반도체 봉지용 고충진 AlN/Epoxy 복합재료

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Highly filled AlN/epoxy composites for microelectronic encapsulation

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KEY WORDS : AlN filled EMC, thermal conductivity, binary mixture, maximum packing fraction, CTE

ABSTRACT

Increased temperature adversely affects the reliability of a device. So, package material should have high thermal diffusion, i.e., high thermal conductivity. And, there are several other physical properties of polymeric materials that are important to microelectronics packaging, some of which are a low dielectric constant, a low coefficient of thermal expansion (CTE), and a high flexural strength. In this study, to get practical maximum packing fraction of AlN (granular type) filled EMC, the properties such as the spiral flow, thermal conductivity, CTE, and water resistance of AlN-filled EMC (65-vol%) were evaluated according to the size of AlN and the filler-size distribution. Also, physical properties of AlN filled EMC above 65-vol% were evaluated according to increasing AlN content at the point of maximum packing fraction (highly loading condition). The high loading conditions of EMC were set $D_L/D_S=12$ and $X_S=0.25$ like as filler of sphere shape and the AlN filled EMC in this conditions can be obtained satisfactory fluidity up to 70-vol%. As a result, the AlN filled EMC (70-vol%) at high loading condition showed improved thermal conductivity (about 6 W/m-K), dielectric constant (2.0~3.0), CTE(less than 14 ppm/ °C) and water resistance. So, the AlN filled EMC (70-vol%) at high loading condition meets the requirement for advanced microelectronic packaging materials.

기호설명

Φ_m : the maximum packing fraction that can be achieved by the ideal filler-size distribution

K_e : the Einstein coefficient.

1. Introduction

Recently, package density is increasing for performance improvement and cost reduction. But, as package density increases, the electrical energy consumed in a device ultimately appears as heat, elevating the temperature of the active junction and other parts of the package housing of device. Increased temperature adversely affects the reliability of a device [1]. So, package material should have high thermal diffusion, i.e., high thermal conductivity. And, there are several other physical properties of polymeric materials that are important to microelectronics packaging, some of which are a low dielectric constant, a low coefficient of thermal expansion (CTE), and a high flexural strength [2].

Generally, epoxy molding compounds (EMC) consists of components such as epoxy resin, a hardener, and an inorganic filler, etc. Thermal conductivity of a plastic package strongly depends on the property of the filler used. Thermal conductivity of filler is very high when compared to that of an epoxy resin that has low atomic density. But, the thermal conductivity of a compound filled with filler is not as high as the filler itself.

To more effectively solve the thermal dissipation

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problem, the use of highly thermal conductive ceramic fillers (listed in Table I) can be considered.

[Table 1]

The review papers [3] show that AlN filled EMC, which compared with any other filler such as silica and alumina, showed excellent thermal conduction and physical properties for advanced microelectronic encapsulation material. But, unfortunately, AlN filled EMC cannot be highly filled above 65 vol% differently like silica filled EMC, because AlN have higher porosity and specific surface area. Therefore, for higher filler loading by filler-size distribution to improve fluidity of EMC, the two-parameter Mooney equation (Equation1) can be applied to predict the viscosity of the filled system [2].

$$\ln \frac{\eta}{\eta_0} = \frac{K_e}{1 - \dfrac{\Phi}{\Phi_m}} \quad (1)$$

The highest loading is achieved with a combination of filler shapes or sizes so that the interstitial spaces are filled. The Mooney equation describes the nonlinear behavior of the viscosity increase as the filler loading approaches the maximum packing fraction. It can be expected that the viscosity of compounds will be lower as the maximum packing fraction of the Mooney equation is increased [4].

In this study, to get practical maximum packing fraction of AlN (granular type) filled EMC, the properties such as the spiral flow, thermal conductivity, CTE, and water resistance of AlN-filled EMC (65-vol%) were evaluated according to the size of AlN and the filler-size distribution. Also, physical properties of AlN filled EMC above 65-vol% were evaluated according to increasing AlN content at the point of maximum packing fraction (highly loading condition).

2. EXPERIMENT

Raw materials & the manufacturing process

Cresol novolac epoxy/ phenol curing systems were used as epoxy resin system. Also, a coupling agent, an accelerator, and natural wax were used as additives. Si-O layer coated aluminum nitride (supplied by ART Co. U.S.A., having the average particle sizes of 2, 13, and 23 microns) was used as the filler.

A two-roll mill, which can support high torque, was chosen as a mixer in consideration of the high viscosity of a filled EMC (with over 50-vol.% of filler). A aluminum nitride-filled master batch was mixed at the roll surface temperature of about 90℃ for a proper dispersion time of 10 minutes to lower the degree of curing to the minimum. After that, the melt mixed EMC was cooled and crashed into granules. A disc-shaped EMC (which was made from preheated granules) was forced to flow into a heated cavity by a transfer molding machine with the pressure of 75 kg_f/cm^2, and after that, it was molded at 175℃ for 2.5 minutes. The molded EMC was post-cured at 175°C for four hours.

Physical properties

Spiral flow

A spiral flow test is extensively used by IC manufacturers to check the fluidity of thermosetting molding compounds, and all material vendors report the data [3]. This test consists of loading the molding compound into the heated transfer pot of the press and transferring it through a spiral coil with a semicircular cross section until the flow ceases. According to the test procedure (ASTM D3123), the recommended pressure and temperature are 110kg_f/cm^2 on the material and 150℃ for the mold. But, in this study, the test was carried out at 75kg_f/cm^2 and 175℃.

Thermal conductivity

There are various equations including volume fraction, to estimate the thermal conductivity of composite materials. But, no equation can actually predict the thermal conductivity of complicated composite materials because predicting thermal conductivity depends on many factors, not just volume fraction. These equations are only useful in estimating thermal conductivity; accurate thermal conductivity should be measured by experimental measurements.

The measurement of thermal diffusivity was carried out by a laser flash method (Sinku-Riko Co. Model TC-7000) at room temperature. Specific heat (C) was measured by a DSC (Perkin-Elmer Co, Pyris I). Also, density of specimen was measured by water displacement. After that, thermal conductivity (k) was calculated by below equation:

$$k = C \times \rho \times \delta$$

Coefficient of thermal expansion

The coefficient of thermal expansion (CTE) of the composite was measured by using a bar-shaped specimen in a linear dilatometer (ANTER Co.) with a heating rate of 5℃/min. from room temperature up to 250℃.

Dielectric properties

The dielectric properties of the composites material was measured by using a disc-shaped specimen

(10Φx2mm) with a LF Impedance Analyzer (Hewlett Packard, model HP 4192A, testing frequency: 1MHz) at room temperature. The sample was coated on both sides of the cross-sectional surface with a silver paste to let the electricity flow well on the surface.

Water resistance

The surface of the sample (40Φx4mm) was polished with sandpaper before immersing it in water at 85℃ for 7 days. To measure the degree of water resistance, the surface of the immersed sample was fully dried by wiping the moisture with dried cloth, and after that, the weight change of the sample was measured every 24 hours.

3. Conclusions

1. EMC filled with large-size AlN particles (65-vol.%) showed superior properties in fluidity, thermal conductivity, and water resistance. But, EMC filled with small-size AlN showed good properties in dielectric constant, CTE. A binary mixture of an AlN-filled (65-vol.%) EMC showed improved fluidity, thermal conductivity, dielectric constant and water resistance (compared to EMC filled with single size particles AlN). Maximum improvement was obtained when the fraction of small particles in the binary mixture of AlN is 0.2 ~ 0.3. The CTE of EMC was decreased by increasing the volume fraction of small particles in the binary mixture of AlNs.

2. According to conclusions 1., high loading conditions were set $D_L/D_S=12$ and $X_S=0.25$ like as filler of sphere shape and the AlN filled EMC in this conditions can be obtained satisfactory fluidity up to 70-vol%. As a result, the AlN filled EMC (70-vol%) at high loading condition showed improved thermal conductivity (about 6 W/m-K), dielectric constant (2.0~3.0), CTE(less than 14 ppm/ °C) and water resistance. So, the AlN filled EMC (70-vol%) at high loading condition meets the requirement for advanced microelectronic packaging materials.

후 기

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참고문헌

(1) J. H. Lupinski, in "Polymer Materials for Electronics Packaging and Interconnection" (American Chemical Society, Washington DC, 1989) p. 2-13.

(2) L. T. Manzione, in "Plastic Packaging of Microelectronic Devices" (Van Nostrand Reinhold, New York, 1990).

(3) W. Kim and J. Bae, I. Choi and Y. Kim, *Polym. Eng. Sci.*, **39** (1999) 756-766.

(4) D. J. Cumberland and R. J. Crawford, in "Handbook of Powder Technology" (Elsevier Science Publishers, Amsterdam, 1987) Vol. VI, Chap. 4.

Table I The physical properties of inorganic fillers and epoxy resin

Materials	Dielectric constant	Coefficient of thermal expansion (ppm / K)	Thermal conductivity (W / m-K)	Volume resistivity (Ohm -cm)
Crystalline silica	3.8 ~ 5.4	15	14	10^{14}
Alumina	8.9	6.7 ~ 7.1	20 ~ 25	10^{13}
AlN	8.8	4.5	130 ~ 260	5×10^{13}
Epoxy	6 ~ 8	50 ~ 90	0.02 ~ 0.04	10^{14}

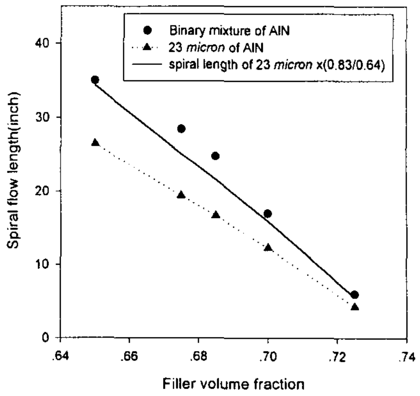

Figure 1. The spiral flow length of AlN filled EMC as a function of filler content in the binary mixture of AlN compared with single size AlN

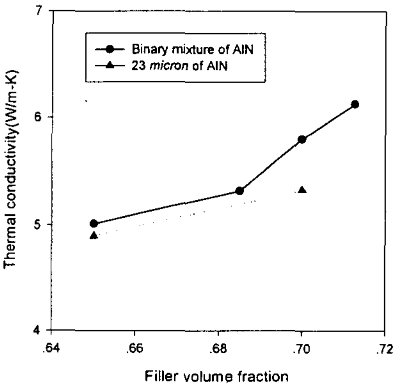

Figure 2. The thermal conductivity of AlN filled EMC as a function of filler content in the binary mixture of AlN compared with single size AlN.