

# FABRICATION AND CHARACTERIZATION OF INK-JET PRINTED ALUMINA THICK FILM WITH LOW-LOSS RESIN INFILTRATION

Hyo Tae Kim, Jihoon Kim, Young Joon Yoon and Jong-hee Kim

IT Convergence Lab., Korea Institute of Ceramic Engineering and Technology, Seoul 153-801, Korea

## Introduction

Three dimensional (3D) integrated packaging generally consisted of basic substrate, internal electrodes, internal functional layers such as embedded passive components consisted of decoupling capacitors, resistors and inductors, and interconnects like microvias and through-holes. Typical ways to form a dielectric layers in the conventional ceramic process are screen printing or tape casting method. Since 1990's, low-temperature co-fired ceramic technology (LTCC) became popular in the ceramic RF components and 3D package modules [1]. And also flexible and organic based printed electronic packages became popular, recently. Though LTCC technology and polymer based organic technology exhibit their own advantages, they also confront with several subtle drawbacks such as shrinkage mismatch, inter-diffusion between dissimilar materials and layer and brittleness in the LTCC, and such as inferior dielectric properties [2], low thermal stability in the organic based materials. Ink-jet printing method has been recently drawn a great interest as one of the most feasible process technology in the printed electronics and direct writing applications[3]. Most of the ink-jet printing applications are patterning conductive thick film layers for electronic packages.

In this work, we introduce a new approach to form a dielectric substrate layers by ink-jet printing method. A hybrid thick film dielectric layer consisted of low loss ceramic and low loss resin was constructed by ink-jet printing of alumina powders suspension ink followed by low loss resin infiltration into the voids of porous alumina body. This paper report preparation of alumina ink, jetting process of alumina droplets to form thick film layers, evaluation of powder packing density of the printed layers, resin infiltration, and characterization of dielectric properties and microstructures of forming layers.

## Experimental

### Preparation of Alumina Ink

Fully spherical and controlled particle sizes of commercially available alumina powders (ASFP-20, Denka, Japan) with average particle size of 0.2 $\mu$ m ( $D_{50}$ ) was selected for high packing density in the alumina thick film layer. The alumina suspension for ink-jet printing was prepared by using 8 ~ 10 wt% solid loading in the DMF(N,N dimethylformamide,

boiling point: 153°C, Surface tension: 40.4 dyne/cm ) solvent, and about 10vol% of dispersant (BYK-111, BYK Chemicals) to the alumina powder amount was added for homogeneous ink dispersion. The alumina suspension was dispersed in the high density polymer (PE) jar with zirconia balls for 24 to 48 hours. The proper rheological properties such as surface tension and viscosity of suspension for ink-jet printing are 25-45mN/m and 3-20mPa·s, respectively.

### Ink-jet Processing of Alumina Ink

The ink-jet printer (UJ200, Unijet Inc.) with 50 $\mu$ m nozzle (Microfab Technologies) was used for alumina ink and resin jetting process. The expelled droplet sizes were 150~160pL with travelling velocity of 2.5 ~ 3.2 m/sec. The diameter of jetting droplet was 61 ~ 65 $\mu$ m and printed droplet sizes were 130~180 $\mu$ m after drying. The printed layer thickness was about 1.3 $\mu$ m and was varied with the ink-dot pitch conditions. After complete drying of printed porous alumina layers, a solvent diluted low-loss resin (cynate ester based) ink was jetted over the alumina layers, then cure at 280°C for 24-48 hours in nitrogen atmosphere. The schematic of ink-jet printing of alumina and resin followed by low-temperature curing (<350°C) is illustrated in Fig.1.

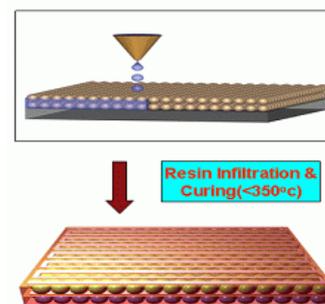


Fig.1: Schematic diagram of forming low-temperature thick film dielectric layers by ink-jet printing.

## Result and discussion

### Characterization of Ink-jet Printed Alumina Film

The microstructures of printed alumina dots and two dimensional layers were analyzed by FE-SEM for primary observation to check the ink and jetting condition. Fig. 2 shows the surface profile of jetted alumina single dot for jet condition adjustment [4]. The surface undulation of the droplet can be adjusted

by either co-solvent system, jetting parameter, or drying conditions.

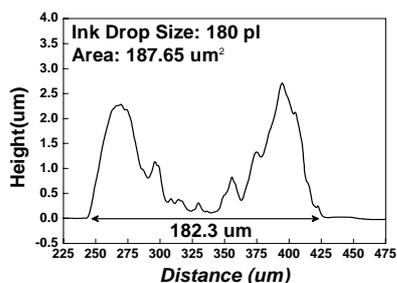


Fig.2: Surface profile of ink-jet printed alumina single droplet after drying.

Fig. 3 shows the effect of selection of alumina powder sizes and shapes on the jetted film quality. Fig. 3(a) and 3(b) used uni-modal with non-spherical and multi-modal with spherical shape alumina powders, respectively. Films made of multi-modal with spherical shape resulted in a smoother and film surface and higher powder packing density [5]. The packing densities of the film was evaluated both the dimensional calculation with film weight measure and image analysis of the cross-sectional FE-SEM image. The packing density of the irregular shape (non-spherical) powder packed film was about 58%, while that of spherical shape powder packed film was over 60%, typically 68 to 75%.

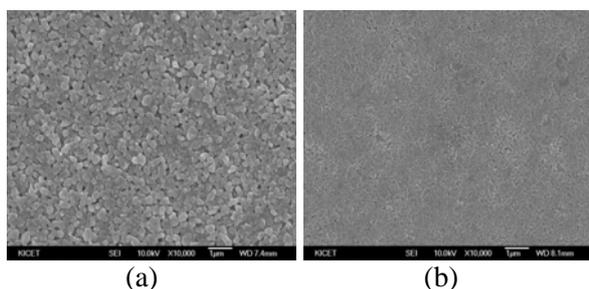


Fig.3: Planar microstructure view of ink-jet printed alumina powder bed layer after drying: used (a) non-spherical and (b) spherical powders.

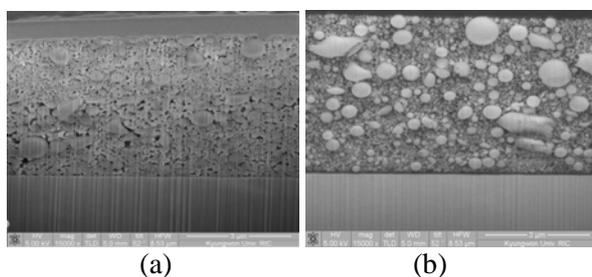


Fig.4: Cross-sectional view of the resin infiltrated alumina layers: (a) before and (b) after infiltration.

After resin infiltration, the silver or gold conductor was deposited on the alumina film then dielectric properties were measure using impedance analyzer (4294A, Agilent Technologies Inc.) interconnected by

micro-probe station (M150, ). The dielectric constant and dissipation factor (DF) were measured at 1MHz. Fig. 5 show the dielectric constant and loss spectrum of the cynate ester resin infiltrated alumina thick film after 280°C curing and room temperature silver (Ag) top electrode coating [6]. The dielectric constant and loss were about 5.7 and over 200 at 1MHz, respectively.

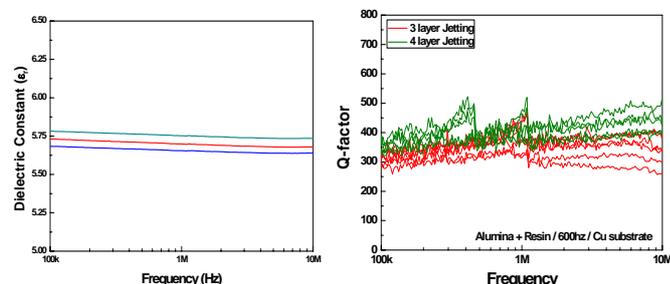


Fig.5: Dielectric properties of ink-jet printed alumina thick film with low loss resin infiltration.

## Conclusion

1. Ceramic-organic composite thick films over 60 vol% of dielectric powder loading has been fabricated at the temperatures lower than 300°C using ink-jet printing method and low-loss resin infiltration processing technique.
2. Dielectric properties of thus obtained ceramic-organic composite film exhibited dielectric constant of 5.7 and Q factors over 200 at 1MHz.

**Acknowledgments:** This work was supported by a grant from the Fundamental R&D Program for Core Technology of Materials funded by the Ministry of Knowledge Economy (Grant No. M2007010011)

## References

1. T. Yamamoto, Technology and Application of Multilayered LTCC, CMC Books Japan (2005).
2. M. Kakimoto, A. Takahashi, High Performance Materials for Electronic package Substrate, CMC Books Japan (2005).
3. J.H. Song, M.J. Edirisinghe, J.R.G. Evans, *J. Am. Ceram. Soc.*, 82 (12) (1999).
4. R. Noguera, M. Lejeune, T. Chartier, *J. Eur. Ceram. Soc.*, 25(2005) 2055-2059.
5. J.H. Kim, E. H. Koo, Y.J. Yoon, H.T. Kim,, *Ceramic Transactions* published by The American Ceramic Society (June 2009).
6. E. H. Koo, Y.H. Son, H.W. Jang, H.T. Kim, Y.J. Yoon, J.H. Kim, *Ceramic Transactions* published by The American Ceramic Society (June 2009).