Technical Note

Thermal Applications

Introduction

This technical note defines a general method and the criteria for measuring and ensuring that Micron® memory components operate below their maximum allowable temperature. The specified temperatures will help ensure the reliability and functionality of Micron's memory components as defined in the product data sheets.

The primary consideration for the functionality and reliability of Micron's semiconductor products is the junction temperature. The Maximum Junction Temperature table shows an overview of junction temperature limits based on product families. It is essential that each device operates below the defined junction temperature to ensure proper functionality and long-term reliability of the device.

Temperature Definitions and Terms

Much of this document is based on specifically defined temperature terms used throughout this technical note as well as other Micron documents and web sites:

Junction Temperature, Reliability — The temperature at which the device will be permanently damaged. This is a stress rating only, and device functional operation at or above the conditions indicated is not implied. Exposure to absolute maximum rating conditions for extended periods may affect the reliability of the part for various device and package reasons.

Junction Temperature, Functionality — These temperature limits are derived from Micron's test temperatures. The Junction Temperature, Functionality is the temperature below which the part should be designed to operate. Maintaining the temperature of Micron's semiconductor products below this temperature will ensure the functionality of the product to data sheet specifications.

P_B — The power dissipated down through the substrate where the component is attached.

P_C — The power dissipated up through the top case of the component.

Thermal Resistance or Impedance — The thermal resistance between two locations x and y. (R_{xy} and θ_{xy} are typical nomenclatures.) For many Micron products, thermal resistance can be considered a fixed value. For a few products, like Micron’s 3DS with logic or other multidie products, thermal resistance changes for varying power scenarios. It is Micron’s recommendation that a customer uses a detailed computational fluid dynamics (CFD) model to analyze a 3DS with logic device and estimate maximum junction temperatures. Micron provides detailed Flotherm models of these packages and internal temperature sensors within these devices for correlation.

Psi-JT and Psi-JB — Characterization parameters that are similar to resistances, but differ in that they are measured during still and forced air resistance measurements. During these measurements, the direction of power dissipation isn't understood; therefore, these parameters are prone to significant error when used to calculate junction temperature. The advantage of providing Psi is that they take less steps to measure during thermal characterization.

Device Thermal Information

Thermal Resistance Model

Figure 1: Model of Device Thermal Resistance Parameters

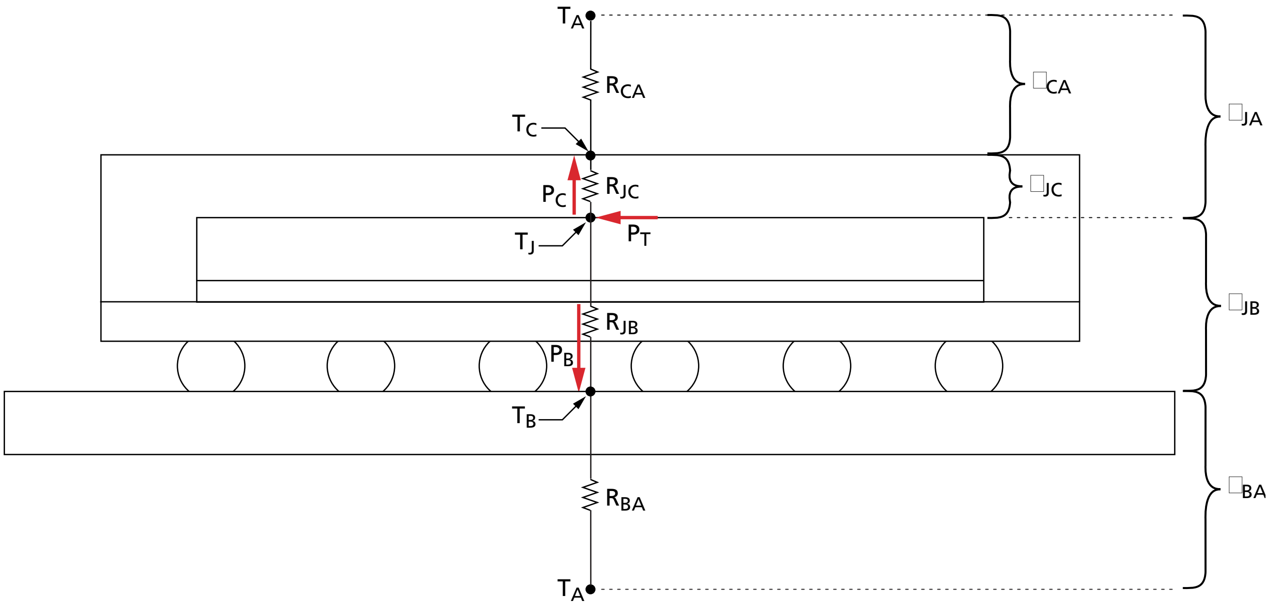

Table 1: Thermal Resistance Parameters

Symbol	Description	Unit
T_A	Temperature of ambient air	°C
T_B	Temperature of board	°C
T_C	Temperature of case	°C
T_J	Temperature at junction of device, typically the maximum temperature of the hottest die	°C
P_B	Power dissipated down through device to board	W
P_C	Power dissipated up through device to top of case and out to ambient air, heat sink, or other surface	W
$P_T = P_{TOTAL}$	Total power dissipated at junction of device	W
$\theta_{BA} = R_{BA}$	Thermal resistance between board and ambient air	°C/W
$\theta_{CA} = R_{CA}$	Thermal resistance between case and ambient air	°C/W
$\theta_{JA} = R_{JA}$	Thermal resistance between junction and ambient air	°C/W
$\theta_{JB} = R_{JB}$	Thermal resistance between junction and board	°C/W
$\theta_{JC} = R_{JC}$	Thermal resistance between junction and case	°C/W
θ_{JT}	Thermal characterization parameter (Psi) from junction to case	°C/W
θ_{JB}	Thermal characterization parameter (Psi) from junction to board	°C/W

Junction Temperature

The die temperature, T_J is probably the most difficult to measure, but is the most important to understand or be able to estimate to ensure functionality and reliability of the product. Some devices have internal temperature sensors that enable a measurement within the die at a specific location. If this feature is not available in the device, it may be easier to measure the case or board temperature, and then estimate the die temperature with θ_{JC} or θ_{JB} and a power estimate. The best method to use depends on the application and measurement capability of the user. Attempts to calculate the junction temperature using traditional θ_{JA} calculations are ***not*** recommended. Using the traditional method can produce significant errors because important parameters such as airflow, flow type, adjacent components, heat dissipation direction, PCB thickness, and PCB copper content aren't accounted for with enough detail to apply to a real application. A real application is typically very different than the JEDEC-defined environments, where the thermal impedance values are determined. This can lead to very erroneous temperature estimates based on the θ_{JA} or θ_{JMA} calculations.

Table 2: Maximum Junction Temperatures

Device	Application	T_J Max (°C)
DDR SDRAM	Commercial	85
	Industrial	90
	Automotive (AAT)	110
DDR2 SDRAM	Commercial	90
	Industrial	100
	Automotive (AAT)	110
DDR3, DDR4	Commercial	100
	Industrial	100
	Automotive (AAT)	110
	Automotive (AUT)	130
DDR5 SDRAM	Commercial	100
	Industrial	100
LPDDR, LPSDR, LPDDR2, LPDDR3	Commercial	85
	Wireless	90
	Wide Extended	110
	Industrial	90
	Automotive (AAT)	110
	Automotive (AUT)	130
LPDDR4, LPDDR5	Wireless	90
	Wide Extended	110
	Industrial	100
	Automotive (AAT)	110
	Automotive (AUT)	130
GDDR5, GDDR5X, GDDR6	Commercial	100
	Industrial	100

Table 2: Maximum Junction Temperatures (Continued)

Device	Application	T_J Max (°C)
RLDRAM	Commercial	100
	Industrial	100
NAND	Commercial	85
	Industrial	90
	Automotive (AAT)	110
	Automotive Grade (AUT)	130
NOR	Industrial	90
	Automotive (AAT)	110
	Automotive Grade (AUT)	130
e.MMC, e.MCP	Wireless	90
	Industrial	100
	Automotive (AIT)	100
	Automotive (AAT)	120
UFS, uMCP	Wireless	90
	Industrial	100
	Automotive (AIT)	100
	Automotive (AAT)	110
µSSD	Industrial (AI)	100
	Automotive (AT)	110

Notes: 1. The maximum junction temperature in each device grouping is considered the maximum reliability rating for that grouping.
2. DRAM refresh rate is device-dependent; refer to device data sheets.
3. For products not listed, see data sheet for product-specific junction temperatures.

Case Temperature

The case temperature should be measured by attaching a thermocouple to the top center of the component. This should be done with a 1mm bead of conductive epoxy, as defined by the JEDEC EIA/JESD51 standards. Care should be taken to ensure the thermocouple bead is touching the case. The case temperature can then be used to estimate the junction temperature using Equation 1.

(EQ1)

$$T_J = T_C + (P_C \times \theta_{JC})$$

where:
T_J = Junction temperature
T_C = Case temperature
P_C = Power through case = P_{TOTAL} x (% through case)
θ_{JC} = Thermal resistance from junction to case

Note: P_C can vary significantly depending on the application. With a “perfect” heat sink, P_C can approach 100%. With no case cooling and a high copper content board, P_C can be very small with most heat dissipation going into the board. In many applications, the case and junction can be assumed to be the same temperature. However, this depends on the direction of the heat loss and power level. See Table 3. Certain applications and products are better suited to this type of analysis.

Board Temperature

The board temperature should be measured by attaching a thermocouple to the center lead of the longest side, or the trace for a BGA, of the desired component. This should be done with a 1mm bead of conductive epoxy, as defined by the JEDEC EIA/JESD51 standards. The board temperature can then be used to estimate the junction temperature using Equation 2. For most applications, this method is less desirable than using θ_{JC}, but is better than using the traditional method of θ_{JA}.

(EQ2)

$$T_J = T_B + (P_B \times \theta_{JB})$$

where:
T_J = Junction temperature
T_B = Board temperature
P_B = Power through board
θ_{JB} = Thermal resistance from junction to board

Note: P_B is often higher than P_C because of conduction into the board, but can change greatly, depending upon the application. See Table 3.

Ambient Temperature

Ambient temperature is a vague term that has been defined numerous ways by various references. Some have defined it as the system ambient, the temperature of the incoming or outgoing air temperature. Others have defined it at some distance from the component of interest. The JEDEC EIA/JESD51 standards have a very specific definition, but this definition only applies to the JEDEC environments. For the purpose of determining the junction temperature in an application, Micron makes no recommendation on how to define the ambient temperature. The ambient temperature should not be used for predicting the junction temperature, but may be useful for first-level measurement or design evaluations.

Power Dissipation

The total power dissipation P_{TOTAL} of a component is a critical consideration because power causes device heating. In a typical application, parameters such as memory controller, number of memory components in a system, and software application all have a significant influence on the per component power dissipation. For help estimating power dissipation, contact Micron Application Engineering or reference the relevant technical notes on the Micron web site micron.com/support. After the total power per component has been determined, the percent of power dissipation through the case and through the board must be estimated. Table 3 can be used as a starting point to estimate power distribution based on some typical products and applications.

Table 3: Power Distribution Examples

These are examples only to highlight the concept; actual values should be based on modeling or testing of the real application.

Application	%P_C	%P_B
0m/s, high-conductivity JEDEC test board	5	95
0m/s, low-conductivity JEDEC test board	10	90

Application	$\%P_C$	$\%P_B$
2m/s, high-conductivity JEDEC test board	15	85
2m/s, low-conductivity JEDEC test board	25	75
0m/s, 12-layer PCB module	50	50
2m/s, 12-layer PCB module	75	25
12-layer PCB SSD (enclosed with TIM)	90	10
12-layer PCB SSD (enclosed without TIM)	50	50

Sensitivity Analysis

In many applications, a detailed understanding of the heat dissipation direction or other critical variables in the T_J calculation are poorly understood. When this happens, it's often convenient to calculate a range of heat flow assumptions. For example, you might measure the case, then calculate T_J for 75%, 50%, and finally 25% power through the case. This approach will often indicate if the difference between percent directions of heat flow is significant. This same approach can be used to study P_{TOTAL} or case temperature and their effect on T_J. This will often give the thermal engineer direction to understand the critical thermal physics of the application and where to focus future efforts. See case studies below.

Modeling and Simulation

If more accurate thermal predictions are required, computational fluid dynamics (CFD) and finite element analysis (FEA) modeling of the device is suggested. It is not recommended that JEDEC standard thermal impedance measurements be used for determining die temperatures. These parameters are very application-dependent and will give erroneous predictions. The JEDEC standard thermal resistance parameters are designed solely for comparing like packages under similar conditions. Micron can provide a variety of detailed and compact thermal models of components and assemblies on a request basis. Contact your sales or applications engineer for more details.

Steady State

Prior to making measurements, the component and system should be allowed to reach steady state temperature. The time required to reach steady state could vary greatly by application, but can be determined by taking measurements over a long period of time to ensure the temperature does not change. A personal computer can take 30 to 45 minutes to reach steady state with no airflow.

Case Study 1 (Environmental Chamber)

Environment: high airflow, socketed, no heat sink
Memory power: low power, 160mW

Assumption 1)

100% of power through case
Power total ~ 0.160W
Case = 74°C
Worst case $\theta_{JC} = 7$ °C/W
Junction = (0.160W x 1 x 7 °C/W) + 74°C = 75.1°C

Assumption 2)

50% of power through case
Junction = (0.160W x 0.5 x 7 °C/W) + 74°C = 74.6°C

Assumption 3)

25% of power through case
Junction = (0.160W x 0.25 x 7 °C/W) + 74°C = 74.3°C

The conclusion from this analysis is that with low power it isn't necessary to have a thorough understanding of the direction of heat dissipation. All three scenarios have junction temperatures that are within the measurement capability of a thermocouple. Additional analysis might be needed to better understand the case temperature or power dissipation, but with the assumptions above, the junction is insensitive to the direction of heat dissipation.

Case Study 2 (Multidie Products)

Product: Multidie NAND package
Environment: low airflow, large system, adjacent hot components
Power: 1.5W total for all die
θ_{JC} = 5 °C/W
T_J limit = 110°C

Maximum T_C = 110°C - (1.5W x 0.5 x 5 °C/W) = 106.25°C
for 75% through case = 104.38°C
for 25% through case = 108.13°C

For this scenario, the higher power dissipation of the memory makes θ_{JC} and the heat dissipation direction more critical to the analysis and should give direction where to focus additional thermal studies.

References

JEDEC standards, including JEDEC EIA/JESD51, are available on the JEDEC website at: jedec.org.

Revision History

Rev. Q – 07/2022

- Updated e.MCP industrial value to align to Automotive (AIT) products

Rev. P – 11/2021

- Added µSSD values in Maximum Junction Temperatures table

Rev. O – 08/2020

- Updated DDR5 values in Maximum Junction Temperatures table

Rev. N – 03/2020

- Updated automotive temperature values for e.MMC, e.MCP and UFS, uMCP in the Maximum Junction Temperatures table
- Updated doc ID number

Rev. M – 01/2020

- Updated Temperature Definitions and Terms section
- Updated Thermal Resistance Parameters table
- Updated Maximum Junction Temperatures table

Rev. L – 04/19

- Updated NOR Automotive Grade 1 value from 125°C to 130°C in the Maximum Junction Temperatures table

Rev. K – 01/17

- Updated Maximum Junction Temperatures table in Junction Temperature section

Rev. J – 08/16

- Updated Maximum Junction Temperatures table in Junction Temperature section

Rev. I – 04/16

- Updated Introduction section
- Updated Temperature Definitions and Terms section
- Updated Device Thermal Information section
- Updated Thermal Resistance Parameters T_J Description
- Updated Junction Temperature section
- Updated Maximum Junction Temperature Table
- Updated Case Temperature section
- Updated Board Temperature section Note
- Updated Ambient Temperature section
- Updated Description of Power Distribution Examples
- Added Sensitivity Analysis section
- Updated Modeling and Simulation section

- Added Case Study 1
- Added Case Study 2

Rev. H – 07/13

- Updated Introduction section
- Updated Junction Temperature Definitions and Terms section
- Updated Junction Temperature section
- Deleted T_J Operating Range column in Junction Temperature table
- Updated Case Temperature section
- Updated Board Temperature section
- Updated Ambient Temperature section
- Updated Power Consumption (Power Dissipation) section
- Updated Power Distribution Examples table
- Updated Modeling and Simulation section
- Updated Steady State section

Rev. G – 04/13

- Updated Introduction section
- Updated Junction Temperature Definitions and Terms section
- Updated Thermal Resistance Parameters figure
- Added Thermal Resistance Parameters table
- Updated Junction Temperature section
- Updated Component/Module Ambient section
- Updated System Ambient section
- Deleted Air Flow section
- Updated description in Power Consumption section
- Updated Power Distribution Examples table

Rev. F – 05/10

- Updated table: Junction Temperature, Functionality

Rev. E – 05/08

- Updated table: Junction Temperature, Functionality

Rev. D – 01/07

- Updated template
- Updated table: Junction Temperature, Functionality
- Revised text for readability
- Created revision history

Rev. C – 02/04

- Added flash device to table: Junction Temperature, Functionality
- Changed location of figure: Case Temperature vs. Bulk Airflow for a Typical Personal Computer Application

Rev. B – 08/03

- Deleted table: Typical Specification
- Added temperature definitions and terms
- Added figure: Depiction of Thermal Resistance Parameters as Defined by JEDEC
- Added table: Junction Temperature, Reliability
- Added table: Junction Temperature, Functionality

Rev. A – 04/02

- Initial release

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