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Controlling warpage of molded package for inkjet manufacturing

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Abstract

A system consisting of four silicon dies and several discrete components was encapsulated with epoxy mold material and the package was used for the evaluation of inkjet manufacturing in electronics. Experimental samples showed that the molding process induces thermo-mechanical stresses that warp the package after the mold resin is cured at elevated temperature. The molding process was modeled using the finite element method (FEM), and different package structures were simulated to see how those affect the final warpage of the package. Material properties of the mold material were measured and used in the FE model. The viscoelastic behavior of mold material was modeled with a sum of Prony series terms and a time–temperature shift factor was used to include the temperature effect. To verify the modeling assumptions, the surface profile of an experimental package was measured with an optical profilometer and the measurements were compared with the simulated profile. A good correlation was found between the measured and simulated profile of the package. The simulations with different package structures showed that e.g. an additional film placed on top of the mold resin reduces significantly the warpage of the package.

Keywords: FE modeling; Encapsulation; Molding; Warpage; Inkjet

1. Introduction

Packaging of IC components improves their durability against environmental stresses and makes handling easier during assembly. Multichip module (MCM) and System-in-Package (SiP), for example, are packaging approaches where several components are integrated inside a single package. The SiP approach increases the integration rate and modularity, and can result in reduced costs [1].

The application, manufacturing process, and conditions of use set requirements for the structure of the package and the materials that can be used. The thermal, mechanical, and electrical properties of the package's materials must meet the specifications and the cost of materials and manufacturing must remain within certain limits.

Traditionally, the electrical connections inside a SiP are made using wirebonding or internal wiring boards [1]. We adopted a novel method for interconnection and began to study the applicability of inkjet printing in electronics manufacturing. For this purpose, a functional system consisting of several unpackaged dies and discrete components was designed such that all the electrical connections were accessible on one side of the package after the encapsulation of the components. After the encapsulation, the electrical connections to components and a multilayer wiring board can be directly inkjetted on the component side of the package, which simplifies the manufacturing process considerably.

This paper focuses on the reduction of the warpage of the package after the components are encapsulated with epoxy-based mold resin. Warpage is undesirable because the second-level interconnections require a flat surface for a ball grid array (BGA) for better reliability, and also the accuracy of inkjetted drops is better when there is less height difference on the print area. The finite element method (FEM) was used to model the molding process and different assemblies were simulated to determine the resulting warpage of the package.

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2. Printable electronics

Printable electronics has gained a lot of attention recently for its potential in rapid, low-cost, and flexible manufacturing [2]. Many of the same methods can be used as in traditional graphic printing. Equipment such as inkjet, flexo, or gravure printers can be used to print the desired patterns on a substrate. Instead of forming graphic images, the aim in printable electronics is that the printed image should have some electrical function, such as a conductive line, insulative layer or semiconductive structure. Roll-to-roll printing can be used for high volume and large area circuit manufacturing, such as RFID tags [3].

The benefit of inkjet manufacturing in comparison with traditional PCB manufacturing is that it is a maskless, fully additive, and non-contact manufacturing method. Without the need for masking and etching steps, circuits can be manufactured rapidly, at low cost, and without the material waste encountered in subtractive processes, such as photolithography. The manufacturing method is also well suited for manufacturing flexible circuits on thin plastic films or paper. The accuracy of inkjetted patterns is approaching the conventional photolithography-based PCB process. Currently, commercially available printheads can eject 1 pl drops that yield approximately 20 μm line widths on suitable substrates. This is in many cases sufficient for IC contacts and PCB wiring purposes. A superfine inkjet has been reported to deposit sub fl drops that can achieve line widths of less than 1 μm which are capable of patterning ultra-fine wiring [2–6].

3. SiP for inkjet manufacturing

A SiP was designed to demonstrate printable electronics manufacturing using an inkjet printer. The components of the SiP were first assembled on a carrier tape and then these were encapsulated with epoxy-based mold resin. The epoxy also keeps the components in place such that the wiring layers can be directly inkjetted on the component side. The conductive patterns are made with ink that contains solvent and nano-silver particles with a mean diameter of 5 nm. To prevent coagulation, the particles are covered with dispersant material that is removed by heating. Due to quantum size effect, the nano-sized particles can be sintered at a much lower temperature than bulk silver would require. Inkjettable dielectric material is also available, which allows the formation of multilayer structures by inkjetting conductive and insulative layers in turns. The printed structure can be processed directly from a digital file, which makes possible short set-up times and customizable products [2,4,7].

The recommended sintering condition for the inkjetted nano-silver ink is 220–230 °C for 1 h [8]. The easiest way to sinter the ink is to place the module in an oven, which means that all of the packaging materials must tolerate the sintering conditions. With multilayer structures the package must spend several hours at the sintering temperature and therefore care must be taken that packaging materials can stand the thermal loading. Although the silver ink used for this application requires a rather high sintering temperature, there are available inks with sintering temperatures of 100 °C or below that allow a wider variety of low-cost materials to be used in inkjet manufacturing. In addition, more advanced sintering methods are being developed to reduce thermal loading during sintering by applying the heat only locally to the areas where it is required. For example, laser sintering has been studied for this purpose and it has shown promising results [9].

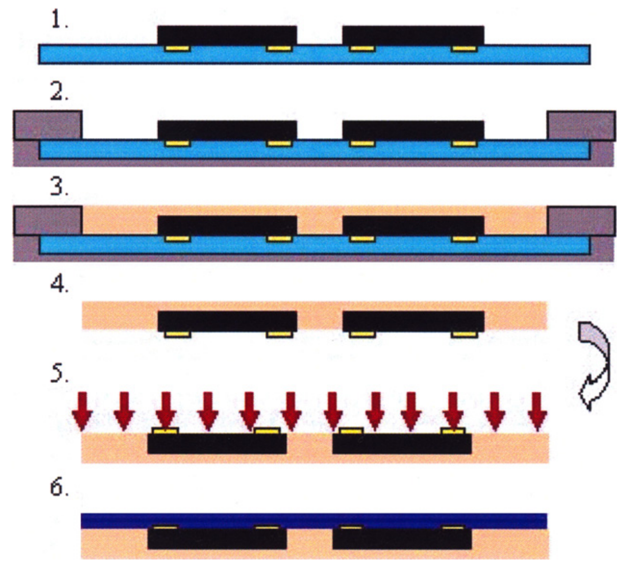

Fig. 1. The process of manufacturing a SiP package.

Thermo-mechanical stresses of the package can be reduced using mold material with low modulus or by reducing the difference between the values of the coefficients of thermal expansion (CTE). Mold material usually has much higher CTE value than components, and filling it with e.g. silica can help in getting the mold material to match components' CTE value better. On the other hand, the use of fillers results in a rough mold surface, at least from a microscopic point of view. The first inkjetted conductive layer requires a smooth surface, because line widths as low as 40 μm need to be patterned on it. To reduce roughness on the mold surface, fillers were not used in mold resin. The chosen epoxy-based mold resin had also high temperature resistance (up to 330 °C), which ensures that it is not damaged during several sintering phases that the processing of multilayer wirings requires.

The process of manufacturing the SiP is described in Fig. 1. The process is divided up into the following steps:

Step 1: Components are assembled on a carrier tape with an adhesive layer.
Step 2: The tape containing the components is placed in a mold cast.
Step 3: Mold resin is poured into the cast and is cured at 120 °C.