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ScienceDirect

Procedia Engineering 168 (2016) 1613 – 1616

Procedia Engineering

www.elsevier.com/locate/procedia

30th Eurosensors Conference, EUROSENSORS 2016

The effect of reflow process on the physical properties of die attach adhesives

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Abstract

Suitable selection of packaging materials is critical for microelectromechanical system (MEMS) devices to maintain their performance and to provide physical protection, mainly to the electrical connections. Several different materials can be used in MEMS packaging and different properties are required from these materials. Temperature can markedly influence the properties of polymer materials used in the packaging of MEMS devices, which may critically affect their performance. For die attach adhesives (DAA) the mechanical moduli of the material are typically key properties to ensure their compatibility with different MEMS components. Another critical parameter is the coefficient of thermal expansion (CTE). It is common that the temperature changes during the assembly and use of MEMS components, which can easily lead to thermo-mechanical stresses in the packages and thereby to failures. The main sources of these stresses are the mismatches between the CTEs of different materials and the unsuitable mechanical properties of materials. In addition to the mechanical properties, the electrical properties of the DAAs are critical for the functionality of MEMS devices. They may also be easily changed due to temperature. Consequently, it is essential to investigate the stability of both mechanical and electrical properties of DAAs at various environments. In this study, the effect of the high temperature during a reflow process on the properties of two DAAs was investigated.

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Keywords: MEMS; Die attach adhesive; reflow; packaging;polymer; materials characterization

1. Introduction

Polymer materials are used increasingly in microelectromechanical system (MEMS) sensor packages. At high temperatures these materials may cause reliability problems, as their properties may change. Reasons for failures and issues involved in the reliability of MEMS are widely discussed in [1]. The failure mechanisms can be categorized to thermomechanical, electrical and environmental failures [2]. The thermomechanical failures are commonly caused by temperature changes which cause thermomechanical stresses due to the mismatch between the coefficient of thermal

Peer-review under responsibility of the organizing committee of the 30th Eurosensors Conference
doi:10.1016/j.proeng.2016.11.473

expansion (CTE) values of the materials. These stresses may result in signal variations which can be critical to the functionality of a device [3]. In addition to the temperature changes in use conditions of a MEMS device, the changes during its assembly of cause often problems. Especially with polymer materials the stresses caused by the temperature changes can be critical due to the great CTE values of polymers and their tendency to deform at high temperatures. It is also important to notice, that the high temperatures used in the assembly affect also the curing degrees of the polymer materials. If polymer material cures further, it may considerably affect its mechanical, thermal and electrical properties. One of the problems caused by the CTE differences is the bending of the whole package which in return may cause variation in the behavior of the devices or failures [4].

Many polymer materials are used in MEMs structures. One of the key factors for stress-free packaging are die attach adhesives (DAA) which bond the MEMS chip onto the substrate [10]. They are commonly used as thin films and it is vital that they have enough flexibility not to cause thermal stresses to the MEMS components. If DAA is not suitable for the device or the environmental conditions it is used in, high stresses may form in the structure and it is warped. It has been reported that high stresses in MEMS structures have led to warpage of the MEMS components, resulting in alternation of the output signal of piezo-resistive or capacitive components in the sensor [5-9]. Choosing the component materials with the desired physical characteristics is the key to minimalize the stress caused by them [10,11]. However, in order to understand the behavior of the DAA materials in various processing conditions it is critical to carefully study their properties in different conditions.

The aim of this study was to study how the properties of two DAAs used in MEMS packaging change at high temperature exposure. It is common in electronics that components are exposed to several reflow soldering processes during their manufacturing and therefore, a reflow soldering profile was used for the temperature aging. Test samples of neat DAA were exposed to three reflow cycles. The mechanical, thermomechanical and electrical properties of the two DAAs were characterized before and after the reflow aging.

2. Materials and characterization

2.1. Materials

Two commercial DAA materials were studied. The ester resin of the first DAA (Resin DAA) was designed for high throughput die attach applications and to minimize stress and warpage. The second DAA (silicon DAA) was silicon based adhesive with a low-Tg (-125°C). This DAA was designed to deliver suitable stress relief and high-temperature stability. The DAAs were cured according to the curing profiles suggested by their manufactures. To study the effect of the reflow process, a part of the cured samples was exposed to three reflow cycles The reflow was conducted according to IPC/JEDEC reflow profile standard J-STD-020D.1 for lead-free soldering.

2.2. Materials characterization

2.2.1. Thermomechanical measurements

CTEs and glass transition temperature (Tg) values of the samples were measured using a thermomechanical analysis (TMA) equipment (Q-400, TA Instruments). A quartz macroexpansion probe was used. To ensure a good contact between the probe and the samples a force of 0.02 N was used. The dimension change of the specimen was recorded as a displacement of the TMA linear variable differential transformer (LVDT) system. One to three samples were used for each test series and the change was recorded two times in the temperature range of -50–270°C for each sample. Each sample was initially equilibrated at -50°C by liquid nitrogen, and then ramped up to 270°C with a heating rate of 10°C/min. After heating, the sample was rapidly cooled down again to -50°C and the cycle was repeated a second time. The first TMA run was performed to study the properties with the thermal history of the samples and the second heating run was used to study the samples without its thermal history. This data was used to extract both CTE and Tg values.

The CTE was obtained by calculating the slope of the temperature-dimension curve for the second heating. A significant increase in the CTE indicated the Tg range of the material. The Tg was obtained by extrapolating the slopes of the TMA curves before (α_1) and after (α_2) the Tg and calculating their intersection. The results were analyzed using Universal Analysis software. Additionally, changes in the mechanical moduli of the materials were measured by dynamic thermomechanical analysis (DMA) (Diamond Pyris, Perkin-Elmer). A same temperature range as TMA measurements was used for the DMA measurements. A tension probe was used for the bar shaped samples. The frequency of force application during the measurements was 10Hz.

2.2.2. Dielectric constant measurements

The changes in electrical properties of the DAAs were also measured. this was conducted using a dielectric analyzer equipment (Alpha analyzer, Novocontrol). Frequency sweeps between 1kHz-1MHz at temperatures of -40°C, 23°C and 125°C were used. To do the measurements 20mm-diameter 0.5mm-thick samples were sandwiched between the electrodes of the apparatus.

3. Results and discussion

3.1. TMA measurements

The results of the TMA measurements are shown in Fig. 1a. They showed relatively small alternations in the CTE values of the DAAs after the exposure to the reflow process. The CTEs, α_1 and α_2, of Resin DAA decreased between 6-13% after reflow. On the other hand, the T_g value of Resin DAA increased 77% which indicated that further curing had occurred in the material, even though the changes in the CTE values were small. The Tg of Silicon DAA was below the typical use temperature of this material and also below the measurement range used in this study. Therefore, Tg or α_1 were not measured for this DAA. The α_2 value of Silicon DAA slightly increased after the reflow exposure.

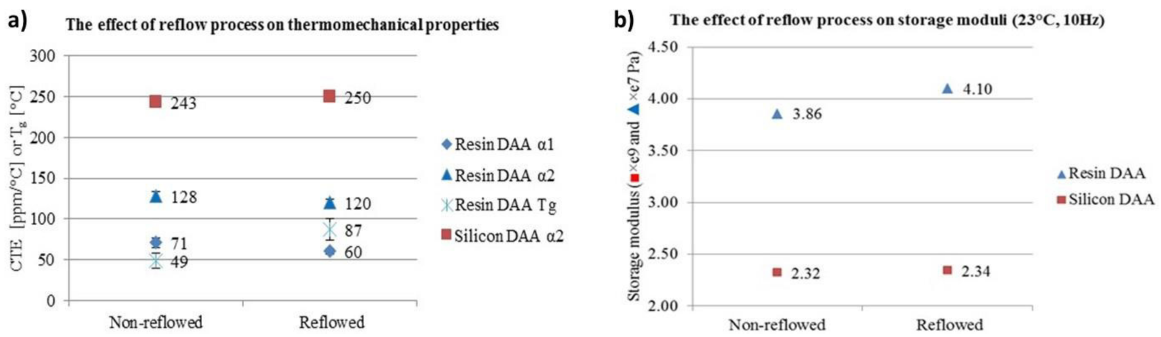

Figure 1a) The mean values of the TMA measurements. b) The mechanical moduli of the DAAs measured by the DMA

3.2. DMA measurements

The results of the DMA measurements are shown in Fig. 1b. The results showed a 6% increase in the storage modulus of the reflowed Resin DAA. This was most likely due to further curing of the material, which was also indicated by the increase of its Tg value. Silicon DAA remained stable after the reflow condition and no marked changes were seen in its value.

3.3. Dielectric constant measurements

The results of the dielectric constant measurements are shown in Fig. 2. A clear change was seen for Silicon DAA. The reflow process markedly decreased its dielectric constant especially at the lower temperatures. This indicated that some morphological changes occurred in this material during the reflow aging, even though its other parameters remained fairly stable. The effect of the reflow aging on the dielectric constant of Resin DAA was a lot less, although its other parameters indicated that it had cured further during the reflow aging. On basis of the results it seemed that the curing degree did not affect the dielectric properties of this DAA considerably.

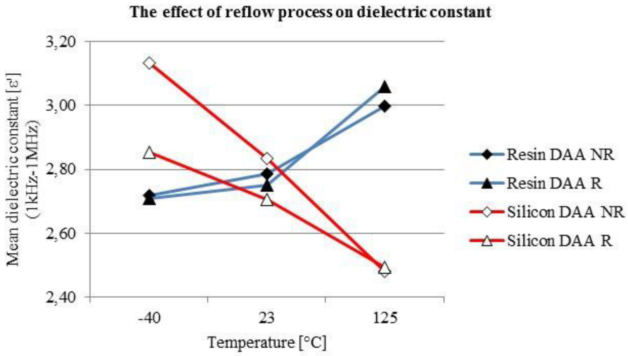

Figure 2 Reflow process alters the dielectric constant values of DAAs (R: reflowed, NR: non-reflowed)

4. Conclusions

The effect of a reflow process on the properties of two die attach adhesives (DAA) was studied. One material had an ester resin and the other one was silicon based. Thermomechanical analysis, dynamic thermomechanical analysis, and dielectric constant measurement of the samples were conducted to study the changes in their properties.

The silicon DAA remained thermomechanically stable after being exposed to the reflow process, however its dielectric constant was markedly affected by the reflow processes. On the other hand, the ester DAA was affected by the reflow process and its Tg value increased considerable. Additionally, its mechanical modulus increased. This was assumed to be caused by further curing of the material during the reflow process. On the other hand, the dielectric constant of the ester resin DAA was not affected by the reflow process indicating, that the curing degree might not critically affect the dielectric value for this material.

Acknowledgements

We would like to thank Tekes (The Finnish Funding Agency for Innovation) for its support of this work.

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