

Inkjet Printing Approach to Fabricate Non-sintered Dielectric Film with High Packing Density for 3D Package Integration Technology

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Abstract

We have successfully demonstrated the inkjet printing method to create Al_2O_3 films without a high temperature sintering process. In order to remove the coffee ring effect in the ink drop, we have introduced a co-solvent system in order to create Marangoni flow in the ink drop, which leads to the dense packing of ceramic powders on the substrate during inkjet process. The packing density of the Inkjet-printed Al_2O_3 films is around 60% (max. 70%) which is very high compared to the value obtained from the same material films by other conventional methods such as film casting, dip coating process, etc. The voids inside the films (which are around 40% of the entire film volume) are filled with the polymer resin (Cyanate ester) by the infiltration process. This resin infiltration is also implemented by the inkjet printing process right after the Al_2O_3 film ink-jetting process. The microstructures of the printed Al_2O_3 films are investigated by Scanning Electron Microscope (SEM) to understand the degree of packing density in the printed films. The inkjet-printed Al_2O_3 films have been characterized to investigate its thickness and roughness. Quality factor of the printed Al_2O_3 film is also measured to be over 300 at 1MHz.

Key words: Inkjet Printing, Al_2O_3 , Hybrid materials

I. Introduction

With the current explosive growth of information communication technologies, it is required to realize 3D system integration of hetero-materials including organic with inorganic materials and multi-functionality from various technologies based on information, nano, bio, energy, etc. As of today, Low Temperature Co-fired Ceramics (LTCC) technology has been used to realize 3D-system integration concept by embedding active or passive components into the ceramic substrate itself. However, LTCC technology is not appropriate to achieve the concept of the future 3D system integration which requires to build up a system from different materials and components systems.

Recently, the direct-writing by the inkjet-printing has significant attention since it is feasible to pattern and fabricate fine features directly from design or image files. The inkjet printing is very promising in terms of manufacturing multi-layer 3D system integration since inkjet-printing process provides the better layer-to-layer alignment and also it is a contactless process.[1]

In this presentation, we have formulated alumina suspension inks with spherical alumina powders and used them to deposit alumina film layers for 3D-system ceramic package substrate. These alumina layers were prepared by the Inkjet-printing process technology without high temperature sintering process.

II. Experimental Procedure

Alumina powders with $D_{50}=0.2\mu m$ were used in the alumina ink formulation. The alumina solid content in the solvent was fixed at 8vol% in this experiment. Based on the boiling points and surface tension values of many different solvents, both single-solvent and co-solvent ink systems were formulated. The rheological evaluation was carried out in order to understand the printability of the formulated inks by measuring their surface tension and viscosity. The formulated alumina inks were printed on Cu plates. The inkjet printing unit (Uni-jet Co. Korea) is equipped with a piezoelectric nozzle with 50 μm orifice from Micro-fab technology. The ink droplet ejection was monitored by CCD camera. The roughness and thickness of the inkjet-printed alumina layers were measured by Dektak 150 surface profiler. The microstructure of the inkjet-printed layers was looked at by focused-ion-beam field emission scanning electron microscope (FIB FE-SEM Nova 200).

III. Result and discussion

Since our goal is to fabricate non-sintered Al_2O_3 substrates, it is preferred that the inkjet-printed alumina layer should have a high packing density of more than 60%. High packing density will help the inkjet-printed layers perform as 3D-system package substrates with

better electrical and mechanical properties. In order to obtain highly packed alumina layers by inkjet-printing, it is important to understand the evaporation phenomena of ink droplets on the solid surface. Depending upon the ink solvent compositions, two different types of micro-flows were obtained, outward flow and inward flow. With these two different ink flow inside the ink droplets on the surface, we fabricated alumina layers on Cu substrates. The microstructures of the films were investigated in order to understand their alumina packing rate inside the layers.

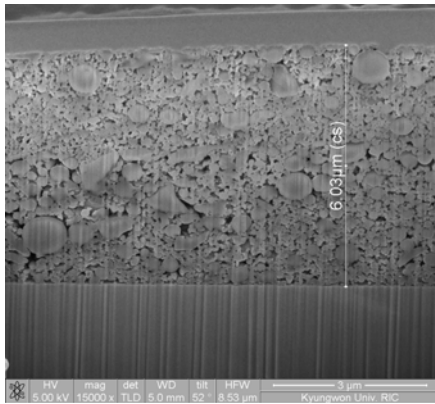


Fig.1 FIB(Focused Ion Beam) SEM image of inkjet-printed Al_2O_3 film on Cu plate.

The FE-SEM image of the alumina film from Al_2O_3 ink is presented in Fig. 1. It could be inferred from FE-SEM images that the film is both film is well packed with alumina powders. In order to precisely evaluate the packing density of the films, we calculated the packing density with the weight of the films and the volume of the films. The packing density was evaluated by the following equation:

$$\text{Packing_density} = \frac{W_{\text{Film_weight}}}{\rho_{\text{density}}} \times \frac{1}{A_{\text{area}} \times t_{\text{film_thickness}}} \times 100$$

where W is the film weight; ρ is the density of alumina; A and t is the printed area and thickness of the alumina film. From this equation, the inkjet-printed alumina layers showed that their values fell between 60~ 70%.

The packing density of the inkjet-printed alumina layers indicates that there are roughly ~40% of micro-voids inside the films. In order to fill out those voids, we selected Cyanate ester as our resin material in this experiment. Cyanate ester has a very low dielectric constant (3 at 1MHz) and a low dielectric loss (0.004 at 1MHz), providing specific suitability for the package substrate application.[2]

The dielectric properties of the inkjet-printed alumina films were investigated. Fig.2 shows Q-values and dielectric constant of these films.

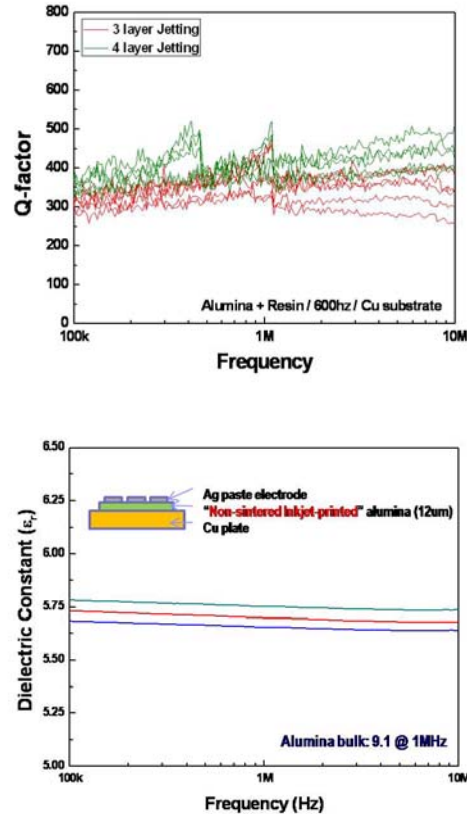


Fig. 2 Dielectric properties (Q-value and Dielectric constant) of the inkjet-printed Al_2O_3 layers.

IV. Conclusions

In conclusion, we have formulated the alumina layers by the inkjet-printing method. The inkjet-printed alumina layers from both inks showed the relatively similar packing density at around 60vol%. The rest 30% of micro-voids in the inkjet-printed alumina were filled with Cyanate ester resin by the same inkjet printing method. The dielectric properties of these films indicated that these films are reasonably good enough for the ceramic package application.

Reference

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