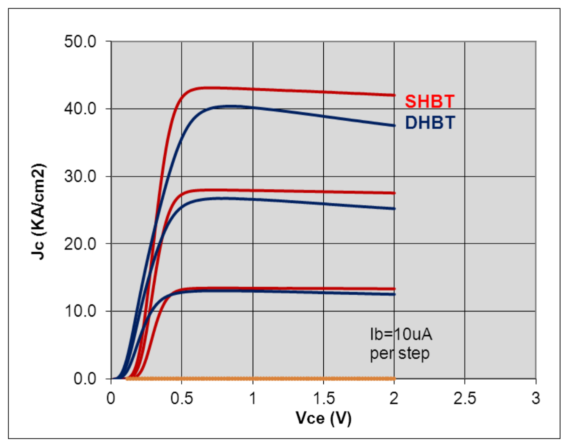

Fig. 4. IV Curves for DHBT and SHBT with emitter size of 2x6 um^2

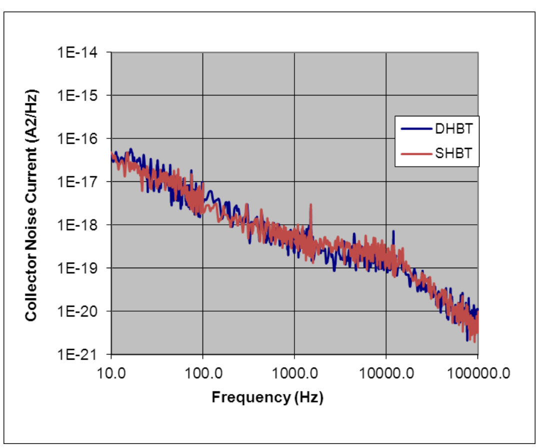

Fig. 5. Collector current 1/f noise spectra for DHBT and SHBT at Ic of 2mA for a 2x6 device.

HBT Parameter	Unit	SHBT	DHBT
Current Gain		150.0	145.0
Vce Offset Voltage	V	0.14	0.07
BVebo	V	6.5	6.5
BVceo	V	7.5	7.5
BVcbo	V	18.0	28.0
Ft at Jc of 50KA/cm^2	GHz	55.0	48.0
Fmax at Jc of 50KA/cm^2	GHz	65.0	35.0
Varactor Parameters			
Max Tuning Range		2.7:1	7:1
Max Tuning Voltage	V	14	20
Varactor Breakdown Voltage	V	18	28

Table 1. Key parameters of HBTs and Varactors