TSDC MEASUREMENTS OF UNDERFILL ENCAPSULANT USED IN MICROELECTRONIC PACKAGING

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Abstract
The thermal stimulated depolarization current (TSDC) technique was used to study the dielectric relaxation of underfill encapsulant used in microelectronic packaging. The dependence of electrical properties of the underfill on the polarizing temperature, polarizing field and heating rate were analyzed from the TSDC spectra as a function of temperature. A single α-relaxation peak associated with the glass transition temperature T_g of the underfill was observed. A value of Tg can be estimated which can be compared to the T_g determined by differential scanning calorimetry (DSC). The activation energy and relaxation time of the dielectric relaxation of the underfill were determined from the TSDC measurements.

Introduction

Underfill epoxy materials have been used extensively in microelectronic packaging applications [1 -4]. With the rapid development of semiconductor devices in terms of its miniaturization, I/O density and complex circuit design, the underfill epoxy plays a vital role in alleviating the problem of thermal expansion mismatch between a printed wiring board organic substrate, the IC chip and solder balls. The introduction of an underfill polymer will reinforce the physical and mechanical properties of the solder joints between the chips and the substrate and provide a drastic fatigue life enhancement.
Studies of the thermal and mechanical properties of the underfill are essential and have been carried out by means of differential scanning calorimetry (DSC), thermal mechanical analysis (TMA) and dynamic mechanical analysis (DMA) [1-4] whereas little related research in the study of depolarization relaxation with the thermally stimulated depolarization current (TSDC) technique has been reported. It is the purpose of this work to investigate the electrical depolarization and dielectric relaxation of an underfill epoxy.

Experiment

Preparation of underfill epoxy

The underfill epoxy (UF-6800) used in this study was supplied by 3M Hong Kong Limited. Its chemistry is that the epoxy is toughened type resin whereas its curative is polyamine . The specified quantity of epoxy resin and hardener (2:1) was mixed together with a cartridge nozzle. The mixture was cured at 150°C for 15 minutes. A batch of samples with a thickness of 150 μm and a diameter of 10 mm were made. Each sample was coated with aluminum on both sides as electrodes.

Experimental setup

The theory for measuring the thermally stimulated depolarization c urrent (TSDC) was established by Bucci and Fieschi [5,6]. The schematic diagram of TSDC measurement is given in Figure 1. Its experimental procedure is illustrated in Figure 2. Prior to the TSDC measurement, the sample mounted by two copper plates in a thermal chamber was first polarized by applying a d.c. voltage V_p at a temperature T_p for a fixed period of time (t_p=20 min). In the second step, the sample was cooled down to room temperature while the poling voltage applied to the sample was still kept on. After removal of the applied voltage, the sample was reheated at a constant heating rate β under short-circuit conditions and the corresponding discharge current was detected by an electrometer and recorded by a computer.

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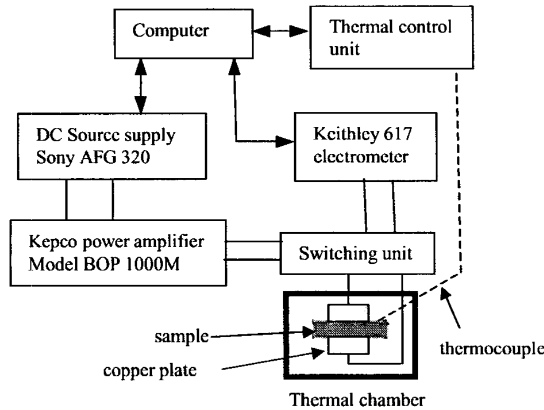

Figure 1. Schematic setup of the TSDC measurement.

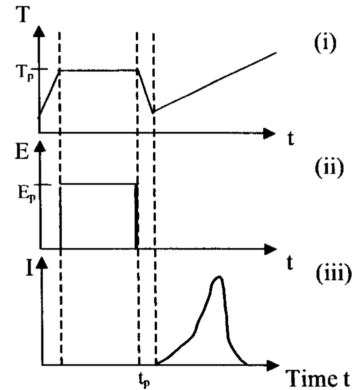

Figure 2. Procedure for the thermally stimulated discharge current measurement.

Results and discussion

From the TSDC spectra, with the temperature range between 25 °C and 140°C, as shown in Figure 3, four pieces of identical samples were polarized under a poling field, E_p= 10, 20, 40 and 60kV/cm, respectively, with the same poling temperature, T_p = 120°C. Each polarized sample was reheated with the same heating rate of 5°C/min throughout the measurement. A single α-relaxation peak was observed in each discharging current curves as shown in Figure 3. The occurrence of the peak represents the dielectric manifestation of macromolecular motions which occur when the amorphous epoxy is heated through its glass transition region [7]. There is no significant change in the position of the peak occurring at 90°C under different poling fields whereas the peak amplitude increases linearly with the increase in the poling field.

Two identical samples with the same poling field (E_p = 40kV/cm) and poling temperature (T_p = 120°C) were reheated at 1, 5,10 and 15 °C/min respectively, to obtain the TSDC curves as shown in Figure 4. Increases in amplitude and peak temperature were observed when the heating rate increases . The reason is that the initial polarization has to be released in a shorter time while the dielectric responds less quickly, resulting in the increase of the peaks and the shifts to higher temperature [8]. With a TSDC curve at a low heating rate of 1 °C/min, its α-relaxation peak temperature T_m can be considered as a corresponding glass transition temperature T_g of the underfill [9]. So, the T_g value was found to be 74.9°C which is quite closed with the value (T_g = 72.8°C) determined by a DSC single heating-scanning measurement.

The activation energy E and relaxation time τ_0 were estimated from the TSDC curves with different heating rate (Figure 4) according to the Bucci-Fieschi theory as follows [5]:

In the case of a single relaxation process obeying the Arrhenius equation [5]

$$\tau(T) = \tau_0 \exp(E / kT) \tag{1}$$

the discharge current density J(T) is given by the equation [5]

$$J(T) = (P_0 / \tau_0) \exp(-E / kT) \cdot \exp[-(\beta \cdot \tau_0)^{-1} \int_{T_0}^{T} \exp(-E / kT) dT] \tag{2}$$

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Where P_0 is the initial polarization, τ_0 is the relaxation time of dipole polarization at infinite temperature (s), τ is relaxation time of the dipole polarization, β is the heating rate (K/s), E is the activation energy of dipole orientation or disorientation (eV), T is the absolute temperature (K) and k is Boltzmann's constant [1.3807×10^{-23} (J/K)]. By differentiating (2), we get

$$T_m = [(E/k)\cdot\beta\cdot\tau_0\cdot\exp(E/kT_m)]^{1/2} \qquad (3)$$

Where T_m is the maximum peak temperature. In case of changing β to measure the variety of maximum peak temperature T_m of the TSDC curves, the relation between $\ln(T_m^2/\beta)$ and $1/T_m$ is plotted as shown in Figure 5. The activation energy E and the relaxation time τ_0 are thus obtained from its gradient and the Y-intercept are E=0.70eV (67kJ/mol) and $\tau_0=8.78\times10^{-10}$ s.

Figure 6 displays the comparison of TSDC spectra for samples polarized by the same poling field of 40 kV/cm at different poling temperature with a subsequent heating rate of 5°C/min. It was found that the α-peak shifted to higher temperature as the poling temperature increased.

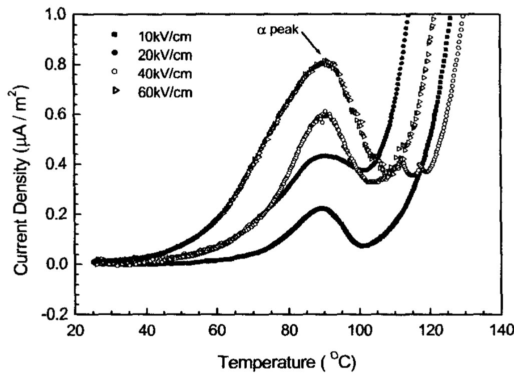

Figure 3. TSDC spectra of epoxy under different poling field.

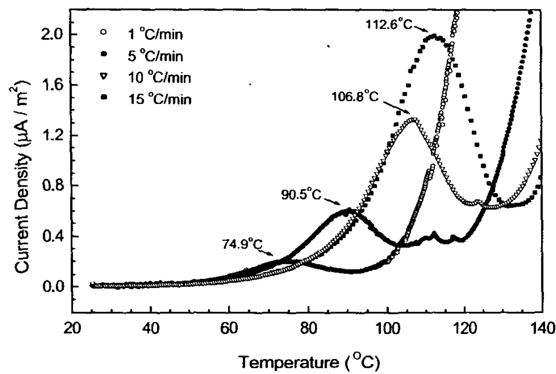

Figure 4. TSDC spectra of epoxy under different heating rate.

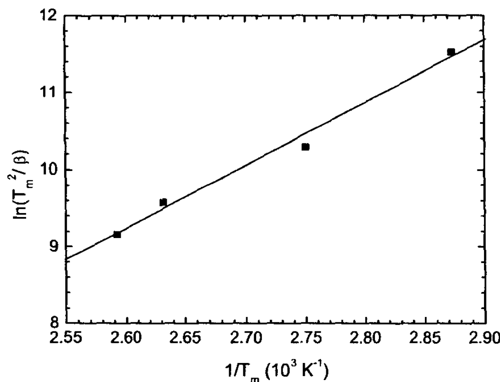

Figure 5. Plot of $\ln(T_m^2/\beta)$ against $1/T_m$ obtained from TSDC spectra.

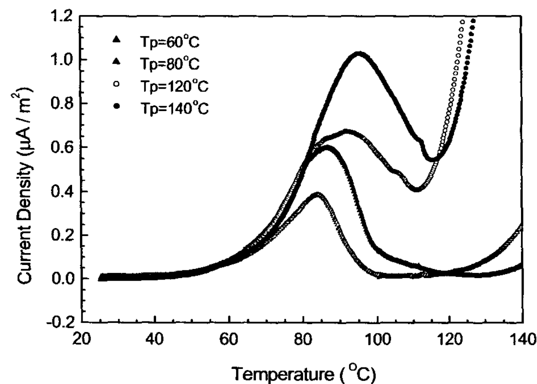

Figure 6. TSDC spectra of epoxy with different poling temperatures.

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Conclusions

The TSDC technique was applied to study the dielectric relaxation of the underfill ep oxy. Single α-relaxation peak associated with the glass transition temperature T_g appeared at 90°C due to the dielectric manifestation of the macromolecular motions in the epoxy which occur near its glass transition region.

The location of relaxation peak was greatly affected by the heating rate and the poling temperature but does not change with the strength of the poling field. The activation energy and relaxation time were estimated from the TSDC spectra. The peak temperature corresponding to the glass t ransition temperature determined at a lower heating rate was comparable with the value measured by the DSC.

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References

[1] C. P. Wong, S.H. Shi and G. Jefferson, *IEEE Trans. Comp., Packag., Manufact. Technol.* **21** (1998) 450.
[2] L. Wang and C.P. Wong, *IEEE Trans. On Advan. Packag.* **22** (1999) 46.
[3] D. Suryanarayana, T.Y. Wu and J.A. Varcoe, *IEEE Trans. Comp., Hybrids, Manufact. Technol.* **16** (1993) 858.
[4] C.P. Wong, Y. Rao and J. Qu, *Int. Symp. Advan. Packag. Mat.* (1998) 73.
[5] C. Bucci and R. Fieschi, *Phys. Rev. Lett.* **12** (1964) 16.
[6] C. Bucci and R. Fieschi, *Phys. Rev.* Lett. **148** (1966) 816.
[7] J. Bayard, E. Dargent and J. Grenet, *IEEE Proc.-Sci. Meas. Technol.* **145** (1998) 53.
[8] J. Vanderschueren and J. Gasiot, *Thermally Stimulated Relaxation in Solidss,* Springer-Verlag, NewYork, 1979, Ch.4.
[9] P.K.C. Pillai, P.K. Nair and Rabinder Nath, *Polymer* **17** (1976) 921.

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