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Inkjet printed dielectrics for electronic packaging of chip embedding modules

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ABSTRACT

The inkjet printing of a dielectric layer as part of an assembling process for a semiconductor device was evaluated. This layer embeds a chip so that a space-saving package with surface conformal conductive paths instead of wire bonds can be designed. Three different polymer solutions were tested whereas the polyimide ink is favored due to the high thermal stability and dielectric strength of the printed layer. By multiple printing of dielectric layers on top of each other a sufficient layer thickness and cover of the chip edges as well as accurate contact holes can be realized.

1. Introduction

The inkjet technology offers new possibilities for packaging of semiconductor modules of electronic devices. The general advantages of inkjet printing are widely described [1–8] as a flexible and full-additive manufacturing technology. In semiconductor industry a general trend is seen for producing modules with multiple chips and also the inclusion of passive components at small package geometries. This leads to a higher package complexity and therefore increases the requirements for the interconnection between the different chips and the connection to the board. In case of power packages, e.g. for automotive drive application very thick interconnect wires up to 650 μm in diameter are needed for high current interconnections. The power chips get controlled by several logic chips and lots of space-consuming wires are needed for an appropriate module design. By the inkjet technology the standard wire bond process could be replaced when the interconnections are made of printed metal lines along the substrate topography. The expected advantages are as following:

- Realization of very complex modules with multiple 3D interconnects between chips and board connections at small geometric sizes.
- Downsizing possibilities for the chip with better cost performance.
- Higher electrical performance of power chips due to shorter interconnects and lower resistivity as well as lower parasitic losses.
- Easy change of designs for assembling different chip sizes and interconnects by just alterations of the print program.

In Fig. 1, a cross section part of a module with a chip attached on a lead frame substrate is depicted, which can be regarded as an extract of a much more complex module with several logic and power chips implemented. The applied chip thickness can be as low as 60 μm or even thinner.

For the dielectric layer the usual criteria as part of a package component regard a high dielectric strength, a good adhesion to substrate, chip and conductive paths, low thermal expansion coefficients, low ionic contents, etc. A high thermal stability is also required since further processes for packaging will take place after the dielectric layer deposition. Thermal stress may occur during a sintering process of the printed conducting ink, e.g. a silver nanopaste, or during a possible molding for encapsulation of the package as well as the soldering of the package on a board. The most common polymer class for the application as a dielectric layer in the semiconductor industry are polyimides beside epoxy compounds, benzocyclobutene, polybenzoxazole, acrylates. Other restrictions for the dielectric polymer result from the special

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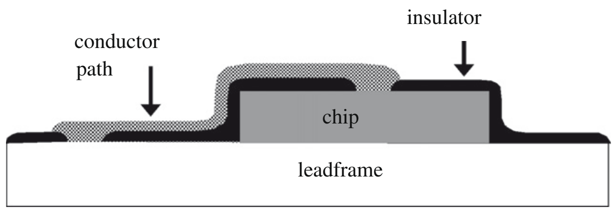

Fig. 1. Extract of a module assembly made by first inkjet printing of an insulation layer and than printing of a conductive layer on top.

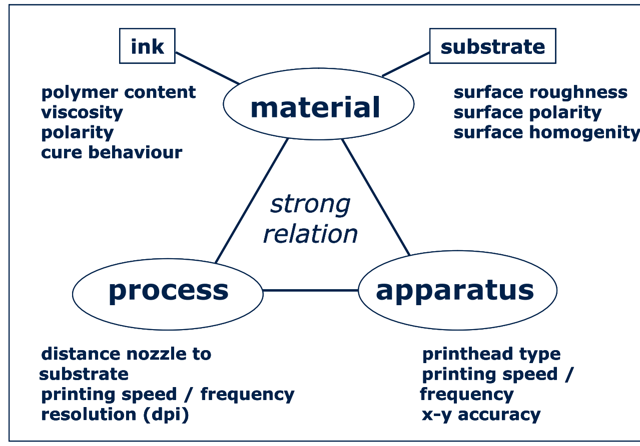

Fig. 2. Relation of parameters on inkjet print result.

demands of the inkjet process itself. The polymer ink has to be at a very low viscosity and the solvent of the ink solution should evaporate as fast as possible for a precise print accuracy.

So far there is no literature published upon inkjet printing for coverage of a topographic structure like a chip step as depicted in Fig. 1. Only a few publications can be related to semiconductor packaging of both, dielectric and conductive layers performed by inkjet technology. Mäntysalo and Mansikkamäki [1] printed a planar dielectric layer based on an epoxy compound as well as conductive lines of silver nano-particles for integration of actives and passives inside a System-in-Package (SiP). Before printing, the active and passive components were embedded by a mold compound so that the printed connections could be placed on a flat surface. In another publication of Mäntysalo et al. [2] a multilayer design for SiP could be demonstrated by printing a dielectric layer with open contact holes on top of printed microvias. Hayes et al. [9] describes the inkjet printing of a dielectric layer based on a thermosetting epoxy ink and the possibility of printing Chip-Scale Packages (CSPs). In two other publications [10,11] this group demonstrated the accuracy of polymer prints by printing a microlens array of single polymer dots of only 40 μm in diameter. Inkjet printed dot sizes of about 30 μm of a polystyrene polymer could be realized by de Gans [4] to be applied for polymer light-emitting diode displays (PLED). The inkjet printing of polyimide as a very thin dielectric layer as part of a capacitor was described by Subramanian et al. [3]. Also a 20 nm thin dielectric layer was printed by this group on top of a conducting path in the approach of a full printed transistor [5]. Some more literature exists of printing conducting polymers (e.g. poly(ethylenedioxythiphene), (PEDOT)) for e.g. PLED's [6–8,12–14], where the inkjet printing is considered as a low-cost fabrication method at high resolution.

2. Instrumentation and methods

The results of inkjet printing are depending on a variety of parameters which can be related in principal to the material, the process and the apparatus (see Fig. 2). Small changes of material properties (e.g. polymer content) or process parameters can have a major influence upon the print results. For high accuracy printing special print equipment is needed which is mostly defined by the diameter of the nozzle orifice. The total print speed depends on the number of nozzles per printhead as well the chosen resolution (dots per inch) and movement speed of the printhead. Especially for printing solvent containing polymer inks the print speed is limited by the fact, that the jetted drop of the polymer solution needs time for evaporation of the solvent to immobilize on the substrate surface. Substrate heating can improve print resolution by accelerating the evaporation process and partly starting cure processes of the polymer. Another approach for the fast immobilization of the jetted drops would be the application of UV curable inks. But this limits the selection of inks to highly polymer concentrated compounds at low molecular weights, which would exclude, e.g. the polyimides.

The experiments were performed at the VTT Technical Research Centre of Finland [15] by use of the XY precision table from iTi [16] and the spectra SE-128 printhead from Dimatix [17]. The printhead consists of 128 addressable nozzles at a orifice diameter of 35 μm to produce drop sizes of 30 pl at a maximum operating frequency of 40 kHz. The nozzle was heated to 60 °C to lower the viscosity of the polymer inks. A heating plate underneath the substrate is used at temperatures up to 200 °C and further thermal curing of the printed polymer are performed by an external oven. As substrates for printing, copper plates with attached chips were used (see Fig. 1). Plating the copper substrate by a silver layer on top of the copper oxide leads to an improved accuracy and stability of the printing process also by smoothening the copper surface.

3. Results and discussion

Inkjet printing of dielectra for electronic packaging is still not established in industry like inkjet printing of conductive lines, where, e.g. commercially available silver nano inks can be used. Therefore, a strategy and optimization steps are needed for successful printing of different polymer ink types. Two ways for optimization can be distinguished in principle. Either one can use a commercially available polymer ink of a different application, like solder resist, with limited dielectric properties as part of an electronic package component. Alternatively, a commercially available dielectric for electronic packaging with limited properties for the inkjet process is employed. The former method offers the advantage of starting with print experiments right away without the need of further optimization of the ink material. But the requirements on the dielectric layer inside an electronic package are quite high to prevent from electrical failures. Special test methods for the electronic device, like temperature cycling, high temperature storage or storage at high humidity by a pressure cooker are well established in the electronic industry to predict the lifetime of the module and to ensure error-free operation at different conditions [18]. The quality criteria of a dielectric polymer layer inside a package are defined for this application by the dielectric strength, the breakthrough voltage, thermal stability, as well as the adhesion strength to copper, silicon surfaces and mold compound. Especially cause of successive packaging processes after dielectric printing like printing and sintering conductive lines or encapsulation by a mold compound a high thermal stability of the printed dielectric layer is needed. Also a high thermal stability of the printed dielectric layer is needed because of successive packaging processes after dielectric printing like printing and sintering conductive lines or encapsulation by a mold compound. Further requirements of the polymer material are low thermal expansion coefficients, a low ionic content, a low water absorption and the lack of halogens due to