

Finite Element Thermal Modelling of Power Transistor

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More than 50% of the failures in power electronic circuits are due to thermal breakdown of the active device. Thermal breakdown occurs when the junction temperature reaches close to 175°C. Thermal analysis is of immense use, not only for finding the optimum power handling capacity of the given heat sink but can also be used for designing the heat sink for the required power dissipation. In this paper, thermal modelling of the power transistor using Ansys® software with the actual practical set up with the heat sinks is analyzed. The simulation is also used to determine temperature of transistor case, which is used to predict junction temperature. This will help to maintain the transistor from not entering the second breakdown and confirm the safe operation of power transistors. The experimental and the simulation results are compared to support the modelling procedure.

Keywords: Finite element; Power transistor; Power dissipation

INTRODUCTION

The electrical characteristics of power semiconductor devices are strongly influenced by internal temperature rise due to heat dissipation, resulting from non ideal conditions of heat abstraction. John N Ellis, *et al*¹ discussed about the electrical modelling of the 2N3055 and Sung K Kang, *et al*² has suggested the overall structure of silicon power transistors and their thermal fatigue effects on soft soldered joints. There exist a mutual interaction between the electrical and the thermal phenomena, and this is to be taken into account during analysis and design process of power electronic devices. Inclusion of the electro thermal interactions in modelling and analysis makes the model of the investigated object (semiconductor device or the electronic circuit) more adequate.

In this paper, thermal modelling using the Ansys® is used to determine the temperature of the transistor case. The simulation can be used to determine the case temperature for various types of heat sinks commercially available with different cooling techniques. This can help in choosing the right type of heat sink for the power application in use. Power transistor in a circuit will be at a higher temperature compared to any other nearby component. Due to this, they rule or control the

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temperature distribution of the circuit's components. Hence, the thermal analysis of the power transistor is of prime importance. This paper also includes the experimental results on resulting temperature as a function of power applied. These results are compared with the Ansys®³ obtained from the modelling and simulation of the structure of the power transistor with the heat sink.

THEORY

The total power dissipation in a transistor is given by

$$P_{tot} = I_c V_{CE} + I_B V_{BE} \gg I_c V_{CE} \quad (1)$$

since $I_B V_{BE} \ll I_c V_{CE}$

The heat dissipated in the collector base junction flows through the thermal resistance between the junction and the mounting base, $R_{th(j-mb)}$. The thermal equivalent circuit is shown in Figure 1. P_{tot} can be regarded as the thermal current and the temperature between the junction and the mounting base $\Delta T_{(j-mb)}$ as the thermal voltage. Then by Ohm's law analogy

$$P_{tot} = \frac{T_j - T_{mb}}{R_{th(j-mb)}} \quad (2)$$

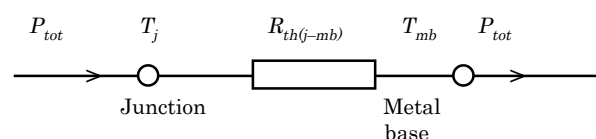


Figure 1 Thermal equivalent model

All semiconductor failure mechanisms are temperature dependent and so lower the junction temperature, higher is the reliability of the circuit. The junction temperature depends on both the power dissipated in the device and the thermal resistance associated with the device⁴. Hence, careful calculation of thermal resistance is a must, when power dissipation in a circuit is to be calculated. The power transistors are usually mounted on a heat sink and the heat flows from the transistor case to the heat sink by way of contact pressure. The heat sink losses heat to the surroundings by convection and radiation. The equivalent resistance model with heat sink is shown in Figure 2.

If the power dissipated is P_D , then the junction temperature is,

$$T_j = P_D (R_{\theta_{jc}} + R_{\theta_{cs}} + R_{\theta_{sa}}) + T_a \quad (3)$$

where, T_a is the ambient temperature, $R_{\theta_{jc}}$ is thermal resistance between junction to case, $R_{\theta_{cs}}$ is thermal resistance between case to heat sink, $R_{\theta_{sa}}$ is thermal resistance between heat sink to ambient.

Hence, the junction temperature will be the sum of the ambient temperature and the thermal resistance times the power dissipated. Thermal resistance of a component is the temperature difference across it for a power dissipation of 1 W.

SCHEMATIC MODEL OF 2N3055

For 2N3055 transistor, the chip with the material layers is shown in Figure 3. The chip has a dimension of $[4.6 \times 4.6] \text{ mm}^2$. The layers included with their approximate dimensions are given in Table 1.

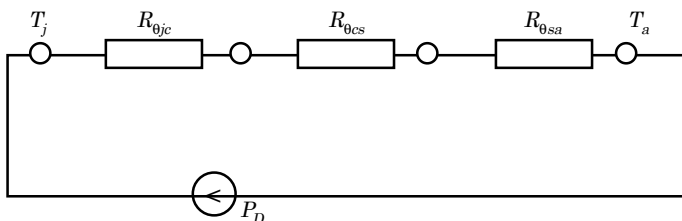


Figure 2 Thermal equivalent model with heat sink

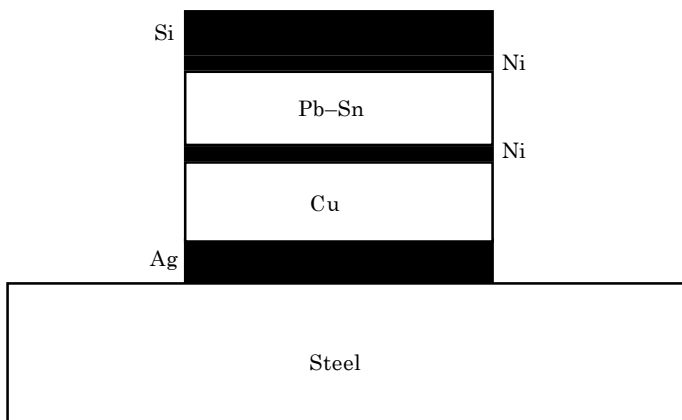


Figure 3 Schematic of power transistor

Table 1 Dimension of the power transistor

| Materials | Length, mm | Breadth, mm | Thickness, μm |
|-----------|------------|-------------|--------------------------|
| Si | 4.6 | 4.6 | 150 |
| Pb-Sn | 4.6 | 4.6 | 100 |
| Ni | 4.6 | 4.6 | 1 |
| Cu | 4.6 | 4.6 | 3000 |
| Ni | 4.6 | 4.6 | 20 |
| Ag | 4.6 | 4.6 | 100 |
| Steel | 5 | 5 | 3000 |

MODELLING OF 2N3055 USING ANSYS®

The chip structure as per Table 1 is first modelled. The transistor case is modelled with the actual dimension specified in the datasheet⁵. The standard heat sink structure shown in Figure 4 is modelled with a thin layer of mica sheet, which is a good thermal conductor and an electrical insulator. The overall structure used for the simulation is shown in Figure 5.

The physical properties of different materials⁶ are to be keyed in by the user, as given in Table 2. The entire power is assumed to dissipate in the full volume of Si as heat generation rate⁷ in W/m^3 . Initial heat sink temperature is defined as room temperature. Film coefficient, nothing but the heat transfer coefficient of the convection is 150 throughout, assuming natural convection. The structure of the heat sink is drawn in AutoCAD⁸, with the mica sheet and the transistor structure and is converted in to .SAT format. SAT stands for 'standard ACIS test' used for storing the modelling information. .SAT files have an open format, which is independent of the type of modelling

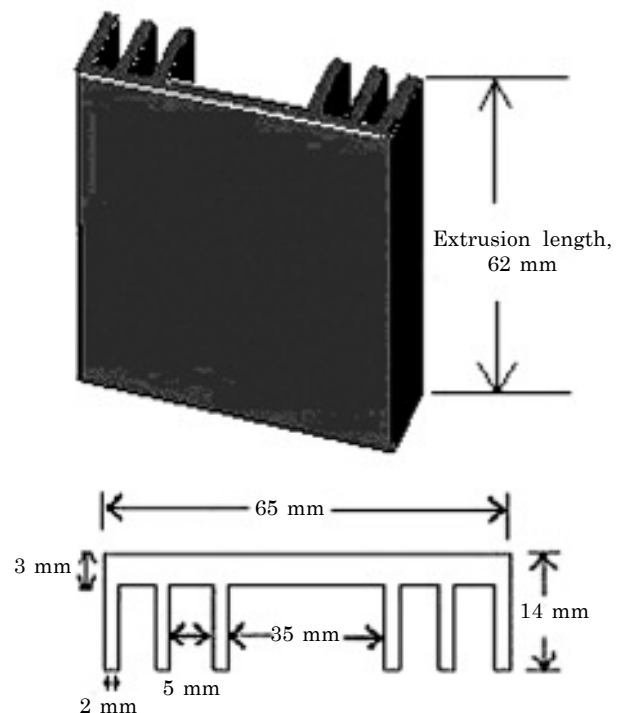


Figure 4 Dimension of the heat sink

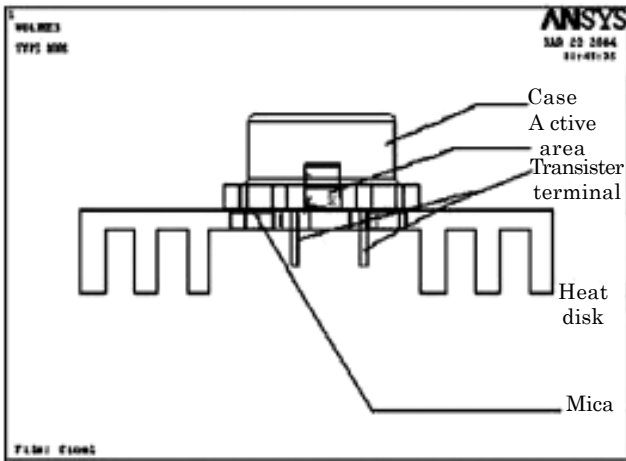


Figure 5 Schematic module used for modelling

Table 2 Properties of the layers included in the module

| Materials | Thermal conductivity, W/mK | Specific heat, J/kg K | Density kg/m ³ |
|-----------|----------------------------|-----------------------|---------------------------|
| Si | 153 | 703 | 2340 |
| Pb-Sn | 65 | 213 | 7280 |
| Cu | 386 | 381 | 3954 |
| Ag | 406 | 235 | 10524 |
| Steel | 53 | 465 | 7833 |
| Al | 200 | 850 | 3900 |
| Mica | 581 | 290 | 8792 |
| Ni | 90 | 8792 | 290 |

used. The .SAT files are then transferred to the Ansys® and is then scaled down to the actual dimensions.

In the pre processing procedure, the chip structure is modelled and placed in the transistor case as shown in Figure 5. The finite element model uses 8 node 3D-thermal solid element (solid 70) (which is the element provided in Ansys® software for one dimensional heat flow analysis) with temperature being the only degree of freedom. The material properties given in Table 2 are applied to the different volumes. Then the structure is overlapped, glued and meshed with the maximum smart size option. After meshing, the maximum number of nodes and elements are 10781 and 53229, respectively.

Steady State Analysis

Load Conditions

Chip volumetric power dissipation in W/m³ is applied to the main silicon volume. The convection is applied to all the exterior areas and the analysis is repeated for different wattages. The reference temperature (initial heat sink temperature) is taken as the room temperature. The steady state nodal solution with the temperature variation as the contour plot is shown in Figure 6, Figure 7, for 7.5W and 15W applied power, respectively.

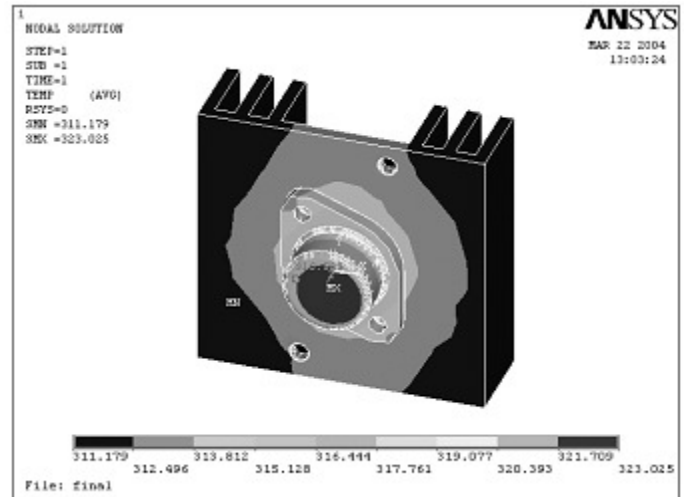


Figure 6 Contour plot with power 7.5 W

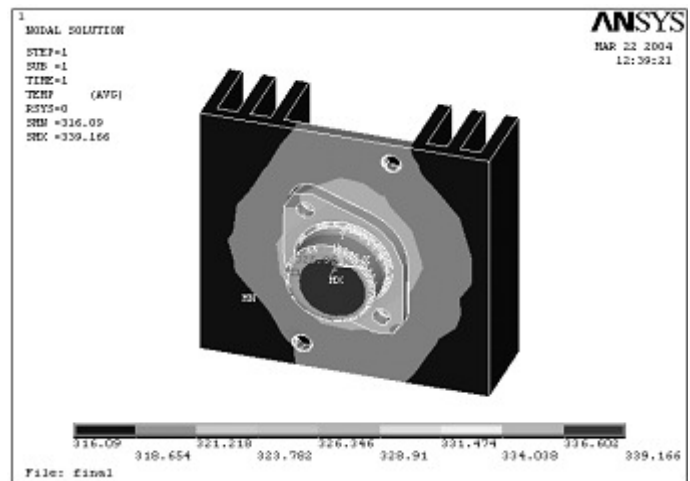


Figure 7 Contour plot with power 15W

EXPERIMENTAL SETUP AND COMPARISON OF RESULTS

The experimental results are obtained using the circuit shown in Figure 8. The same power as used in the simulation is applied to the circuit. Care should be taken to maintain V_{CE} and I_C at constant values as the temperature rises. The sensor placed on the case of transistor, records the temperature rise till steady state is reached for various power levels.

The temperature in the region of the case is recorded by sensor and compared with the calculated data. The sensor used is a linear output type, thermal transducer IC LM 35 with 10mV/°C and with 0.25° C accuracy from -55°C to 150°C. The sensor is mounted on the case of the transistor, so as to have a good contact with the surface. The comparison of the results is given in the Table 3.

The results show good correlation between the simulation and experimental results. From the results, the junction temperature can be predicted using the equation (3).

Table 3 Comparisons of results with heat sink

| Power Applied, W | I_B , mA | I_C , A | V_{BE} , V | V_{CE} , V | Experimental temp of case, K | Simulation temp of case, K |
|------------------|------------|-----------|--------------|--------------|------------------------------|----------------------------|
| 3 | 4.2 | 0.47 | 0.656 | 6.385 | 309.3 | 310 |
| 4 | 4.2 | 0.47 | 0.655 | 8.510 | 310.5 | 311 |
| 5.5 | 4.2 | 0.49 | 0.650 | 11.224 | 312.1 | 313 |
| 7.5 | 4.2 | 0.52 | 0.629 | 14.423 | 316.1 | 316 |
| 12.5 | 4.2 | 0.59 | 0.594 | 21.186 | 319.8 | 321 |
| 15 | 4.2 | 0.63 | 0.571 | 23.809 | 328 | 325 |

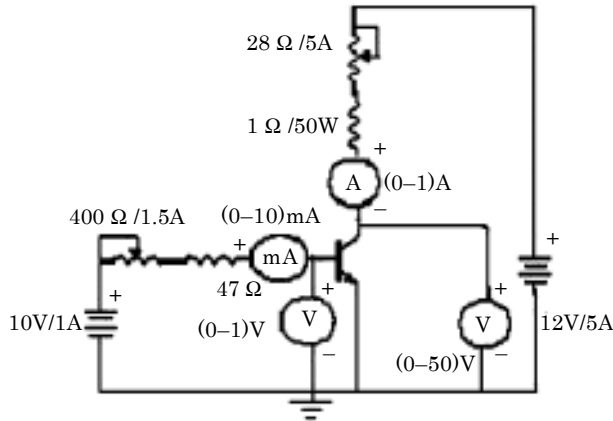


Figure 8 Circuit diagram

CONCLUSION

In any circuit, component reliability is the key factor and a better understanding of the thermal characteristics will be useful in determining and maintaining the junction temperature within the limits. In this paper, the modelling of the transistor with the heat sink is done and this will help in pre determining the junction temperature, which helps in confirming the safe operation of the device.

The heat sinks which are commercially available can be tested and the best heat sink to suit the desired requirements can be found or designed using this

analysis. Heat sinks with different materials and their alloys can be modelled and designed just by changing the material properties for the given power handling capacities.

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