AN_05

Thermal Performance Guide for GaN HEMT Transistors

1. Purpose

The purpose of this application note is to provide users of Dynax RF power amplifiers using AlGaN/GaN HEMTs with a guideline of the thermal performance. It explains the methodology that Dynax uses to determine the thermal resistance values listed in its datasheets. This document mainly introduces the thermal resistance calculation method of our company and the thermal resistance analysis of products with different packaging forms, different application environment and different working states.

2. Introduction

2.1 Important factor affecting MTTF

As MTTF of semiconductor devices heavily depends on device operating temperature, the accurate thermal characterization of these high power devices is crucial in establishing the reliability of the systems that use such devices. The device Tj (channel temperature) is defined as:

$$Tj = \theta jc * P_{diss} + T_C$$

Since Tc(case temperature) is determined by the customer's application，which is generally considered to be constantly 85 degree centigrade in industry, Tj is determined by θjc (junction to case thermal resistance) and P_{diss} (dissipated power). While thermal resistance depends on dissipated power (in the case of the device structure is fixed), because with different power densities, the distributions of temperatures will differ.

Therefore，when we say that Tj restricts the performance of the device, actually, we ignore the dissipation power, which is the source of the junction temperature. To be more precise，MTTF depends actually on the dissipated power under specific operating mode.

So it is important to determine what the maximum channel temperature or the thermal resistance is under specific operating modes, such as CW mode which dissipating large amounts of thermal energy and pulse mode which show a transient thermal response of a device.

2.2 Accurate thermal resistance

Because an important feature of GaN HEMT devices is the high heat in the micro-region, the detection results of many existing junction temperature detection technologies will have large errors. At present, the most widely used GaN HEMT junction temperature detection technology is micro infrared thermal imaging temperature measurement technology, but its spatial re solution is low, and the true heat source width of the device is less than 1um, and the heat source is buried in multiple layers of metal and passivation layer. Below, infrared technology will underestimate the peak junction temperature of the device, so the calculated thermal resistance is lower than the actual value.

2.3 “Casual” comparison

Some semiconductor company product datasheets give simulation values (peak junction temperature), some companies give infrared test values (surface temperature), and some companies give electrical test values (average temperature in the channel, It is much lower than the peak junction temperature); In addition, the thermal power consumption under continuous waves and pulses and even under different pulse conditions is greatly different, so the thermal resistance values under different test conditions and different application conditions cannot be simply compared with each other.

3. Introduction of thermal resistance calculation method

Our company uses finite element analysis to get the precise channel temperature and thus the precise thermal resistance value. Of course, in the process of model establishment, we used statistical analysis to compare the simulation results with the infrared test results to verify the accuracy of the model. The calibration method is introduced below.

The device model is shown in Figure 1. Due to the symmetry of the structure, we think that the temperature in the x direction and the y direction are symmetrical. Therefore, in order to save computing resources, we use a quarter of the structure model, set the material parameters and boundary conditions. After that, the internal temperature distribution of the device is obtained by simulation.

The testing principle of infrared thermal imaging technology is shown in Figure 2. During the test, we placed the device with the cap on a specific piece of furniture, and then placed it on the thermostatic platform of the infrared camera to obtain the surface temperature distribution of the device. T_c is obtained by thermocouple.

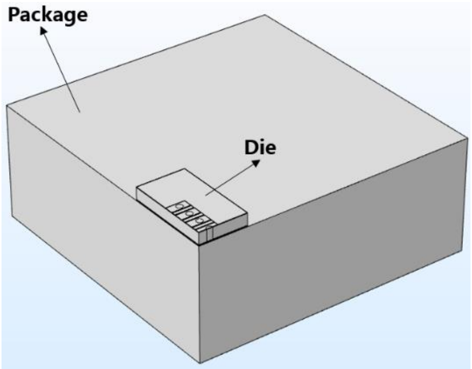

Figure1.Cross section of 1/4 model.

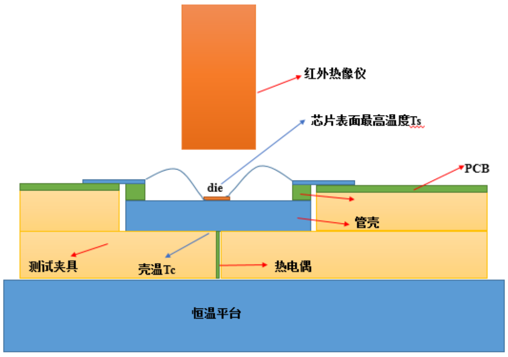

Figure2. The test diagram of IR.

The thermal imaging camera used by our company has a magnification of 15 times and a resolution of 2.7 um, which means that the value measured by the infrared is the average value in the true 2.7 um range. Therefore, we took 4 points within the range of 2.7 um around the peak temperature point obtained from the simulation, and took the average value of the temperature (defined as Taverage) to consider it to be the highest temperature that can be measured by the infrared test (defined as Tsurface). During the model verification process, we took 3 different Die products of different sizes, each of which took multiple devices in different lots for infrared testing, and fitted the test results and simulation results using the above method, and finally three different size products The Taverage and Tsurface fits are very high.

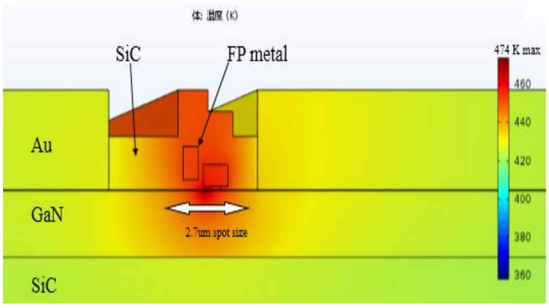

Figure3. Cross section of gate showing averaging effect.

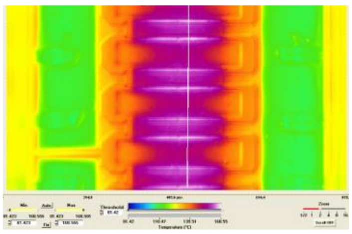

Figure4. IR measurement data

4. Introduction of thermal resistance in different working states

In addition to CW or WCDMA conditions, power amplifier tubes are also used under pulse conditions. In practical applications, the difference in the thermal characteristics of the power amplifier tube may be caused by the difference in pulse width or duty cycle. This is because under different pulse widths and duty cycles, the transient temperature rise and transient thermal resistance caused by the self-heating effect of the device will also change. The larger the pulse width or the duty cycle, the greater the thermal resistance and the higher the junction temperature of the device, which will cause the device to be different under different application conditions.

5. Introduction of different package types / application environment thermal resistance

The thermal resistance of a bare die product is the value under some specific packaging type ,and the thermal resistance of a packaged device can be represented as the sum of a series of component resistances as shown below: $\theta jc = \theta\ die + \theta\ die\ attach + \theta\ package$. Although this is a basic foundation, it is very important to understand that the total resistance is composed of many complex heat transfer mechanisms. When the package material is changed from a CPC material with a thermal conductivity (k) of 230W/mK to a Cu material with a K of 390W/mK, or when the component thickness is changed from 40mil to 10mil, the resistance of the packaged device will change, see in Tabel1.

Table 1.Thermal resistance impacts due to material alterations

	Rθjc(℃/W)	Rdie(℃/W)	Rdie attach+package(℃/W)
40mil CPC	9.2	6.1	3.1
10mil Cu	6.9	5.2	1.7

The same is true for the power amplifier tube, and it needs to be installed on a specific heat sink in actual application. Therefore, for power amplifier tube products, we also perform simulation based on some kind of heat sink (usually a pure copper heat sink). In addition, ideal contact is set between the heat sink and the power amplifier tube, and the back of the heat sink is set to a fixed boundary temperature. But for the DFN packaged power amplifier tube, it is generally soldered to the PCB heat sink through Solder. The longitudinal structure is shown in Figure 5. Then it is necessary to consider the solder thermal conductivity / solder void ratio / the size of the heat dissipation hole in the PCB / pitch / hole Thermal conductivity of the filling and so on. These will have a great impact on the junction temperature of the power amplifier tube.

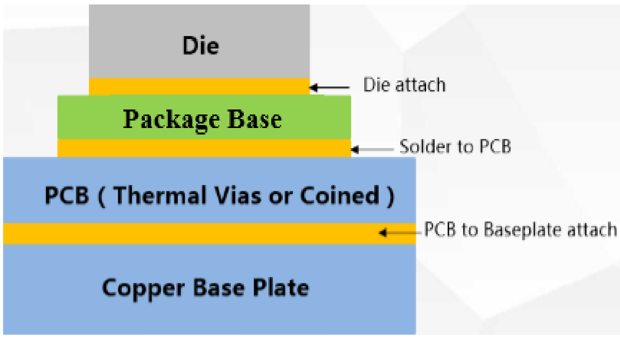

Figure5. Thermal Model Stack-up for DFN Package.

Take table2 for example.

Table 2.The influence of the size and spacing of vial hole on the Rth and Tj

	Ta （℃） *the temperature on the back of the heat sink.	TC（℃） *the maximum temperature on back of the package.	Tj(℃) *Simulated peak junction temperature.	Rθja (℃/W)	Rθjc (℃/W)
Aperture 300um, Spacing is 1000um	85	159	231	15.4	7.6
Aperture 300um, Spacing is 1500um	85	125	191	11.2	7.0

6. Conclusion

This document points out that under different application conditions (different dissipated power/ different operating states / different package forms / different application environments), the thermal resistance of the device is different, resulting in different junction temperatures. Then the MTTF is different. It also introduces the calculation method of the thermal resistance of our products, and customers need to consider specific working conditions when using these data for reliability analysis.

7. Revision history

Table 3. Revision history

Revision	Date	Description
V01	11/2017	Initial version.
V02	04/2020	Update performance data.
V03	11/2021	Update document format.

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