Abs. 1329, 206th Meeting, © 2004 The Electrochemical Society, Inc.

Correlation Between SiGe HBT Doping Profile and Operation Configuration

Zhenqiang Ma, Ningyue Jiang and Guogong Wang

Department of Electrical and Computer Engineering
University of Wisconsin-Madison
1415 Engineering Drive, Madison, WI 53706
Phone: (608) 261-1095, Fax: (608) 262-1267
mazq@engr.wisc.edu

SiGe-based HBTs have demonstrated superior performance as manifested in the recently reported f_T and f_{max} values [1, 2]. Because the SiGe HBT technology is compatible with Si CMOS, SiGe BiCMOS is propitious for on-chip integration of microwave/millimeter wave circuitry with VLSI digital signal processing circuitry. For large-scale integration using SiGe BiCMOS, SiGe HBTs are the exclusive device candidate for fulfilling the requirement of power handling of on-chip microwave transmitters. The heterostructure design (region thicknesses, doping profile and Ge profile and composition) of SiGe HBTs for high-power amplification is different from that for low-power and high-speed applications. Although the industry mainstream SiGe HBTs adopt the typical doping profile of silicon homojunction bipolar transistors with the high-to-low doping concentrations from emitter to base and then to collector region, the Si/SiGe heterojunction present at the emitter/base PN junction offers alternative device doping profile that is suitable for power amplification. Power SiGe HBTs using both common-emitter and common-base configuration [3] have been reported previously. However, there has been no clarification on which configuration should be used for power amplification using SiGe HBTs of different doping profile. In this paper, we analytically address this issue based on small-signal equivalent circuit models of SiGe HBTs. Medici simulation results are provided to support the analyses.

Figure 1 shows the small-signal equivalent circuits that are used for our analyses. The parasitic emitter resistance has been neglected in these two equivalent circuit models, considering that the base resistance r_b is much larger than emitter resistance in advanced industry SiGe HBTs. The relative large values of r_b is owing to the low base doping concentration in these devices. For SiGe HBTs that take the advantage of high injection efficiency resulted from the heterojunction between emitter (Si) and base (SiGe), the value of r_b will be on the same order of the value of emitter resistance. As a result, the emitter resistance in the equivalent circuit models for these HBTs cannot be neglected.

Based on detailed analysis, we derived the high-frequency power gain of SiGe HBTs under the common-emitter and common-base configurations, respectively, as the following,

$$G_e \approx \frac{g_m}{4\omega^2 r_b C_\mu (C_\mu + C_\pi)} \approx \frac{g_m}{4\omega^2 r_b C_\mu C_\pi} \qquad (1)$$

$$G_b \approx \frac{\alpha g_m}{2\omega^2 r_b C_\mu C_\pi} \qquad (2)$$

It is found, by comparing Eq. 1 and 2, that the common-base operation configuration provides higher power gain than the common-emitter configuration at high frequencies with a ratio of 2α in this frequency range.

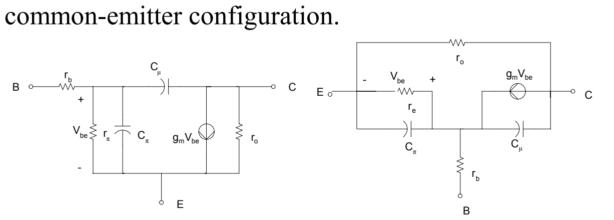
In the intermediate frequency range, SiGe HBTs are potentially unstable. The ratio of maximum stable gain (*MSG*) between the common-base and common-emitter configurations can be derived as,

$$\frac{MSG_b}{MSG_e} = \frac{\dfrac{\alpha}{\omega r_b C_\mu}}{\dfrac{g_m}{\omega C_\mu}} = \frac{\alpha}{r_b g_m} \qquad (3)$$

The ratio MSG_b/MSG_e primarily depends on the value of r_b. For SiGe HBTs with low base doping concentrations, the ratio should be smaller than unity. For HBTs with a heavily doped base region, the parasitic emitter resistance needs to be considered. In this case, the ratio MSG_b/MSG_e readily becomes higher than unity.

In order to verify the general correlation between the device configuration and base doping concentration, we measured two SiGe HBTs with low and high doping concentrations, respectively. The power gain (*MSG/MAG*) versus frequency for these two HBTs is plotted in Fig. 2. Excellent agreement between analyses and measurement is obtained. The analyses were also verified with Medici simulation on two SiGe HBTs with high and low doping concentrations in the base region.

In conclusion, for the first time, we have analyzed the correlation between the base doping concentration of SiGe HBTs and their operation configuration. For SiGe HBTs with high base doping concentrations, the common-base configuration offers higher power gain than the common-emitter configuration at the useful frequency range. For SiGe HBTs with conventional Si BJT doping profiles, higher power gain can be obtained from the common-emitter configuration.



(a) (b)

Figure 1. (a) Small-signal hybrid-π model for common-emitter configuration; (b) Small-signal T model for common-base configuration. Emitter resistances are to be included in the models for SiGe HBTs with high base doping concentrations.

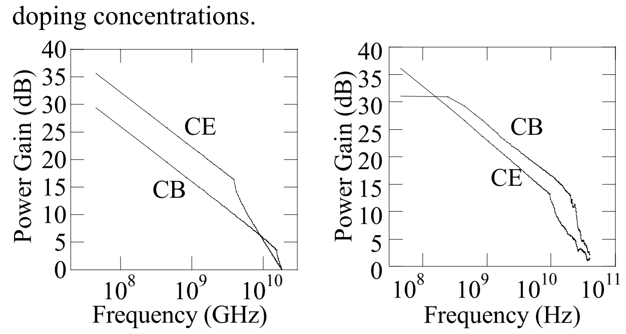


Figure 3. Power gain versus frequency for SiGe HBTs (a) with low base doping concentration ($\sim10^{18}cm^{-3}$) and (b) with high base doping concentration ($\sim10^{20}cm^{-3}$).

1 J.-S. Rieh, et al, *IEDM Tech. Dig.*, 2002, pp. 771-774.

2 P. Kempf and M. Racanelli, *24th Annual Tech. Dig. GaAs IC Symp.*, 2002, pp. 3-6.

3 Z. Ma, et al, *IEEE Trans. on Microwave Theory and Techniques*, Vol. 50, No. 4, pp. 1101-1108, April 2002.