COOLING METHODS FOR POWER SEMICONDUCTOR DEVICES AND DEVICE MOUNTING BETWEEN COOLING FINS

1. Introduction

To radiate generated by power dissipation in a semiconductor device, a cooling measure must be taken, because natural heat radiation from the device case is insufficient, and the junction temperature exceeds the allowable limit of the device. Normally, either self-cooling, air-cooling, water-cooling, or oil-cooling methods are adopted. Described below is how to select cooling fins and how to set a device between the cooling fins, when an air-cooling method is adopted.

Problems regarding thermal cooling are kin to those of an electrical circuit, and the resistance to the heat flow (thermal resistance) must be taken into consideration. An analogy between an electrical circuit and a thermal radiation circuit is given in Table 1.

Table 1 Comparing an Electrical Circuit with a Thermal Radiation Circuit

Electrical Circuit	Thermal Radiation Circuit
Voltage (V)	Temperature (°C)
Current (A)	Power dissipation (W)
Resistance (Ω)	Thermal resistance (°C/W)

The heat radiation circuit shown in Fig. 1 can be obtained by considering heat radiation problems analogous to electrical circuit problems. This equivalent circuit shows how the heat generated at the device junction is influenced by thermal resistances between the junction and the case, the case and the fins, as well as the fins and their ambience. The circuit also shows how the heat is radiated into the atmosphere. Provided that heat P (W) is generated, the following formula is formed. In this catalog, heat resistance of the stud-type device is referred to as $R_{th(j-c)}$, and heat resistance of the flat-type device is referred to as $R_{th(j-f)}$.

$$T_j - T_a = P(R_{th(j-c)} + R_{th(c-f)} + R_{th(f-a)})$$

T_j : Junction temperature (°C)
T_a : Ambient temperature (°C)
P : Power dissipation within the device (W)
$R_{th(j-c)}$: Junction-to-case thermal resistance (°C/W)
$R_{th(c-f)}$: Case-to-fin thermal resistance (°C/W)
$R_{th(f-a)}$: Fin-to-ambient thermal resistance (°C/W)
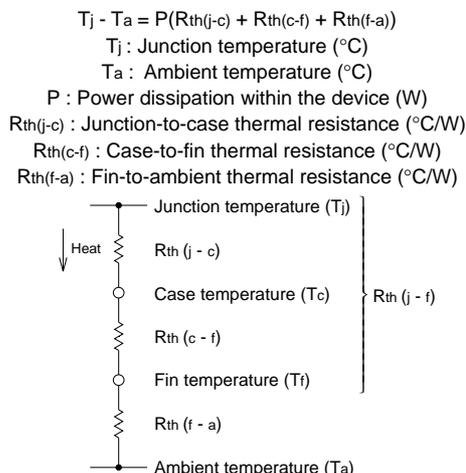
Fig. 1 Equivalent Circuit for Thermal Radiation

In designing a cooling method, a rectifier circuit must first be designated and a device must be selected based on the various electrical conditions. At this point, a maximum junction temperature, a junction-to-case thermal resistance, and internal power dissipation are determined. Therefore, an approximate idea of a case-to-fin resistance is also determined. Moreover, the maximum ambient temperature ($T_{a(max)}$) is determined by other factors, and the only variable will be the fin-to-ambient thermal resistance. A cooling method can be selected by such a process. To select the best method, consideration should be given not only to cooling performance, environmental conditions, mechanical conditions and electrical conditions, but also to economic conditions.

2. Cooling Fin Thermal Resistance

The thermal resistance of a cooling fin depends not only on its size, but also its shape, composition, surface configuration (surface finish, painted or bare, etc.) and orientation. Other factors influencing the thermal resistance are the temperature differences between cooling fin and ambient temperature, the speed of the air striking the cooling fin surface, the air-current, and the temperatures of surrounding objects. Fig. 2-1 shows an example of thermal resistance data regarding heat dissipation fins for the standard flat-type device used in a high-power semiconductor stack.

This data shows that the air-cooling condition with average wind rate of 5 m/s must be used in order to obtain 0.035°C/W of the thermal resistance $R_{t(f-a)}$ between fins and their ambient. Also, Fig. 2-2 shows the maximum transient thermal impedance property, and Fig. 2-3, the relation between average air velocities and pressure drops.

Fig. 2-1
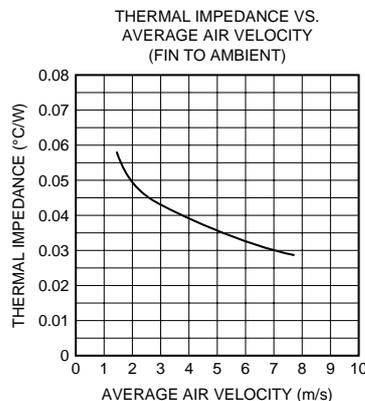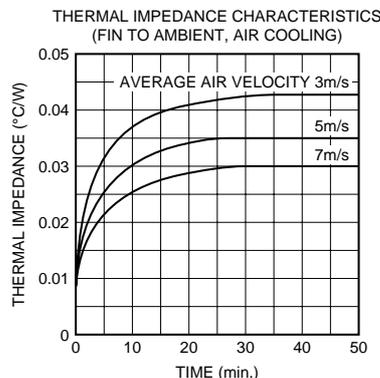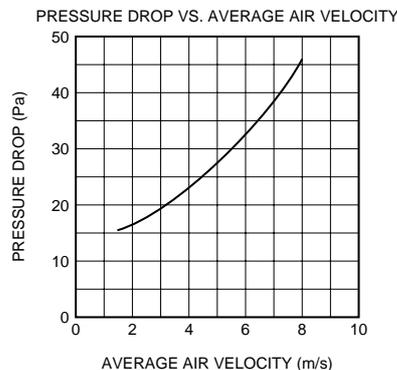
THERMAL IMPEDANCE VS. AVERAGE AIR VELOCITY (FIN TO AMBIENT)

Fig. 2-2

THERMAL IMPEDANCE CHARACTERISTICS (FIN TO AMBIENT, AIR COOLING)

Fig. 2-3

PRESSURE DROP VS. AVERAGE AIR VELOCITY

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3. Device Mounting

Generally, a flat-type device is pressed between cooling fins prior to use. In this process, the following points regarding the design should be considered carefully. If these points are not satisfied, the device may offer insufficient performance or become damaged.

(1) Design a suitable stack whose pressure mounting force is within the specified values.

(2) Keep the uniform pressure condition on the whole contact surface of the device. In this case, flatness of the surface of the cooling fin must be less than 10 μm, and parallelism must be less than 50 μm. Also, an aligning mechanism using a ball must be used in the design of the stack.

(3) Roughness of the surface of the cooling fin must be 3 μm. Apply a compound with good thermal conductivity lightly and evenly over the contact surface. This reduces contact thermal resistance, prevents surface corrosion, and stabilizes the contact surface. Table 2 is an example of the compound used for our stack. When using a compound, please follow instruction manuals and maker's catalogs.

Fig. 3 shows an example of device setting.

Table 2 Example of Compound Having Thermal Conductivity for Semiconductor Use

Maker	Item
ALCAN	UNIVERSAL JOINTING-COMPOUND

Our stack products are made by ALCAN Co., Ltd.

After removing oxide coating, apply compound.

For roughness of face B and C, 3 μm or less is recommended.
For flatness of face B and C, 10 μm or less is recommended.
For parallelism of face A and B, 50 μm or less is recommended.
For parallelism of face C and D, 50 μm or less is recommended.

Fig. 3 Example of Device Setting

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