Application Note

AH1, AH2, AH3, FH1, FH101 Thermal Resistance Analysis

The Communications Edge ™

Product Information

AH1 Thermal Resistance Analysis

AH2, AH3, FH1, & FH101 Included by Similarity

Introduction

As part of WJ Communications' product introduction process, the thermal resistance of the AH1 packaged device was measured using infrared (IR) microscopy. The thermal resistance from the junction of the GaAs die to the ground tab is determined using measured data and calculated results. For the 0.5 µm MESFET process, WJ's extensive reliability testing has shown that a maximum junction temperature of 160° C will result in an MTTF (mean time between failure) of greater than 1 million hours of usage [1]. This document herein describes analysis confirming that maintaining a mounting temperature at or below 85° C during worst-case operating conditions (5 V, 180 mA [2]) ensures the long-term reliability of the AH1.

Experimental Test Setup

The AH1 is packaged in a standard SOT-89 package. This is a plastic molded surface mount package including a copper tab on the backside to handle the thermal dissipation of medium power die. AH1 test specimens were soldered to a surface-mount application board before testing. The application board is an FR-4 board with four ground planes and an array of plated thru-hole vias to optimize heat transfer through the board. The vias are 0.013" diameter plated-thru with 1 oz Cu and arranged beneath the device as shown in Figure 1. The boards were mounted to an aluminum mounting plate using two closely placed screws. The assembly was then attached to a temperature-controlled test stage.

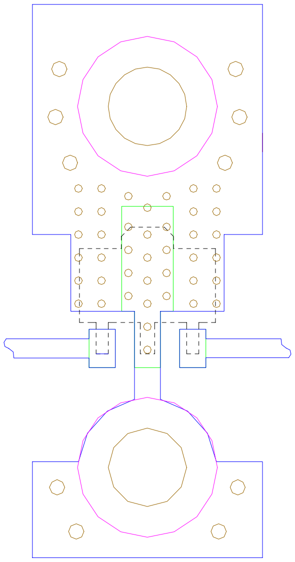

Figure 1. Via and mounting hole configuration on the AH1 application board.

IR measurements of exposed die were made on production parts that had been de-capped using an acid-etch process. Etching removes the molding compound on top of the die with out electrically or thermally affecting the performance of the device. This allows the IR image equipment to take a clear and detailed picture of the die and surrounding leadframe. Images are taken at three different magnifications. The 1x magnification is used to capture the temperature of both the exposed leadframe and the circuit board near the mounted part. 5x magnification provides a more detailed image of the entire die.

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[1] WJ Application Note "MTTF Analysis for WJ Components". http://www.wj.com

[2] WJ Datasheet "AH1 Datasheet". http://www.wj.com

25x magnification provides the most detailed and accurate measurements of the hottest areas of the die and is used to determine the junction temperature.

The data was taken at an 85° C base plate temperature so that the actual junction temperature (Tj) at the maximum rated operating case temperature could be measured. With device-to-device variation, the AH1 has a specification for the maximum operating current of 180 mA at 25° C as stated on the data sheet [2]. Because WJ MESFET devices experience a typical 10% drop in current draw when heated from 25° C to 85° C, the AH1 is expected to draw a maximum operating current of 162 mA, yielding 0.81 W of maximum dissipated power at the maximum operating case temperature of 85° C. For the purpose of determining the final product thermal resistance value, defined as the difference in temperature between the ground tab and the channel divided by the applied DC power, the device was operated under conditions that resulted in maximum power dissipation.

To take into account of the worst-case thermal operating conditions, no RF signal was applied to the device during testing. Therefore all 0.9 Watts of DC energy - 5 V * 180 mA = 0.9 W - consumed is converted into heat energy. Under normal operating conditions, some of the applied DC energy will be used to amplify the signal and released as RF energy, thus reducing the amount of DC energy converted to heat. This conservative test methodology ensures accurate data truly representing the worst case operating conditions for real applications for the AH1.

The thermal resistance of the packaged device is defined as the difference between junction temperature and case temperature divided by the applied DC power. Again this assumes that 100% of the applied DC power is converted as heat. Since there is a thermal gradient across the leadframe, the location of the case temperature measurement is important in determining the thermal resistance of the device. The case temperature is measured on the leadframe of the package far away from the device die where the leadframe becomes essentially isothermal. This temperature is the same as the mounting surface next to the part where the customer can monitor temperature.

Measurement Results

The IR scan data is used to provide a measured junction temperature during maximum operating conditions. The limiting factor of the IR scans is the measurement resolution (3.25 µm) compared to the geometry of the device (0.5 µm gate length). Since the gate length of the MESFET device is less than the resolution of the IR equipment, the IR measurement averages the temperature across the area it is able to resolve. If the IR technique could resolve features smaller than the gate length then it would report the actual temperature distribution. To account for this averaging effect, a correction factor is applied to the IR measured value. The correction factor adds conservatism and accuracy to the junction temperature measurement and overall MTTF analysis.

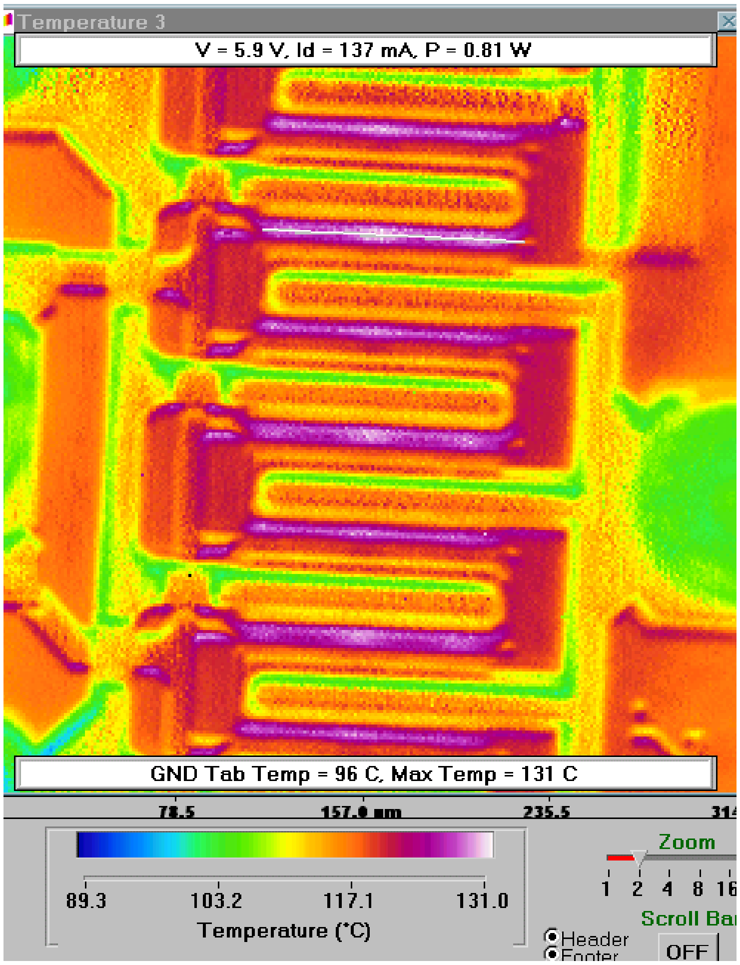
The measured results from the IR scans indicate a thermal resistance of **48° C/W** from the junction to the package of the AH1. The final thermal resistance value takes into account of the measured values and various possible sources of error: the conformal BCB coating used on the die, the correction factor based on the IR optics described above, and the effects of process variation. The correction factor depends on the gate length of the individual FET, the gate periphery of the device, the power of the device, and the measured junction temperature.

In addition, conformal BCB coating on the die can also affect the measured data. Several AH1 devices were measured with and without the BCB coating in order to determine its effect. It was found that the 5 µm coating acts to distort the image and cause a reading that is approximately 5° C lower than the actual maximum device temperature. As a result, the data used for the final analysis for the AH1 are from devices that do not have a BCB coating. Figure 2 displays a 25x IR image of a typical AH1 device without BCB coating.

As with any parameter in a semiconductor process, it is important to include the effects of process variation. To account for this, data was taken on devices from different process lots. Based on the measured data and accounting for all sources of error including process variation, WJ has determined a worst-case thermal resistance of **59° C/W** for the AH1.

Conclusion

Based upon extensive WJ GaAs MESFET history, accurate IR measured results, and modeling simulations, the thermal resistance (θjc) from the junction to the case of the AH1 is 59° C/W. Using the that value and correcting for the 10% decrease in current resulting from the elevated case temperature, a worst-case junction temperature for the AH1 is expected to be 5 V * 0.18 A * .90 * 59 °C/W + 85°C = **132.8° C**, well below the maximum recommended operating junction temperature of 160° C. Based this value and using the Arrhenius equation [3] to calculate the MTTF rating, the AH1 is expected to achieve a **highly reliable MTTF of 15.8 million hours at a case temperature of 85° C**.



Temperature 3

V = 5.9 V, Id = 137 mA, P = 0.81 W

GND Tab Temp = 96 C, Max Temp = 131 C

Figure 2. 25x Magnification of an Infrared Image of a biased AH1 at a case temperature near 85° C

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[3] $MTTF = A^* e^{(Ea/kT)}$ Where: A = 3.71 x 10^{-12} (hrs) (Pre-exponential Factor)
Ea = 1.5 (eV) (Activation Energy for WJ GaAs devices)
k = 8.617 x 10^{-5} (eV/°C) (Boltzmann's Constant)