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A Thermal Resistance Measurement of HBT with Pulsed Current I-V Setup and Its Scalability with the Total Emitter Area

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1. Introduction

An accurate method to determine the thermal resistance (R_{th}) of HBT's is proposed and presented in this paper. The principle of this method is based on the current gain (β) decrease of HBT's either from ambient temperature rise or internal DC power dissipation. For this purpose, the conventional pulsed I-V setup is modified to pulsed current I-V setup, which means the input port of the device (usually the base) is stimulated by constant current rather than constant voltage as is the usual case when one tries to characterize junction-type transistors. By using this measurement setup, two main mechanisms affecting the current gain decrease were effectively separated, which was not apparent in the previous method. The measurement setup achieves the isothermal condition over a range of elevated base-plate temperature (T_{base}) by setting pulse width less than the thermal time constant of the device. The DC measurements were carried out using the same test setup without changing any connections so that any errors involved with the test environment could be avoided. The proposed method was applied to various HBT's with different emitter fingers. It showed a good predictability of thermal resistance of different emitter area device by the inverse scaling with the total emitter area.

The previous DC method [1] enables simple measurements, but it lacks the accuracy because it doesn't exactly separate ambient temperature and power dissipation effects. Sometimes it leads one to a rather unphysical conclusion that R_{th} decreases as the ambient temperature increases. The existing pulsed method [2] doesn't reflect the true operation of HBT's because it stimulates the base by constant voltage.

2. Thermal Resistance Measurement

HBT's are characterized by nearly ideal I-V curves under negligible internal power dissipation as can be seen in low collector current region of DC data and isothermal condition (Fig. 1). But even in isothermal measurement under pulsed condition, the collector current slightly decreases when P_{diss} becomes large. To avoid this problem, the width of pulse signal should be narrower than the one configured here which can be as narrow as 400 ns. However, these areas are usually not experienced by a normal operation of HBT because the collector current density is more than 80 kA/cm^2. In this work, four AlGaAs/GaAs HBT's with different emitter fingers (each of 24, 22, 18 and 16 fingers) were measured. All HBT's are thought to have the same chip configuration except the number of emitter finger.

At progressively higher currents and temperature, I_C is related to R_{th}, P_{diss} and T_{base} by [1]

$$I_C(T_{base}, P_{diss}) = \left(\beta_1 + \frac{\Delta\beta}{\Delta T}(T_{base} - T_1) + \frac{\Delta\beta}{\Delta T} R_{th} P_{diss} \right) I_B.$$

In the above equation, $(\Delta\beta / \Delta T)\, R_{th}$ can be extracted from the slope of I_C Vs. P_{diss} line at a constant T_{base} which was constructed from DC I-V data as shown in Fig. 2. The slopes of the lines are measured to increase progressively as T_{base} is increased. $(\Delta\beta / \Delta T)$ is extracted from isothermal measurement where P_{diss} can be assumed to be zero. By using pulsed current I-V setup, same I_B condition as DC case is satisfied and β dependency on P_{diss} can be effectively ruled out. It is important to ensure that all conditions are same except T_{base} so that the ratio between two curves produces R_{th}. $(\Delta\beta / \Delta T)$ was measured to be nearly linear [3] and showed a little variance among different base current (Fig. 3).

Table 1 summarizes the measurement results at I_B = 2.0 mA. The measured R_{th} for a 24-finger AlGaAs/GaAs HBT (2 x 20 μm^2/finger) ranges from 96.95 °C/W to 122.14 °C/W as T_{base} is varied from 21.5 °C to 57.7 °C, and it seems to reflect the decrease of the thermal conductivity of GaAs according to the temperature increase. For comparison purpose, we also calculated R_{th} using the same measurement data with the existing methods. DC procedure by D. E. Dawson *et al.* produced R_{th} = 87.32 °C/W at T_{base} = 21.5 °C, which is in good agreement with our method and validates the extraction procedure.

In Fig. 4, we summarize the measurement results of four HBT's with different emitter fingers at T_{base} = 21.5 °C. We have fitted measurement data based on the fact that R_{th} scales inversely with total emitter area [4]. We can conclude that R_{th} of one finger device with the same geometry should be 2283.5 °C/W using the fitting result, which is a typical value for AlGaAs/GaAs HBT.

3. Conclusion

The temperature dependence of β is used to measure thermal resistance of AlGaAs/GaAs HBT. Also the scaling property of thermal resistance with the emitter area based on measurement results is presented. Consequently the pulsed current I-V setup is proven to be useful for the thermal characterization of junction-type transistors. The extracted thermal resistance by the proposed procedure was very close to other existing methods. The implemented pulsed current I-V setup can be extended to pulsed current S-parameter setup for accurate characterization of microwave bipolar transistors.

References

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[4] William Liu, and Ayca Yuksel, "Measurement of Junction Temperature of an AlGaAs/GaAs Heterojunction Bipolar Transistor Operating at Large Power Densities," *IEEE Trans. Electron Devices*, Vol. 42, No. 2, pp. 358-360 (1995)

T_{base} [°C]	(Δβ / ΔT) R_{th} [1/Watt]	(Δβ / ΔT) [1/°C]	R_{th} [°C/W]
21.5	-50.308	-0.5189	96.95
29.9	-54.226	-0.5189	104.50
43.3	-57.780	-0.5189	111.35
57.7	-63.376	-0.5189	122.14

Table. 1. Measured R_{th} of 24-finger AlGaAs/GaAs HBT at different temperature.

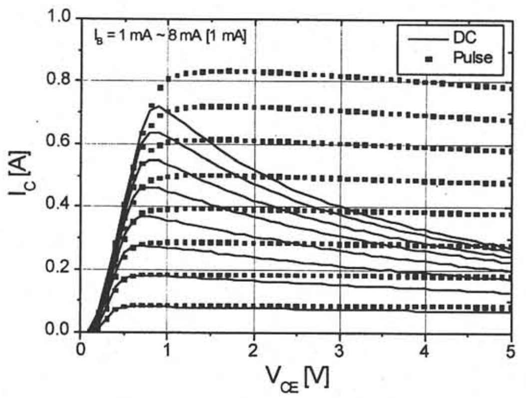

Fig. 1. DC and Pulsed I-V of 24-finger device at T_{base} = 21.5 °C. Pulse-width = 400 ns, Pulse-duration = 1 ms.

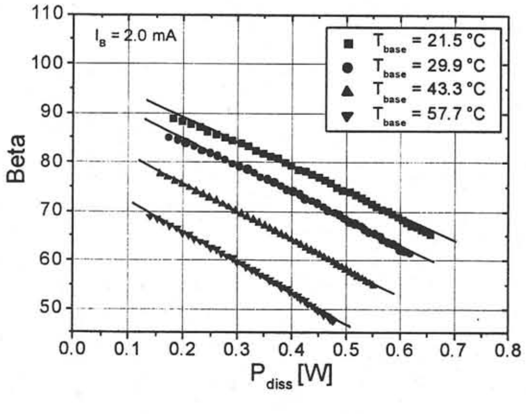

Fig. 2. Current gain dependence on P_{diss} of 24-finger device at various temperature.

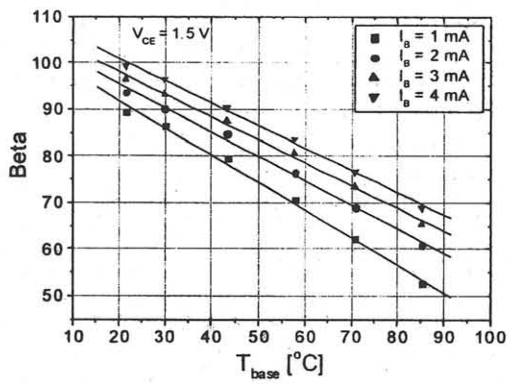

Fig. 3. Current gain dependence on temperature of 24-finger device at various base current.

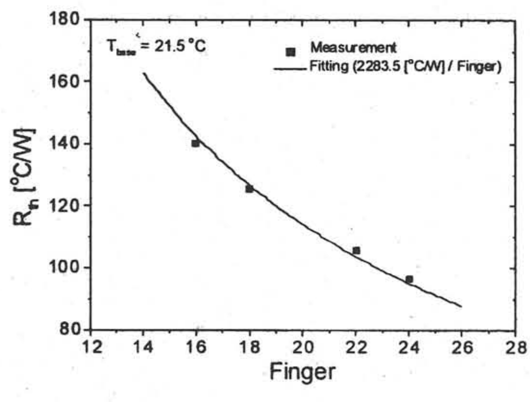

Fig. 4. Thermal Resistance Vs. Emitter Finger at T_{base} = 21.5 °C.