Application of BPDA/PDA Polyimide Films in Multi-chip Modules (MCM)

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Polyimides are widely used as dielectrics in high density multi-chip module (MCM) wiring systems in order to adjust the thermal expansion between LSI chips and substrates. In these MCMs, Copper is commonly used for vias which interconnects different layers. In these structures, there are some drawbacks which adversely affect the multi-layer wiring system. Among them, a major problem is that in order to get a high wiring density, a large number of vias with a very small via diameter have to be created. However, if there are large number of vias, due to the Z-directional thermal expansion mismatch of Cu and the dielectric, stress concentrated around vias leading to fracture and crack formation in the dielectric. Therefore, in this paper, in order to find a promising dielectric material, to the utilized in MCMs, the Z-directional coefficient of thermal expansion (CTE) of polyimide films prepared with different processing conditions was investigated. The Z-directional CTE of the films was measured by the laser interferometric technique.

Keywords: polyimide, thickness-directional, CTE

1. Introduction

Polyimides are widely used in MCMs because of their high thermal stability, chemical inertness, and low dielectric constant [1]. When a polyimide film is applied in a multi-layer wiring MCM, thermal stress is generated during thermal cycling (from rt to curing temperature) of the stacking process. In MCMs, various inorganic materials such as metals (Cr, Cu and Ti), ceramic substrates, and Si-chips are used together with the dielectric. The thermal expansion mismatch of these materials generates thermal stresses at the interfaces, which leads to delamination and crack formation of the dielectric material. In practice, polyimides having the X-Y thermal expansion [2-5] comparable to that of Si and ceramic are generally used in MCMs. Currently, there is a high demand for high density wiring structures in MCMs. In order to fulfill this requirement, a large number of vias with a very small via diameter have to be created in the MCM structure. However, if a large number of vias are created, a major failure would occur during the cure cycle of the polyimide due to the Z-directional CTE mismatch between Cu and the polyimide. It is generally accepted that the Z-directional CTE of the polyimides depends on the curing history of the polymers. However, no research work in this field has been reported, so far, in the literature. Therefore, in this study, the effect of the curing condition of BPDA/PDA polyimide films on the Z-directional CTE was investigated.
2. EXPERIMENTAL SECTION

2.1. Film preparation

The structure of the polyimide used in this study is shown in Fig. 1.

![Molecular structure of polyimide](image)

Fig. 1. The molecular structure of the polyimide used in this study; (a) Polyamic acid (PPA), (b) Polyimide (PI).

The poly(amic acid) solution was spin-coated onto silicon wafers of 150 mm in diameter. The film prebaking was performed at 80 °C for 30 min, followed by four different curing methods as follows: 1) 150 °C/60 min and 350 °C/30 min, 2) 150 °C/60 min and 375 °C/30 min, 3) 150 °C/60 min and 400 °C/30 min, 4) 375 °C/30 min, in a nitrogen atmosphere. After the complete imidization, the average film thickness was about 10 µm.

2.2. Principles behind the laser interferometric technique.

The Z-directional thermal expansion of the polyimide films was measured by the laser interferometric technique [6]. In this technique, the polyimide film was sandwiched between two reflective mirrors (Fig. 2).

![Laser interferometer apparatus](image)

Fig. 2. The laser interferometer apparatus.

The Laser beam was shot to two reflection mirrors, which sandwiched the polyimide, and was reflected multiplicity. The interferential stripe was formed by the phase due to the difference of light-path lengths, when the multi-reflected beam is interfered. This interferential stripe was shifted by following the displacement ΔL, that is the changing difference of light-path lengths at a given temperature. Therefore, the extent of the shift of interferential at stripe N(T) was precisely measured. As a result, ΔL(T) - the change of sample length at a given temperature - can be obtained from the equation given below.

\[ \Delta L(T) = \frac{\lambda}{4} \times N(T) \]

Where \( \lambda \) is the laser wavelength (632 nm). The standard temperature (Ts) was set in the thermal expansion (\( \Delta L / L_0 \)) curve, and the average CTE, \( \alpha \), was calculated from Ts to Ta in the curve, using the following expression.

\[ \alpha = \frac{1}{L_0} \times \frac{\Delta L}{(T_a - T_s)} \]

3. RESULTS AND DISCUSSION

3.1. The effect of curing temperature on the Z-directional CTE of polyimide

The average Z-directional CTE (the measuring temperature ranges from rt to curing temperature) of the polyimide films cured with different conditions are depicted in Fig. 3. As can be seen from this figure, a drastic change in the Z-directional CTE was observed with the
temperature. This behavior may be due to some changes in the molecular interactions and some cross-linkings which change the packing density of the dielectric. The average Z-directional CTEs, measured at 350 °C, of the polyimide films prepared by curing at 350, 375, and 400 °C were found to be 130, 100 and 150 ppm, respectively.

The Z-directional CTE of the polyimide film cured at 375 °C was found to be smaller than that of the other temperatures.

3.2. The effect of step-cure on the Z-directional CTE of the polyimide films

The Z-directional CTEs of polyimide films cured at 150 °C for 30 min followed by at 375 °C for 30 min as well as at 375 °C for 30 min are given in Fig. 4. From this figure, it is understood that the Z-directional CTE of the polyimide film cured at 375 °C for 30 min was nearly constant with the temperature, and was smaller than that of the films cured at 150 °C for 60 min and at 375 °C for 30 min, especially in the high temperature region.

The Z-directional CTE of the polyimide film cured without step-cure at 150 °C for 60 min was found to be 70 ppm. Whereas, the Z-directional CTE of the film cured with the step-cure process followed by curing at 400 °C was found to be 100 ppm.

3.3. The effect of heating rate on the Z-directional CTE of the polyimide films

The Z-directional CTE of the polyimide films cured at a heating rate of 2 °C/min and 4 °C/min are shown in Fig. 5. Here, the films were not pre-baked and the final curing temperature was set for 350 °C. In these cases, the Z-directional CTEs
were found to be approximately 140 ppm.

4. Conclusion

The Z-directional CTE of a polyimide film is a very important property when this film is to be used in a high density multi-layer wiring system. It was found that the Z-directional CTE of the PBDA/PDA polyimide films depends on the curing conditions. We believe that the molecular packings as well as molecular interaction are responsible for this behavior. Among the curing conditions investigated in this study, the least Z-directional CTE has been observed with the polyimide films prepared by direct curing at 375 °C/60 min, without step-curing. Also, with these polyimide films, defect free high performance multi-layer MCMs have been fabricated.

References