THERMAL TRANSIENT ANALYSIS OF Ag THIN FILM INTERFACED LED FOR VARIOUS APPLIED PRESSURE

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Silver (Ag) thin film was deposited on Al substrates at various thicknesses by DC sputtering and tested for thermal interface application. The test was conducted at various applied pressure and recorded the cooling transient curve at 350 mA for all samples. The derived raise in junction temperature (T_J) was low for LED attached with 500 nm Ag thin film coated Al boundary condition at 3 bar applied pressure. Consecutively, the observed difference in total thermal resistance ($R_{\text{th-tot}}$) for the given LED was high for 500 nm thin film at 3 bar pressure when compared with 300 nm thin film at same pressure. Based on the results, Ag thin film with higher thickness will be used an alternative solid thin film interface material for electronic packaging application.

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1. Introduction

Heat is an inevitable by-product of every electronic device, and is usually disadvantageous to performance and reliability. The electronic packaging trend has been to reduce size and increase performance of the product, both of which contribute to exponential increase in power consumption of the system.

The tremendous growth in electronic equipment demands innovative solutions to the new challenges of thermal management which dissipates heat effectively. The major challenges on the thermal management front can be understood by the heat dissipation of electronic devices, which vary from 5 W/cm^2 on a PWB to 2000 W/cm^2 for a semiconductor laser. The junction temperature of the chip has to be maintained below the allowable limit specified by the vendor in most cases for both performance and reliability factor. Many approaches have been tried and implemented for the electronic cooling. Now days, the interface material with optimized or low thickness are giving good improvement in reducing the junction temperature of the LED. Film type thermal interface materials are frequently using to solve this issue. In order to make a good contact between the package and the heat sink and also to complete the thermal joint in adhesive tapes or films, the film is applied to one of the surfaces (heat sink), and forced into contact with the semiconductor package. The applied pressure range varies from 10 psi to 50 psi for a few seconds duration. Thermal contact resistance (TCR) at interfaces must be considered during the optimization of thermal design. From the definition formula of the TCR (TCR = ΔT/q), we can see that the TCR is related to the temperature jump ΔT and the heat flow q at the interface.

In general, the measurement methods of the TCR can be divided into steady-state method and transient-state method. In this study, the transient-state method is used for the experiment. It can complete the measurement in a shorter time and avoid the difficulty in controlling the heat flow of the steady-state method [1]. In the literature [1], the contact resistance decreased with the increase of the contact pressure and showed that the relationship between the TCR and contact

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pressure was nearly linear. The contact pressure is the most important factor affecting the TCR, next to the temperature and the minimum factor is surface roughness [2].

On considering the film type thermal interface material, our group have already tried many type of thin films like BN [3], AlN [4], Al_2O_3[5], Ag-ZnO[6] etc. as thermal interface material for effective heat dissipation from the LED package. The performance of the LED was tested using various boundary conditions with thin film as thermal interface material. Instead of copper, Ag thin film is an ideal candidate for future interconnects. To avoid agglomeration, Al mixed Ag was suggested as interconnects. Porous silver layer was used as electrode in sensor application for high concentration H_2O_2 [7]. Recently our group has published the results of Ni thin film interface material where Ag thin film was used as buffer layer. In this work, Ag thin film is considered alone as thermal interface layer and the performance of LED was tested at various thickness of Ag layer with various applied pressure during the measurement.

1.1 Theoretical background

In reducing thermal interface resistance, the application of pressure has a vital role and decides the interface contact resistance. The total thermal resistance (R_T) is the sum of three resistances [8]:

$$R_T = R_{C1} + R_M + R_{C2} \tag{1}$$

Where, R_T = Total Thermal Resistance, R_{C1} = Contact thermal resistance of surface 1, R_M = Thermal Resistance of the material itself, R_{C2} = Contact thermal resistance of surface 2. The thermal resistance created by the material itself (R_M) for a given thickness was reported as constant as a function of pressure; whereas the contact thermal resistances at the interfaces ($R_{C1} + R_{C2}$) are very dependent on pressure. At low pressures of <15 psi the contact thermal resistances can account for more than 50% of the total thermal resistance (R_T) of a typical interface material.

Therefore pressure acts to mate the interface material to its surfaces, minimizing the amount of air remaining at the interface, therefore decreasing the thermal resistance. The amount of pressure required to reduce thermal resistance is a function of the interface material's compressibility and surface properties. Consequently, the influence of pressure on thermal conductivity of Ag thin film using thermal transient method was studied at various pressures. In addition to this, the influence of thickness was also analyzed and reported in this paper.

2. Experimental technology

2.1 Ag thin film deposition

Ag thin film was deposited on Al substrates (2 x 2 x 0.5 cm) at various thicknesses (300nm, 500nm and 700 nm) by DC magnetron sputtering at room temperature. For thin film deposition, the chamber was initially evacuated to base pressure of 5.5×10^{-5} mbar using turbo molecular pump backed by a rotary pump. All thin films were deposited at 5×10^{-3} mbar chamber pressure. Ar (99.999%) gas was used as sputtering gas at the gas flow rate of 12 sccm. Before loading the substrate to the deposition chamber, the substrate was cleaned by using ultrasonic cleaning for about 10 minutes at 50°C in ethanol solution. The cleaned substrates were then loaded into the chamber and pre-sputtered to remove the surface oxidation of the metal target. During the film deposition, the distance between the substrate and target was fixed at 7 cm and the rotary drive system was used and fixed 25 RPM for all coating to get the uniform thickness of the deposited Ag thin film. DC power of 100 W was used for deposition. Later the prepared thin films were tested as thermal interface material at various applied pressure using TEA module (TTF 100). The applied pressure was fixed not exceeded to an international standard for characterizing interface materials (< 6.9 bar).

2.2 Thermal Transient Analysis Ag thin film interfaced LED

The thermal performance of prepared Ag thin film on Al substrates at various applied pressure was tested and thermal transient curve was captured based on the electrical test method JEDEC (Joint Electron Device Engineering Council) JESD-51. Thermal Transient Tester (T3Ster) was used to perform the experiment in still air condition. During the measurement, various pressures from 1bar to 4 bars were applied on LED package to analyze the performance of LED as well as the Ag coating as thermal interface materials.

In order to test the thermal resistance as a result of applied pressure, the transient curve was recorded at 350 mA at room temperature and the current densities were calculated as 3.37 A/mm^2. The LED was forward biased for 100s and the transient cooling curve of heat flow from the LED package was captured for another 900s. The experiment was repeated 3 times to confirm the repeatability / reproducibility of the results. The obtained cooling profile of the LED for different thickness of Ag thin film coated on Al substrates at various applied pressure was processed for structure functions using T3ster Master Software. The pressure was applied using TEA 100 attached with JULABO (supply gas pressure) cooling arrangement.

3. Results and Discussion

From the thermal transient analysis, the cooling curve was captured for all samples and given in fig. 1. it clearly depicts the influence of film thickness and the applied pressure on the temperature of the device. A noticeable difference in rise of junction temperature was observed with 300 nm Ag thin film for different applied pressure and also explained the change in pattern of cooling curve with respect to the applied pressure. In order to get the exact information, the transient cooling curve was processed by T3Ster master software and extracted the rise in junction temperature of the device for various boundary conditions such as thickness and applied pressure. The observed values are summarized in fig.2 as bar chart.

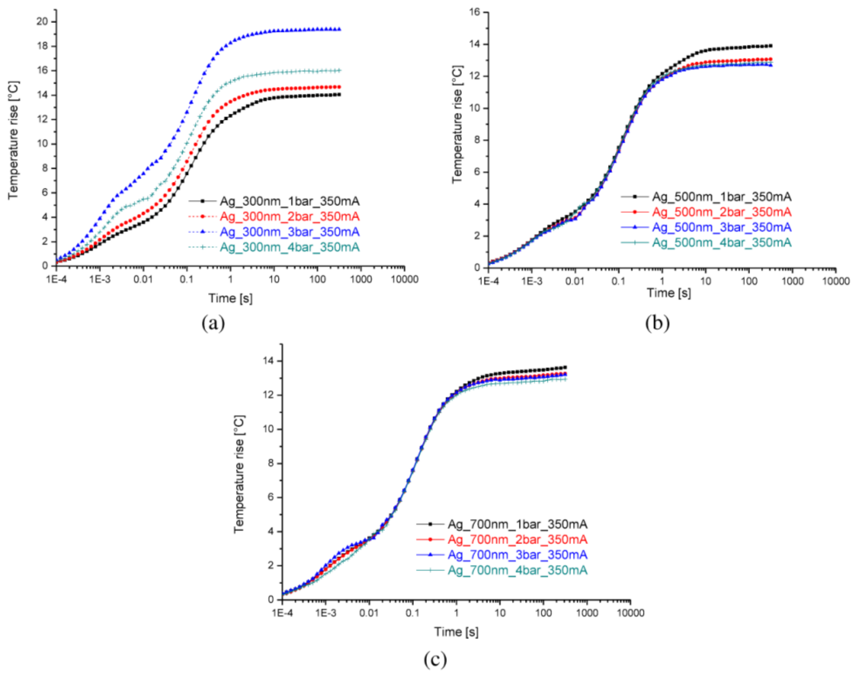

Fig. 1 Transient cooling curve of Ag thin film interfaced LED tested at various pressure for various Ag thin film thickness a) 300 nm, b) 500 nm and c) 700 nm

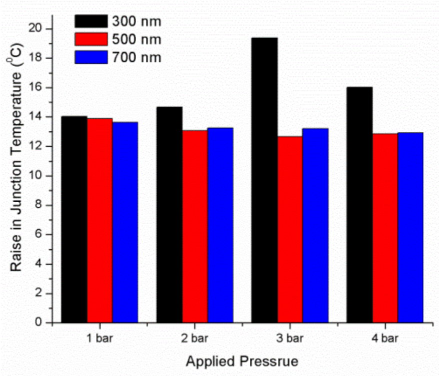

Fig. 2 Variation in rise in junction temperature of LED at different thickness of Ag film for different applied pressure

Fig.2 extensionally shows the exact behavior of Ag thin film and the influence of thickness and also the applied pressure on T_J values. From the fig.2, the T_J values are decreasing with the applied pressure increasing for the Ag thickness of 500 nm and 700 nm. Very low value in T_J of 12.5 °C was noticed with 500 nm sample at 3 bar applied pressure. An unexpected increase in T_J was also observed with 300 nm sample at 3 bar applied pressure. Overall, the T_J values are increasing for 300 nm samples with increasing applied pressure. This increase may due to thermal stress as a result of high applied pressure for metal thin film. It is noted that the decrease rate of the TCR was slowing when the contact pressure reaches a certain value. This is because that plastic deformation occurs at the interface of the materials. When the contact pressure was big enough, the contribution of the contact pressure to augmenting the actual contact area would be weakened [1]. But it is compensated by using higher thickness of film and hence low value of T_J is possible with higher thickness of Ag thin film.

From the transient analysis, the cooling curve is analyzed and achieved the cumulative structure function curve as shown in fig.3. From the cumulative structure function curve, the $R_{th\text{-}tot}$ value of the LED was derived and plotted verses applied pressure as shown in fig.4. Fig.4 evidences the impact of pressure on thermal resistance of the LED and shows good performance at higher applied presser for higher Ag film thickness. At 3 bar pressure, the difference in $R_{th\text{-}tot}$ ($\Delta R_{th\text{-}tot}$) from the fig.4 was high for 500 nm thin film when compared with 300 nm thin film. Moreover, the low pressure (1 bar) does not influence much on Rth-tot for all thickness.

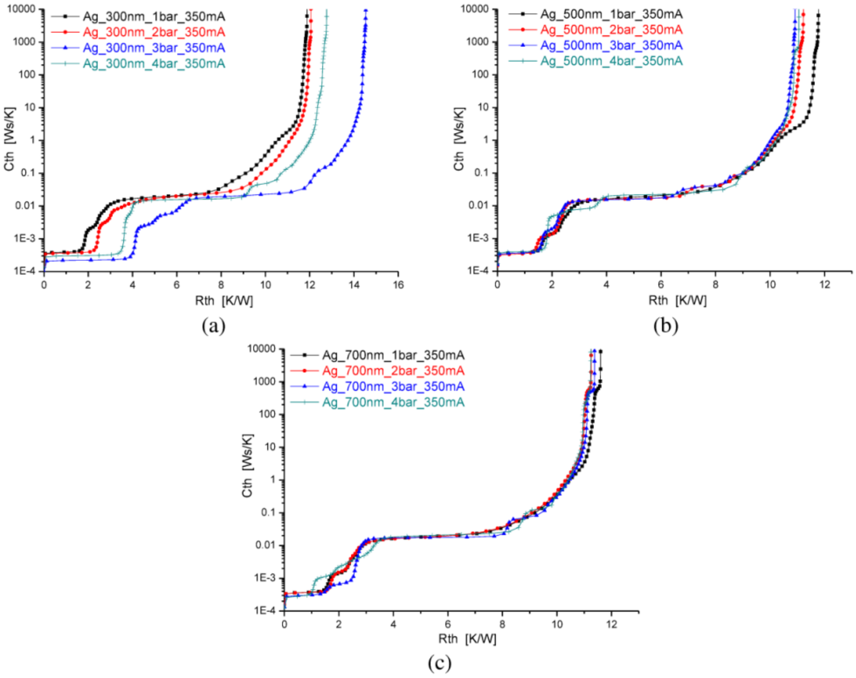

Fig. 3 Cumulative structure function curves of Ag thin film interfaced LED tested at various pressure for various Ag thin film thickness a) 300 nm, b) 500 nm and c) 700 nm

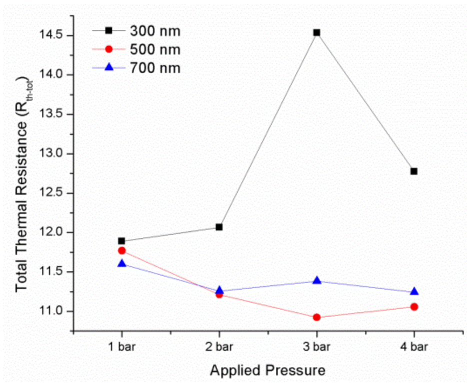

Fig. 4 Variation in total thermal resistance of LED at different thickness of Ag film for different applied pressure

Increasing the contact pressure can enlarge the actual contact area, which causes the TCR to decrease. It is noted that the decrease rate of the TCR was slowing when the contact pressure reaches a certain value. This is because that plastic deformation occurs at the interface of the materials. When the contact pressure was big enough, the contribution of the contact pressure to augmenting the actual contact area would be weakened [1]. Based on this reason, the observed $\Delta R_{th\text{-}tot}$ was low at high applied pressure (>4 bar) and evidenced from the fig.4

Contact pressure, which is the most pronounced influence factor on the TCR, affects the value of TCR by changing the real contact area. The number of contact spots increases as well as the mean radius of contact spots enlarges as the contact pressure increased. That results in the good contact heat transfer at moderate high contact pressures. The micro hardness is high at high pressures according to Eq. (15) in ref. [9] and ref. [10], so the TCR is less sensitive to the contact pressure at high pressures. For smooth surfaces, the deformations of the contact spots are more significant than rough ones, as well as the changes of contact spots density under the contact pressures are larger. Hence it is possible to decrease the thermal contact resistance at the interface for higher applied pressure.

4. Conclusion

It is concluded that the heat transfer enhancement is relatively weak for a contact set at high pressures. 500 and 700 nm of Ag thin film showed better performance on reducing the junction temperature of the LED at high pressure. The total thermal resistance of the LED was low for 500 nm Ag thin film at high applied pressure. Overall, the Ag thin film with higher thickness may also be suggested as solid thin film interface material when packaged at moderated pressure for better temperature elimination from the LED package.

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