Simulation and Modeling of Thermal Effects in 4H-SiC NPN BJTs

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Introduction:

Owing to the superior material properties and the nature of the device, silicon carbide BJT is very attractive for power switching, RF power amplification, and high temperature applications. In these applications, the power density can be quite high. As a consequence, the device temperature is inevitably higher than the ambient temperature. Because the p-type base layer is incompletely ionized at room temperature, the temperature effects in 4H-SiC NPN BJTs are complicated and difficult to predict. In this work, a simulation study on the 4H-SiC BJT characteristics at different temperatures is conducted. Several important effects are discussed. A DC spice model with temperature effects is also constructed.

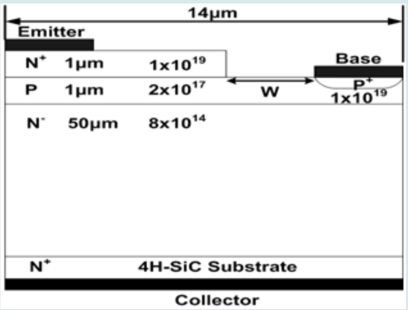


Fig.1： Cross-sectional schematic of the simulated device.

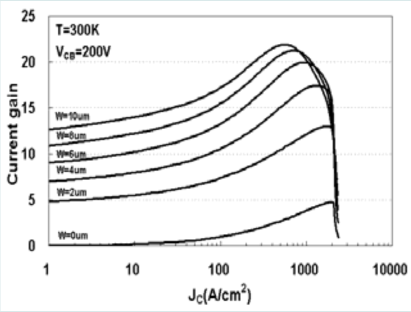
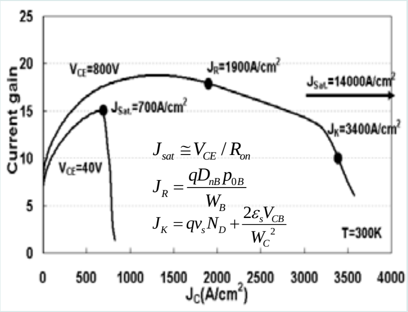


Fig. 2： Current gain vs. J_C for different W.



$$J_{sat} \cong V_{CE} / R_{on}$$
$$J_R = \frac{qD_{nB}\,p_{0B}}{W_B}$$
$$J_K = qv_s N_D + \frac{2\varepsilon_s V_{CB}}{W_C^{\,2}}$$

Fig. 3： Current gain vs. J_c at different bias conditions.

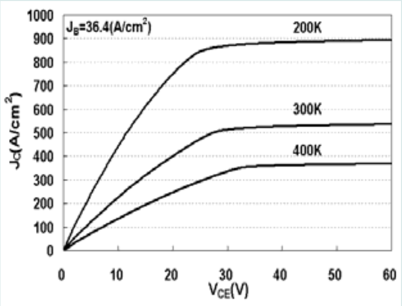


Fig. 4： J_C-V_{CE} for the same J_B at different temperatures.

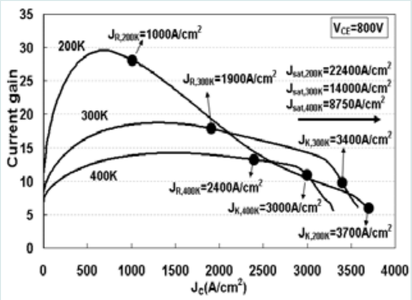


Fig. 5： Current gain vs. J_c at different temperatures.

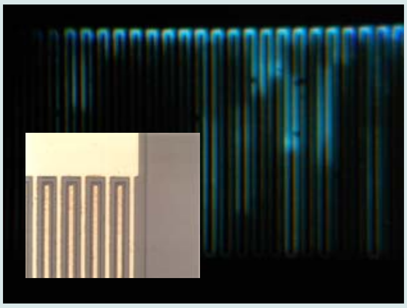


Fig. 6： A photograph shows the non-uniform current distribution in the device.

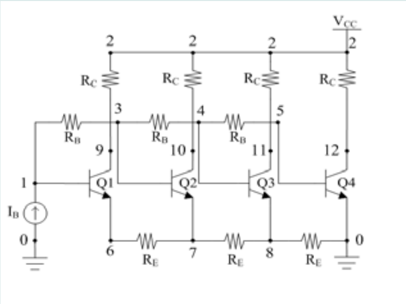


Fig. 7： A four BJT network to model the effects of parasitic resistances in the long fingers.

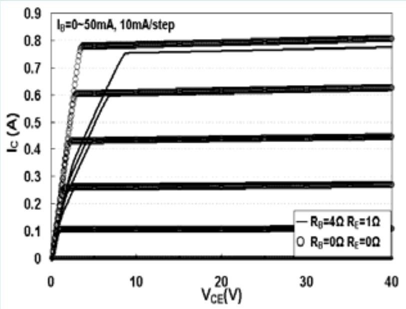


Fig. 8： Comparison of IVs with and without the finger parasitic resistance.

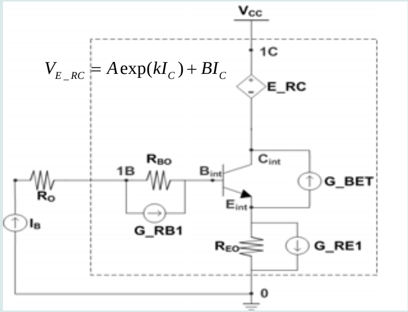


Fig. 9： SiC BJT equivalent circuit model.

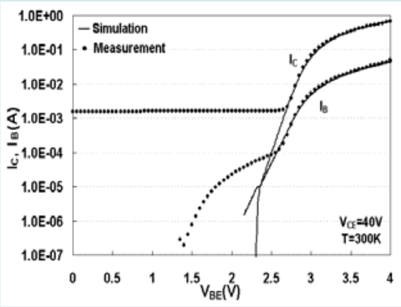


Fig. 10： Gummel plot of the proposed spice model and measurements at 300K.

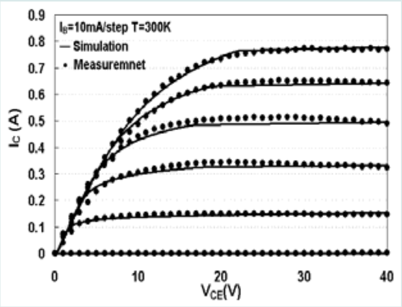


Fig. 11： I_C-V_{CE} curves of the proposed spice model and measurements at 300K.

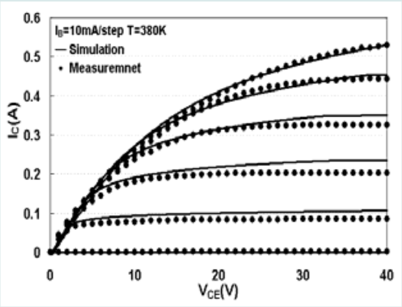


Fig. 12： I_C-V_{CE} curves of the proposed spice model and measurements at 380K.

Conclusion:

Simulation results show that base contact locations, high current densities effects and the non-uniform current distribution have significant effects on BJT characteristics. At low V_{CE}, current gain is found to be limited by forced gain condition. At high V_{CE}, current gain is limited by high level injection in the base at temperatures of interest. A spice equivalent circuit is constructed to model DC characteristics with thermal effects. The results are in good agreement with measurement.