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Effect of Thermal Contact Resistance of Heat Transfer in the Mold

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Abstract: In this study, through common computational fluid dynamics analysis software (COMSOL Multiphysics) to predict heat transfer for the hot-pressed mold of semiconducting vacuum laminator. The predicted results are compared with the experimental measurements to verify the accuracy of simulations. The mold heated by electric pipes that were formed as concentric circle similarly and installed the mold within upper and lower symmetry. In a closed mode, the whole cavity of the mold will lie in a vacuum. Assume that the external ambient room temperature and natural convection boundaries, there are thermal contact resistance between parts.

key words: heat transfer, thermal contact resistance.

1. Introduction

Dry film coating technique has been used early in many industries that include printed circuit board (PCB), lead frame, IC packing and other precision etching industry as well as image transfer process of flat panel display industry. In terms of PCB board technology, the traditional way of roller lamination is already quite mature, but not in terms of the wafer technology. A new dry film vacuum laminator technique for wafer has been developed. Heater within the mold of vacuum laminator was needed, and the mold must be sealed as well as vacuum, until the heater stops, besides, the effect of thermal contact resistance at contact interface was considered for this subject. In this study, the result of COMSOL simulation shows the whole heat distribution of the mold, and to compare with the result was accurate through experimental measuring by thermocouples. The major benefit is to understand the heat distribution and to improve the design promptly.

2. Specification of Model and Boundary Condition

As shown in Figure1, the dimensions of mold are $450 \times 450 \times 143$mm, they consist of stainless and aluminum parts, and there were two heat insulators (PEEK) set between heater and a certain aluminum part, this setup could prevent heat loss. In this case simplified model of a quarter because of that assume all the parts are symmetric (As shown in Fig2.). By the boundary conditions of each module, the maximum power of heat source is constant, no heat radiation and the outward heat transfer mode of mold by natural convection.

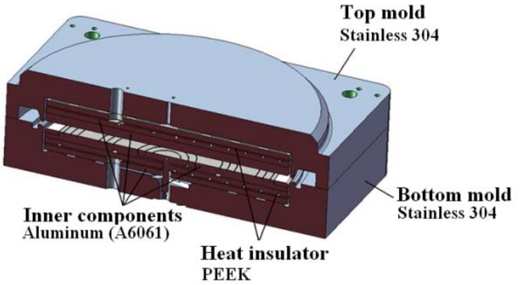


Fig1. The mold of dry film vacuum laminator

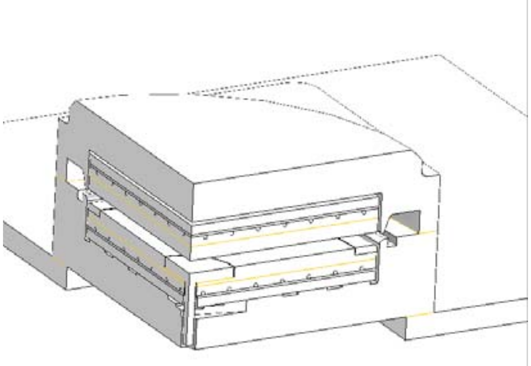


Fig2. Construction of analyzed model

There are thermal contact resistances between each part because of their roughness and air fills the gap between the surface[1-2], that's an important factor for the thermal conductivity way of modeling the interface is to define a thermal joint conductivity, h_j (W/m^2 • K), the calculation of interface resistance has been discussed by M.M Yovanovich et al[3]., as follows the same method to calculate them. Figure 3 shows the interfaces between each part that specified. The contact mode of interface 1 and interface 2 are occurred with the gravity, they are different from the locking contact mode of interface 3 and interface 4. Here follows a brief summary for thermal joint conductivity. h_j is defined as the sum of the conductivity through those regions that are in contact and those where there is a gap,

$$h_j=h_c+h_g$$

where h_c is the contact conductivity and h_g is the gap conductivity. h_c is determined by the expression,

$$h_c=1.25k_s\frac{m}{\sigma}\left(\frac{P}{H_c}\right)^{0.95}$$

where k_s, m, σ, H_c are parameters specifying the material and surface characteristics of surface, and P is the contact pressure that include gravity and locking force in this article. Calculating the locking force (F) as follows,

$$F=W\frac{\mu\pi d-l}{\pi d+\mu l}$$

where F, W are locking force and screw axial force(Kg), l is screw lead(mm), d is the effective of diameter(mm) and μ is friction coefficient.

The gap conductivity, h_g is determined by the expression,

$$h_g=\frac{k_g}{Y+M}$$

where k_g is the thermal conductivity of the air in the gap, Y is the effective gap thickness, and M is gas parameter that accounts for rarefaction effects at high temperature and low pressure. But in a vacuum, the contact resistance will be much large, that is to say, h_g will close to zero.

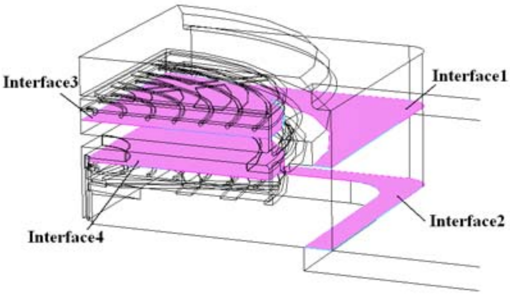


Fig3. The interfaces between each part

3. Experimental setup

In experimental setup side, thermocouples (k type) and a signal acquisition device (DAQPRO 5300) were needed. DAQRPO can retrieve data from it and then transfer to computer via RS232 protocol. Thermocouple is a common thermal sensor to get electrical signals as temperature detection and heater on/off controller. Figure4 shows the location of temperature sensors.

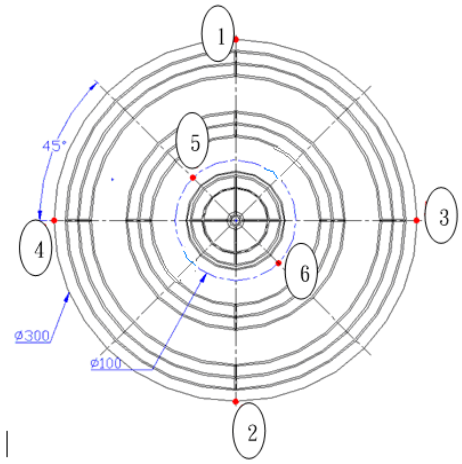


Fig4. Location of thermal sensors on working surface

4. Results and Discussion

Computer-Aided Engineering (CAE), a well known skill that could be obtained much unknown information from it or redesign until suitability before manufacturing. That's the importance of simulation for engineer. This section will get much useful information on heat transfer.

4.1 Heat transfer on steady state

As shown in Figure5 and Figure6, it was on steady state, the whole temperature distribution and vector of mold were predictable, and set temperature of 100 degrees Centigrade on working surface as a stopping point to match the actual situation. Figure7 shows the predicted result of temperature distribution on working surface, and compares with the experimental measurements which ranges between 100.4 and 101.4 degrees Centigrade, this shows the simulation result match well with the experimental data.

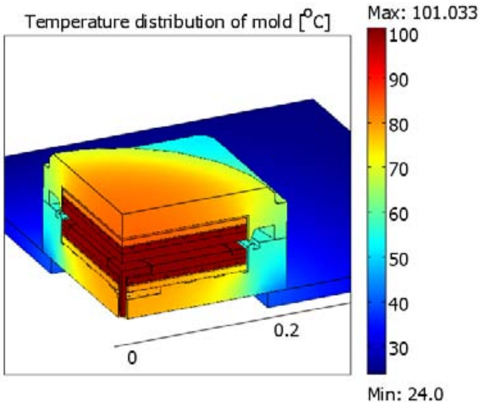


Fig5.The whole temperature distribution of the mold

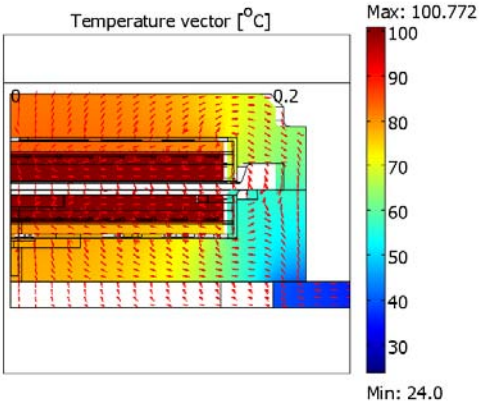


Fig6. Distribution of temperature vectors

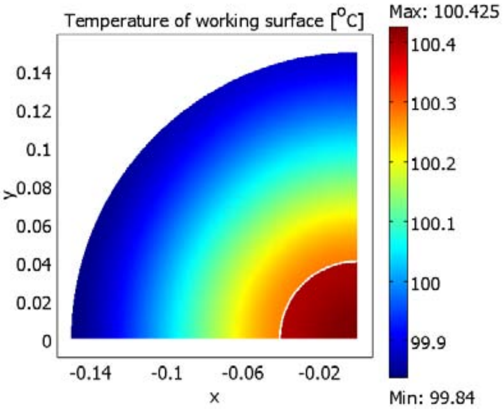


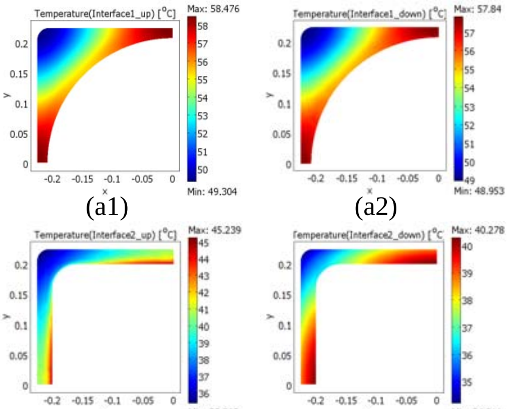
Fig7. Distribution of temperature on working surface

4.2 The result of interface thermal resistance

The effect of thermal contact resistance was investigated, in the previously as shown in Figure3, there are four interfaces between parts. Figure8 shows the predicted results of interface 1 and interface 2, the difference in temperature at interface 1 is smaller than 1 degree Centigrade, but at interface 2 will approximate 5 degrees Centigrade. This cause of the difference was mainly heat transferred to the bottom board. Figure9 shows the predicted results of interface 3 and interface 4, the difference in temperature of them were smaller than 0.1 degrees Centigrade. This cause of the phenomenon was that both the interfaces were near the heat source, the contact situation was not too bad and in a vacuum environment, that's why the predicted results of them were much closed. Finally, compare with the difference in temperature of those interfaces as shown in Table1.

Table1. Comparison of analysis results

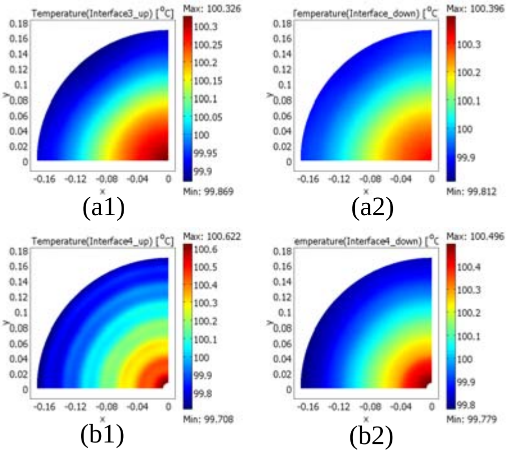
	up	down	Different
Interface1	58.5℃	57.8℃	0.7℃
Interface2	45.2℃	40.3℃	4.9℃
Interface3	100.3℃	100.4℃	-0.1℃
Inteface4	100.6℃	100.5℃	0.1℃



(a1) (a2)

(b1) (b2)

Fig8. Temperature distribution of Interface 1(a) & Interface 2(b)



(a1) (a2)

(b1) (b2)

Fig9. Temperature distribution of Interface 3(a) & Interface 4(b)

5. Conclusion

In this study, solid heat transfer and thermal contact resistance are the mainly objects of study. Due to computing simulation with COMSOL Multiphysics^{TM} software, the predicted results match well with the experimental data and was accurate. However an optimal design, a prior prediction could add the efficiency of design and make cost down of manufacturing.

6. Reference

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