

A Difference of Thermal Design Between GaN and GaAs

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Abstract

We measured and simulated thermal resistances among many layouts of GaAs FET and AlGaIn/GaN HEMTs on SiC substrate. In GaAs FETs, their thermal resistances strongly depended on the total gate width, the gate pitch and the thickness of the dies. In AlGaIn/GaN HEMTs on SiC substrates, the dependence was weaker than that of GaAs FET. However, the thermal resistances of AlGaIn/GaN HEMTs on SiC substrates also depended on the die size.

INTRODUCTION

As a promising candidate for the next generation of microwave power devices, AlGaIn/GaN HEMTs have attracted much research interest due to the inherent advantages of their high voltage and high power density. In X-band and Ku-band, AlGaIn/GaN HEMTs have been reported [1, 2] and products using this technology have been released. In Ka-band and millimeter-wave frequencies, AlGaIn/GaN HEMTs with impedance matching circuits and AlGaIn/GaN HEMT MMICs were reported [3-6].

Along with increasing power density, the consumption power increases. While the output power density of AlGaIn/GaN HEMT is some times as high as those of GaAs FET, the efficiency of AlGaIn/GaN HEMT is under twice as high as GaAs FET. Therefore, thermal design for AlGaIn/GaN HEMT is more important than that of GaAs FET. Channel temperatures with various pulsed operating conditions were reported at a kW-class S-band AlGaIn/GaN HEMT [7].

In this paper, we demonstrate a difference of thermal design between AlGaIn/GaN HEMT on SiC substrate and GaAs FET by comparing measured and simulated thermal resistances of many layouts.

DIE LAYOUT

Table I shows die layouts of GaAs FETs which we prepared to compare measured thermal resistances. The width of all the dies was 2.8 mm. Three kinds of dies had the same number of fingers, which were 116 pieces. Each die had 30μm of PHS of gold at the bottom. Table II shows the die layouts of AlGaIn/GaN HEMTs which we prepared to compare measured and simulated thermal resistances. The width of all the dies was 3.3mm. Three kinds of dies had the

same number of fingers, 120 pieces. Because the die width was fixed, the difference of number of fingers made the difference of the pitch of the gate.

MEASUREMENT

Four dies were mounted on a package. The packaged device was screwed to a test fixture. The channel temperatures were measured by an infrared thermograph.

Fig.1 shows the thermal resistances for inverse of the total gate width. The thermal resistances of GaAs FETs decreased with the total gate width increasing. The thermal resistances of AlGaIn/GaN HEMTs didn't decrease so much when the total gate width was increased.

TABLE I
DIE LAYOUTS AND THERMAL CONDUCTIVITIES OF GAAS FETs

Finger Length	Number of Fingers	Measured Rth
160 μm	72	1.5 °C/W
170 μm	96	1.2 °C/W
230 μm	116	1.0 °C/W
270 μm	116	0.8 °C/W
370 μm	116	0.6 °C/W

TABLE II
DIE LAYOUTS OF ALGAIN/GAN HEMTs ON SiC SUBSTRATE

Finger Length	Number of Fingers	Die Length	Measured Rth	Simulated Rth
100 μm	120	0.60 mm	0.53 °C/W	0.59 °C/W
200 μm	144	0.70 mm	0.55 °C/W	0.51 °C/W
240 μm	120	0.75 mm	0.53 °C/W	0.49 °C/W
240 μm	144	0.75 mm	0.52 °C/W	0.49 °C/W
290 μm	96	0.75 mm	0.54 °C/W	0.48 °C/W
290 μm	120	0.75 mm	0.53 °C/W	0.47 °C/W
360 μm	96	0.85 mm	0.51 °C/W	0.45 °C/W

For simple comparison, subsequently, similar layouts which were the GaAs FETs with 116 pieces of fingers and the AlGaIn/GaN HEMTs with 120 pieces of fingers were selected. Because these GaAs FETs and GaN HEMTs had same die width, number of fingers and gate pitch respectively, the difference of finger length could be simply compared. Fig.2 shows the thermal resistances for inverse of the finger length. The thermal resistances of GaAs FETs decreased with lengthened the finger length. The thermal resistance of AlGaIn/GaN HEMTs didn't decrease so much when the finger length was lengthened.

The difference between GaAs FETs and AlGaIn/GaN HEMTs was the thermal conductivity of the substrate. SiC which is the substrate of AlGaIn/GaN HEMT has over 200 $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ of thermal conductivity. It is over four times as large as 46 $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ of GaAs. It was expected that vertical thermal diffusion from the channel area was horizontally spread much better in SiC substrate than GaAs. Consequently, AlGaIn/GaN HEMTs had weak dependence of the thermal resistance on the finger length.

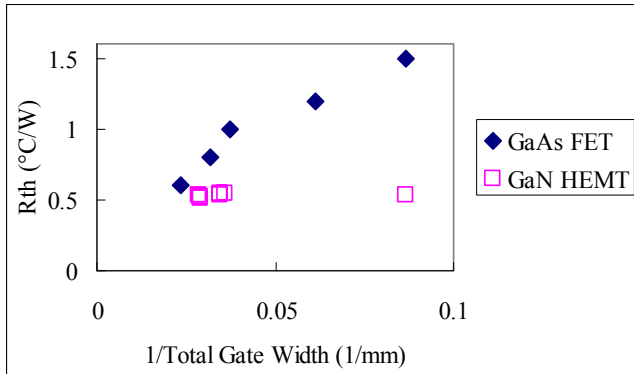


Fig.1 Thermal Resistances of the Dies on Table I and II for the Inverse of the Total Gate Width

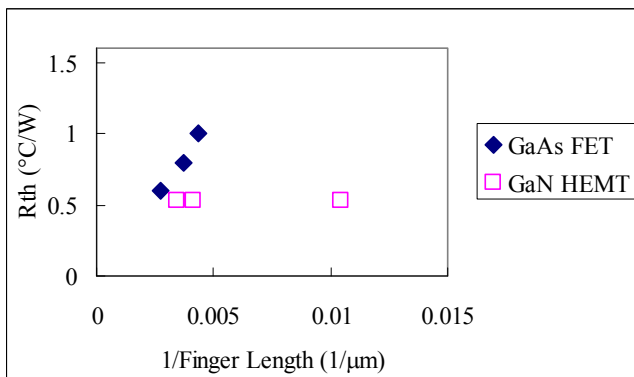


Fig.2 Thermal Resistances of the Dies with the same number of fingers for the Inverse of the Finger Length

TABLE III
CROSS SECTIONAL PARAMETERS OF THE SIMULATION MODEL

Layer	Thickness	Thermal Conductivity
GaN	3 μm	130 W/m·K
SiC	150 μm	200 W/m·K
Au	0.2 μm	296 W/m·K
Solder	30 μm	57 W/m·K
Package	1400 μm	391 W/m·K
Heat Sink	7800 μm	385 W/m·K

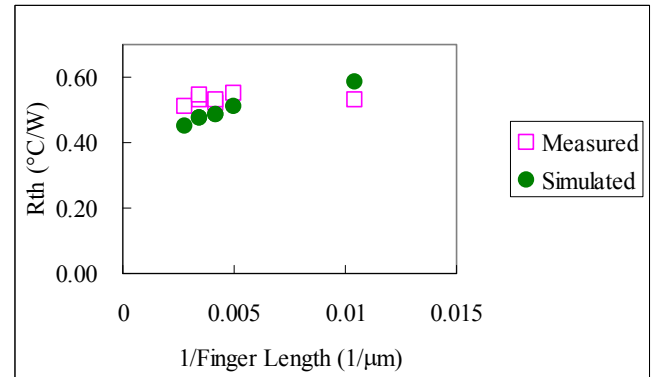


Fig.3 Measured and Simulated Thermal Resistances of the Dies on Table II for the Inverse of the Finger Length

SIMULATION

The thermal resistances of the packaged AlGaIn/GaN HEMTs were simulated with parameters showed table III. The simulation model was that heat was diffused from the channel area as heat source to the bottom of heat sink where was fixed 50 °C.

Fig.3 shows measured and simulated thermal resistances of all the dies on table II for inverse of the finger length. The simulation results were in good agreement with the measurement results. The simulated results showed that the thermal resistances of AlGaIn/GaN HEMTs depended on the finger length. But the dependence of AlGaIn/GaN HEMTs was still weaker than that of GaAs FETs. This difference probably resulted from the high thermal conductivity of SiC layer. Because the solder layer had small thermal conductivity, heat was limited to diffuse vertically at the solder layer and spread horizontally in the SiC layer.

ADDITIONAL SIMULATION

Since the thermal diffusion in AlGaIn/GaN HEMT was limited at the solder layer, it was supposed that the thermal resistance of solder layer decreased by enlarging the die size of AlGaIn/GaN HEMT. Therefore, the dependence of the thermal resistance on the die size of AlGaIn/GaN HEMT was simulated with parameters showed table III. The simulated die layouts are showed in table IV. The width of all the dies was 3.3mm. The difference of the dies was only

die length. In addition, the thermal resistances mentioned above were compared with the thermal resistances simulated without the solder layer. Fig.4 shows the thermal resistances and the difference of thermal resistances between with and without the solder layer for inverse of the die length. When the die length was lengthened, the difference decreased. This means that enlarging the die size of AlGaIn/GaN HEMT on SiC substrate is equal to thinning the thickness of the solder layer.

TABLE IV
DIE LAYOUTS OF ADDITIONAL SIMULATION

Finger Length	Number of Fingers	Die Length	Rth with Solder	Rth without Solder
200 μm	144	0.70 mm	0.51 $^{\circ}\text{C/W}$	0.44 $^{\circ}\text{C/W}$
200 μm	144	1.04 mm	0.47 $^{\circ}\text{C/W}$	0.42 $^{\circ}\text{C/W}$
200 μm	144	1.72 mm	0.45 $^{\circ}\text{C/W}$	0.41 $^{\circ}\text{C/W}$

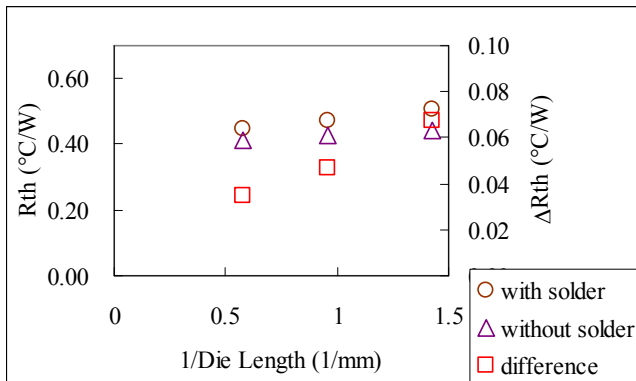


Fig.4 Simulated Thermal Resistances with and without the solder layer and the difference for the Inverse of the Die Length

CONCLUSIONS

The thermal resistances of GaAs FETs were reduced by lengthened the finger length. Those of AlGaIn/GaN HEMTs on SiC weakly depended on the finger length, because of high thermal conductivity of SiC. Since the thermal diffusion was spread horizontally in SiC, the thermal resistance of the solder layer reduced by enlarging the die size. This is a difference of thermal design between AlGaIn/GaN HEMTs on SiC and GaAs FETs. A large die like MMIC of AlGaIn/GaN HEMT has an advantage in thermal design.

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