Dynamic Simulations for Thermal Analysis of MOSFET IPM on IMS Substrate

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Abstract. The authors introduce some further research on the problem depicted in [1]. The transient model has been worked out to check how rapidly the temperature of the chip changes when the applied power changes abruptly. This means searching for the answer: how the thermal resistance and the maximum temperature vary versus time. The simulations required using the 3-D thermal model of considered system that was used in numerical simulations and next, tested with commercial software, ANSYS 5.7 based on Finite Element Method (FEM) and additional calculations.

1 Introduction

The temperature rise above the permissible level results in much worse work of the device or even in its destruction. Enlarging frequency and the requested speed of switching make the conditions more difficult yet. The work introduces our results of dynamic simulations performed for the system: 2 MOSFETs on IPM, described in [1]. The 3-D thermal model of IPM used in the simulations is discussed there. In the model, it has been assumed that the silicon chip is the only heat source in which the heat is dissipated homogeneously. The magnitude of heat dissipation has been fixed on the base of Toshiba transistor 2SK2866a data sheet [2]. Taking into account its catalogue maximum ratings, so called the PD drain power dissipation has been chosen as equal to 125W, which gives the heat generation of 18.1e9 W/m³ when taking into account the volume of the silicon chip.

2 The Thermal Model of IPM

The thermal model used for transient simulations is similar to the one described in [1]. It covers one half of the examined structure, introduced in Fig. 1 and its basic parameters are collected in Table 1. The structure above was the basis to work out the procedure in Ansys software that made possible the dynamic simulations of the heat flow inside the considered IPM module, for the step heat load function.

Fig.1. 3-D view of the IPM thermal model: (a) top view; (b) the cross section

Table 1. The dimensions of the elements of thermal model

Material	length	width	thickness	Comments
	[mm]	[mm]	[mm]	
Al base plate (11)	50	40	2.0	IMS plate
Insulate layer (12)	50	40	0.12	IMS plate
Cu foil (13)	var	var	0.10	IMS plate
Solder	10	10	0.10	
Lead frame	10	10	0.7	Transistor
Silicon chip	4.8	4.8	0.30	Transistor
Epoxy				Transistor

3 The Dynamic Simulations

The simulation has been performed for the step function of power dissipation. Its magnitude has been assumed as equaled to the value of 18.1 e9 W/m^3 , what meets 125W heat source in the silicon chip. The Figures 2-5 compose an example of one typical series of the temperature development to show the changes during heating since the step start till the thermal equilibrium state is reached. We have kept the same scale of temperature for the diagrams to make possible easy comparing.

Fig. 2. The cross-section of the structure. Temperature after 1 s of heating

Fig. 3. The cross-section of the structure. Temperature after 4.6 s of heating

Fig. 4. The cross-section of the structure. Temperature after 10 s of heating

Fig. 5. The cross-section of the structure. Temperature after 100 s of heating

The last figure (after 100 s of heating) gives the steady-state conditions. The temperature does not change any more, having achieved its maximum of 123°C.

The thermal maps from figs. 2-5 permit to estimate the changes of the maximum temperature in the IPM structure that occurs on the top surface of the silicon chip, and the thermal impedance of the module that corresponds to them. Such dependencies have been estimated for different dimensions of Cu foil. The fig. 6 gives the maximum temperature, which is captured on the hottest place, and the fig. 7 thermal impedance curves for the whole structure. One can see that the curves for Cu width 4.0mm coincide the ones for Cu on whole the surface, so the conditions are steady-state with this value.

Fig. 6. Maximum temperature curves for different Cu path width.

Fig. 7. Thermal impedance curves for different Cu path width

4 The Estimation of the RC Ladder

The simulations for the input step function were run to calculate the heat properties for the considered package. The final numbers have been evaluated for dynamic thermal models, covering thermal resistances (R_{th}) and capacitances (C_{th}). Fig. 8 shows the scheme of such a RC ladder, and Table 2 introduces the values, calculated for enlarging Cu width values. With them one can calculate the thermal conditions for any boundary conditions and schemes, where the tested package is applied. The values are calculated versus time (t) according to the formula (1) [4]:

$$Z_{th}(t)=\sum_{i=1}^n R_{thi}\left(1-\exp\left(-\frac{t}{\tau_{thi}}\right)\right) \tag{1}$$

where $n=5$ for our simulations, and

$$\tau_{thi}=R_{thi}\cdot C_{thi} \tag{2}$$

The RC network (ladder) model is five-stages (Fig. 8), what allows us to exam which part of the structure changes and which one can be even neglected. The results proved that the two end stages (IMS) give the significant impact to the curve shape, i.e. to the thermal capacitance.

Fig. 8. The thermal circuit for considered heat flow

Table 2. The R_{th} and C_{th} values calculated for growing width of Cu (marked as ‘d’)

d = 0.5mm				
R_{th1} [K/W]	R_{th2} [K/W]	R_{th3} [K/W]	R_{th4} [K/W]	R_{th5} [K/W]
0.03	0.07	0.17	0.53	0.08
C_{th1} [Ws/K]	C_{th2} [Ws/K]	C_{th3} [Ws/K]	C_{th4} [Ws/K]	C_{th5} [Ws/K]
0.03	0.06	0.24	0.81	41.33
d = 1.0mm				
R_{th1} [K/W]	R_{th2} [K/W]	R_{th3} [K/W]	R_{th4} [K/W]	R_{th5} [K/W]
0.03	0.07	0.18	0.50	0.07
C_{th1} [Ws/K]	C_{th2} [Ws/K]	C_{th3} [Ws/K]	C_{th4} [Ws/K]	C_{th5} [Ws/K]
0.02	0.06	0.23	0.83	51.62
d = 2.0mm				
R_{th1} [K/W]	R_{th2} [K/W]	R_{th3} [K/W]	R_{th4} [K/W]	R_{th5} [K/W]
0.02	0.07	0.19	0.47	0.06
C_{th1} [Ws/K]	C_{th2} [Ws/K]	C_{th3} [Ws/K]	C_{th4} [Ws/K]	C_{th5} [Ws/K]
0.02	0.05	0.22	0.84	63.39
d = 4.0mm				
R_{th1} [K/W]	R_{th2} [K/W]	R_{th3} [K/W]	R_{th4} [K/W]	R_{th5} [K/W]
0.02	0.08	0.19	0.45	0.05
C_{th1} [Ws/K]	C_{th2} [Ws/K]	C_{th3} [Ws/K]	C_{th4} [Ws/K]	C_{th5} [Ws/K]
0.02	0.05	0.22	0.85	72.00

Whole Cu				
R_{th1} [K/W]	R_{th2} [K/W]	R_{th3} [K/W]	R_{th4} [K/W]	R_{th5} [K/W]
0.02	0.07	0.19	0.45	0.05
C_{th1} [Ws/K]	C_{th2} [Ws/K]	C_{th3} [Ws/K]	C_{th4} [Ws/K]	C_{th5} [Ws/K]
0.02	0.05	0.22	0.85	74.08

5 Conclusions

The 3D simulations presented here allow for the sight into the thermal processes taking part in the considered IPM module. They make possible estimating the maximum temperature inside the examined structure that can be used for the thermal impedance evaluation. The obtained curve has been applied to determine the lumped thermal model of the module in the form of the RC ladder.

References

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