Reliability of System in Package

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Abstract

A system in package (SiP) generally contains a variety of systems such as analog, digital, optical and micro-electro-mechanical systems, integrated in a system-level package connected through a substrate. However, there are many electrical and mechanical reliability issues including the reliability issue for embedded structures. A mismatch of thermal coefficients of expansion among packaging materials and devices can lead to warping or delamination in the package. In this study, the effect of material properties of underfill, such as Young's modulus and CTE, are investigated through FEM simulation. Experimental investigation on the warpage of the package is also carried out to verify the simulation results. The results show that the reliability of the system in package is closely related to the material properties of underfill. The results of this study provide a good guidance for the material selection when designing the system in package.

Introduction

System in Package (SiP) is now the fastest growing microelectronic packaging technology since it is a cost-effective solution to high-density system integration in a single package. It has many advantages including the area reduction on PCB, electrical performance improvement, decrease of power consumption, reduction of EMI problem and total cost reduction in system, etc.

Bluetooth is a standard technology for wireless connectivity of mobile computers, mobile phones, portable handheld devices and providing internet connectivity. It is based on a low-cost, low power, short-range radio link which cuts the cords used to tie up digital devices and therefore become the fast adopted technology in industry.

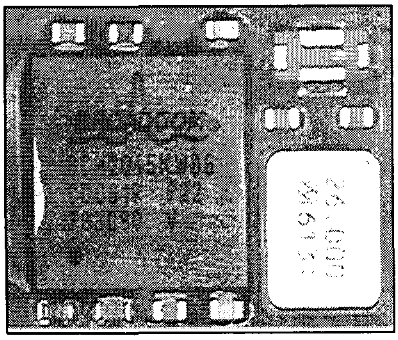
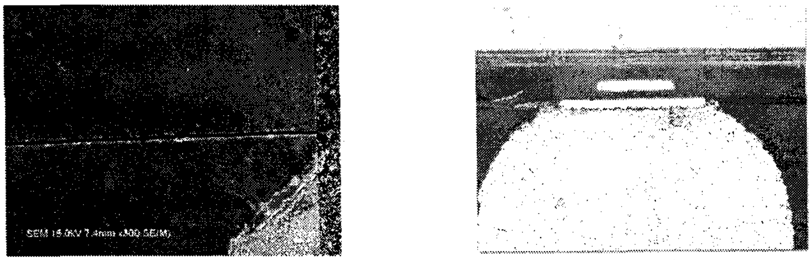


Figure 1 A system in package for a bluetooth module



(a)

(b)

Figure 2 Failure modes of a system in package: (a) Die broken (b) Interface delamination

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The system in package contains many components as shown in Fig.1. During the manufacturing process of the system in package, it has become susceptible to defects and internal residual stresses as dies, components, electric functionality and geometric complexity have increased. The mismatch of thermal expansion coefficient (CTE) among packaging materials and devices may lead to various failure modes during manufacturing processes, such as die broken, solder crack, substrate interface delamination. Fig.2 shows two typical failure modes of the bluetooth system in package during reflow process. Die broken is mainly caused by the stress concentration of the principle stress in the die while the interface delamination is due to the overloading of shear stress on the interface among die, substrate, undefill and EMC. Various studies of the effect of underfill on the reliability of package have been performed [1-9]. However, limited studies have been found for the system in package.

The thermo-mechanical behaviors of a system in package for a bluetooth module have been investigated during reflow process. The finite element method (FEM) is used for the simulation analysis. The maximum principle stress in the die, the maximum shear stress on the interface among the die, substrate, undefill and EMC and the warpage of the SiP package are considered. The effects of the material properties of underfill, such as CTE and Young's modulus, on the reliability issues are investigated.

FEM Model

2D plane strain finite element model for the bluetooth SiP is constructed as shown in Fig.2., which is composed of a silicon die, EMC, underfill, solder bumps and substrate. The thermo-mechanical analysis is carried out using ABAQUS v6.6 [10].

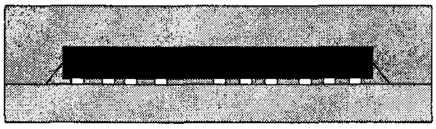


Figure 3 Geometry structure of Bluetooth package

The elastic material properties for the die, EMC, solder and substrate are given in Table.1. The temperature-dependent Young's modulus of underfill is considered. Only the value of Young's modulus at 25°C is shown in Table 1.

Table 1 Material properties of bluetooth system in package

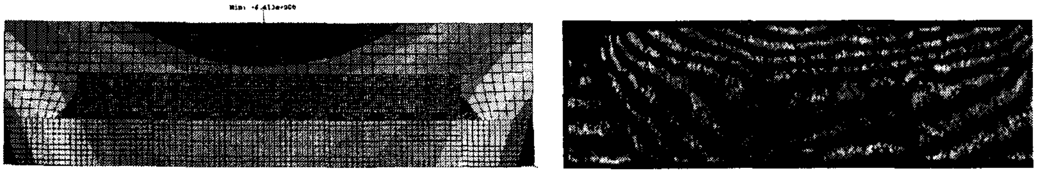
Material Name	Young's Modulus (GPa)	CTE (ppm/°C)	Poisson's ratio	Tg (°C)
Die (Silicon)	130	2.6	0.27	
EMC	26 (<Tg)	8	0.25	143
	0.38 (>Tg)	30		
Underfill	7.8 (25 °C)	32	0.33	137
		100		
Substrate (FR4)	23.3	13.5	0.17	
Solder (SnAg)	56	20.04	0.35	

The peak temperature of reflow process is 245°C. The stress-free temperature for the SiP package is assumed to be the peak temperature of reflow process. After the reflow, the package is cooled to room temperature. This study focuses on the thermo-mechanical behaviors of the SiP package after the cooling.

Results and Discussion

Model Verification

The present FEM model has been verified before it can be applied for the further analysis. Te warpage of the SiP package after cooling to room temperature were obtained from FEM simulation and Moiré experiment, respectively. As shown in Fig. 4, the simulation results are quite comparable to the experimental observations, e.g. the warpage direction shape and the fringe pattern. Therefore, the simulation results match well with the experimental ones and the model is reliable to be used in the parametric study.



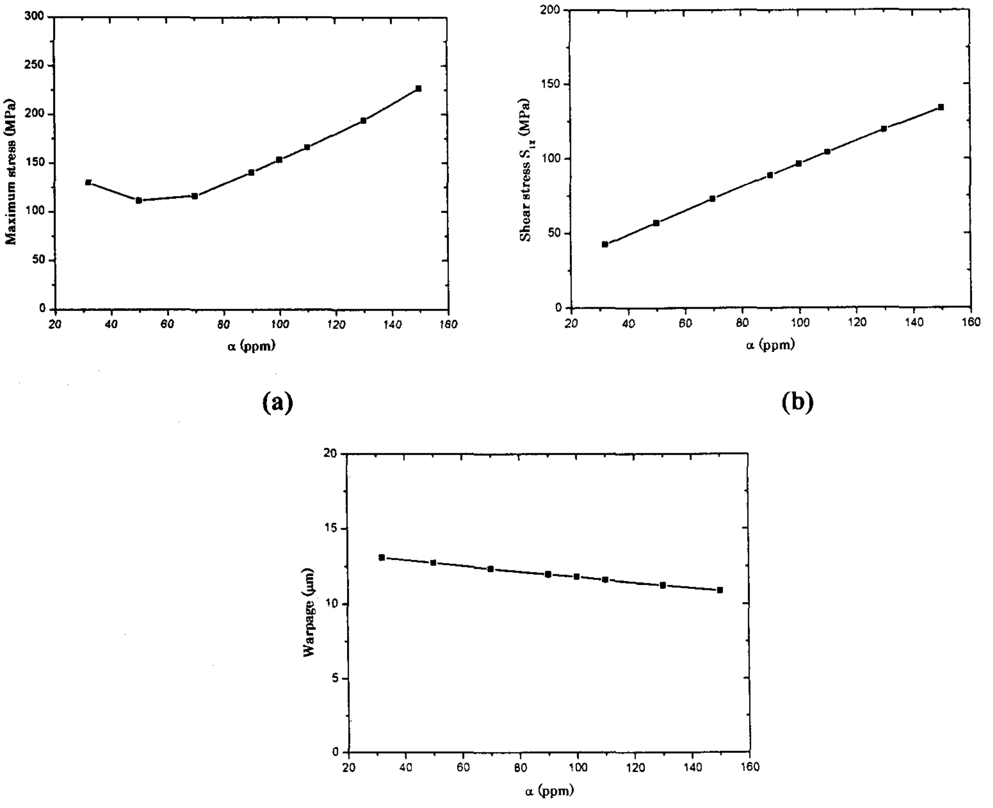
(a) **(b)**

Figure 4 Warpage distribution of bluetooth package after reflow process: (a) FEM simulation result (b) shadow Moiré observation

The effects of the material properties of underfill have been investigated in this analysis. These values are artificially varied to analyze the warpage and stress trends compared with the current material groups used.

Effect of CTE

Fig.4 shows the effects of underfill CTE on the reliability of the Bluetooth SiP package with (a) the maximum principle stress (MPS) in the die versus CTE, (b) the maximum shear stresses (MSS) on the interface Vs CTE and (c) the maximum warpage versus CTE. When CTE of underfill is higher than 50ppm/K, the maximum principle stress in the die increases with increase of CTE, while the maximum shear stress on the substrate and warpage decrease. The maximum principle stress in the die increases with decrease of CTE when underfill CTE is lower than 50ppm/K. The minimum MPS is achieved when underfill CTE is 50 ppm/K.



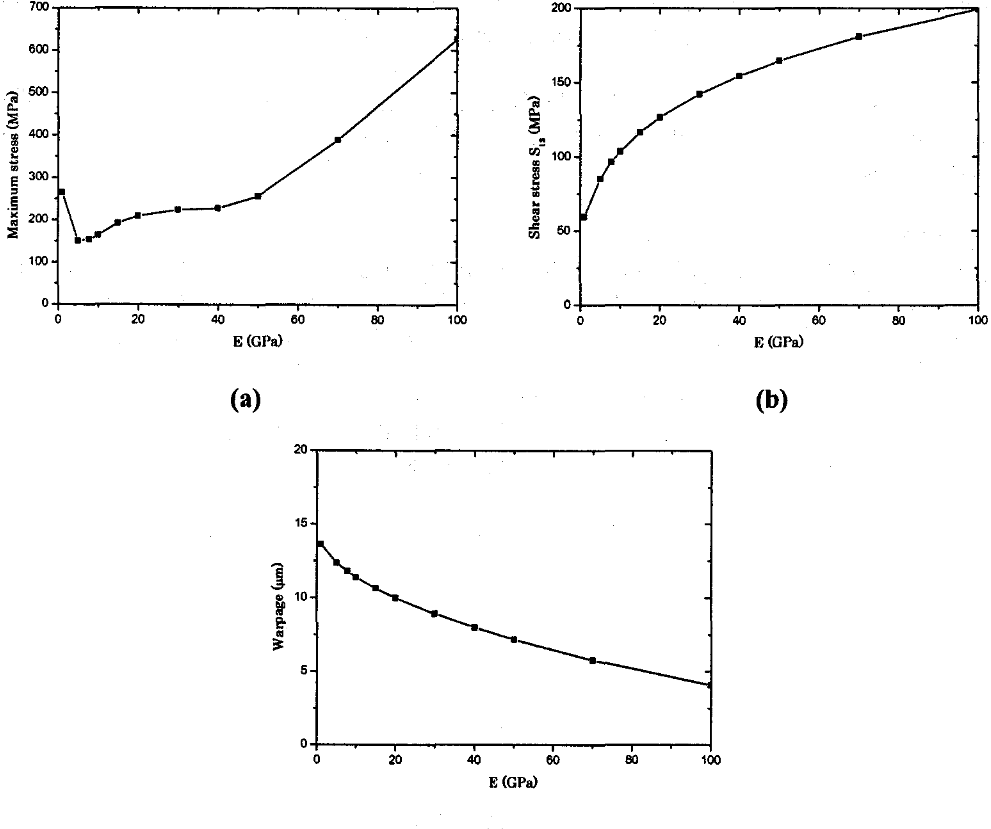
(a) **(b)**

(c)

Figure 4 Relationship between the CTE of underfill and the reliability of the SiP package: (a) MPS in the die, (b) MSS on the interface, (c) Maximum warpage of package

Effect of Young's modulus

Fig.5 shows the effects of underfill Young's modulus on the reliability of the Bluetooth package with (a) MPS in the die Vs Young's modulus, (b) MSS on the interface Vs Young's modulus and (c) maximum warpage Vs Young's modulus. Both MPS and MSS increase with increase of underfill Young's modulus when Young's modulus is above 5GPa. MPS in the die increases with decrease of underfill Young's modulus. The minimum MPS in the die is achieved when underfill Young's modulus is 5 GPa. Warpage of package decreases monotonically with increase of Young's modulus.



(a) (b)

(c)

Figure 5 Relationship between the Young's modulus of underfill and the reliability of the package: (a) MPS in the die (b) MSS on the interface (c) maximum warpage of package

The material properties used in this FEM analysis are elastic. This assumption may not be accurate for underfill and solder, which are visco-elastic and visco-plastic material at high temperatures respectively. In addition, the passive components, such as capacitor, crystal, resistor, etc., are not considered in this study which may cause the inaccuracy too. These are reflected by the comparison between the simulated warpage 12.4μm and the experimental results 8.8μm. Hence, in order to analyze the reliability of package more accurately, more complicated material property model should be used in the FEM simulation.

Conclusions

Thermal stress and warpage arise in the Bluetooth package during the cooling after reflow process due to the CTE mismatch between the components of the package. Failures of the SiP package are mainly caused by the stress concentration in the die and on the substrate interface or the over values of warpage of the package. The Young's modulus and CTE of underfill material have affected significantly the maximum stress as well as the maximum warpage of the SiP package.

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