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Probabilistic Fatigue Life Estimation of Film Capacitor Assemblies Under Thermal Cycling

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1. Introduction

Electronics has various types of components. To connect the components electrically and mechanically, solder joints such as BGA, surface mount and pin-through-hole (PTH) can be used. The fatigue life of BGA and surface mount solder joints was studied extensively [1-4]. However, the fatigue life of PTH solder joints with film capacitors is rarely observed in the literature. In this paper, a simulation model of PTH solder joints in film capacitor assemblies is presented. The fatigue life of the PTH solder joints is estimated. Then, the probabilistic fatigue life is calculated by the uncertainty propagation method.

2. Strain Energy Density Calculation using Anand model

Test coupons consisted of film capacitors, PCB, and PTH solder joint as shown in Fig. 1. The CAD model of test specimens was as shown in Fig. 2.

The viscoplastic model for the lead-free solder was the Anand model [5] that combined the creep behavior with isotropic hardening effects. Other materials were assumed to be linear elastic. VISCO 107 in ANSYS APDL was used for the lead-free solders, while SOLID 185 was for other materials. The loading condition was referred from the JEDEC standard; the maximum and minimum temperatures were -40°C and 125°C, respectively.

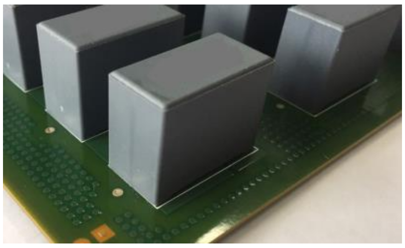


Fig. 1 Film capacitor assembly

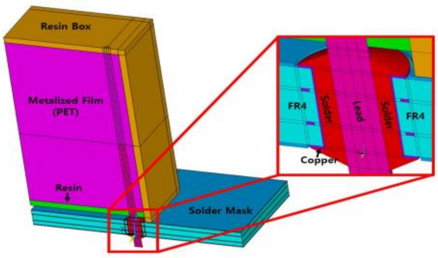


Fig. 2 CAD Modeling

The average strain energy density was calculated using Eq. (1).

$$\Delta W_{ave} = \frac{\sum_{i=1}^{n} \Delta W_i V_i}{\sum_{i=1}^{n} V_i} \quad (1)$$

where ΔW_{ave} is the averaged strain energy density change per thermal cycling; n is the element number of the FE model; ΔW_i is the strain energy density change of ith element per thermal cycling; and V_i is the volume of ith element. During the thermal cycling simulation, the average strain energy density converged after three cycles. The convergence criterion was within 5% fluctuation of the change of average strain energy density [6].

3. Fatigue Life Estimation by Darveaux's model

Darveaux's strain energy density-based model defines the relationship between the number of failure cycles (N) and the average strain energy density (ΔW_{ave}).

$$N_0 = K_1 \left(\Delta W_{ave}\right)^{K_2} \quad (2)$$

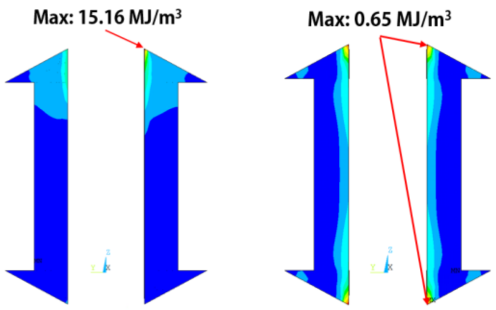
$$N_p = \frac{\mathrm{A}}{K_3 \left(\Delta W_{ave}\right)^{K_4}} \quad (3)$$

where N_0 is the number of cycles to initiate crack; N_p is the number of cycles to propagate cracks until failure; ΔW_{ave} is the net increase in the strain energy density per cycle; A is the crack size; and K_1, K_2, K_3, and K_4 are the empirical constants. Crack initiation can be ignored for lead-free solders. Therefore, Eq. (3) for crack propagation was used to predict fatigue life of the PTH solder joints.

4. Probabilistic Fatigue Life Estimation by Response Surface Model and Monte Carlo Simulation

The fatigue life of the PTH solder joints in film capacitor assemblies can deviate significantly due to inherent randomness of materials and geometry. By sensitivity analysis, dominant design variables were selected. A meta model of the simulation model was constructed by response surface methodology.

The uncertainty in design variables were propagated through the meta model by Monte Carlo simulation. Consequently, the statistical distribution of the fatigue life was calculated.



(a) (b)

Fig. 3 Strain energy density distribution (a) before and (b) after removing the film capacitor

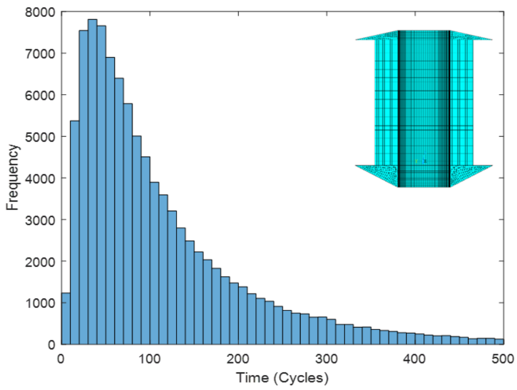


Fig. 4 Predicted statistical lifetime distribution of film capacitor solder joints

5. Results and Discussion

The average strain energy density converged to 0.611 MJ/m^3 after three cycles. As presented in Fig. 3, the strain energy density of the solder joints is distributed before and after removing the film capacitor. The maximum strain energy density in Fig. 3(a) was higher (approximately 21 times) than that in Fig. 3(b). The CTE mismatch between the PCB and film capacitor was dominant compared to that between the lead and the solder joint.

The coefficients in Eq. (3) were estimated by curve fitting between lifetimes from experiments and average strain energy densities from simulations. K_3 and K_4 were estimated to be 0.3938 and 5.3778, respectively. The PTH solder joint lifetime was predicted using Eq. (3). The error was 8.3%. Although the error was acceptable, the prediction does not provide any information regarding the statistical distribution of solder joint lifetimes. To this end, the statistical distribution of the fatigue life was predicted using a meta model and Monte Carlo simulation as shown in Fig. 4. When the uncertainty in geometry of solder joints were incorporated, the durability of the film capacitor assemblies could be estimated. Therefore, the durability of the film capacitor assemblies could be estimated with the predicted statistical lifetime distribution.

6. Conclusions and Future Work

This paper presented a simulation model for PTH solder joints in film capacitor assemblies. Using Anand model and Darveaux's strain energy density-based model, the fatigue life of the PTH solder joints was estimated. Furthermore, the statistical distribution of the fatigue life was predicted using a meta model and Monte Carlo simulation. This study revealed that the effect of the film capacitor on the fatigue life was significant. The CTE mismatch between the film capacitor and PCB should be examined carefully during the design procedure.

In this paper, the deviation of the fatigue life was predicted by incorporating inherent randomness in solder joint geometry. Inherent randomness in the manufacturing process was not considered. In future, various uncertainty sources of manufacturing process and material properties will be considered.

Acknowledgment

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