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Process Optimization of Composite-based Capacitor for LC Resonant Circuits

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Abstract – The need for high-frequency decoupling capacitors to supply the transient current requirements to high-speed devices is ubiquitous in current microelectronics applications. Even though materials and their processes have already been developed in terms of their performances, low manufacturing cost cannot be overemphasized in current microelectronics industry. For this reason, we revisited low cost ceramic filled polymer integrated capacitor. Experiments were performed according to the design of experiment (DOE). The best recipe that has the optimized ratio of material composite was obtained using by response optimizer in Minitab. And also, high-frequency measurements were performed to get frequency dependent data using network analyzer.

Key words – decoupling capacitor, design of experiment (DOE), microelectronics

I. Introduction

The working frequency of Integrated Circuits (ICs) and the number of transistors has been increased, the capacity and speed of decoupling capacitors are inevitable to improve performance of high-speed microprocessors and Application Specific Integrated Circuits (ASICs). Therefore, lots of decoupling capacitors must be attached on Printed Circuit Board (PCB) to supply high-speed switching current, which requires huge amount of area on PCB. However, the prominent problem is the limited space on PCB.

For this reason, we revisited low cost ceramic filled polymer integrated capacitor formation technique and embraced the PCB substrate that can be directly beneath the active components as a strategic solution to overcome technology challenges of smaller geometry and parasitic.

II. Experiments

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2.1 Fabrication

In this study, we used Bisphenol-A epoxy resin and $BaTiO_3$ as a matrix polymer and a ceramic powder, respectively. $BaTiO_3$ is suitable for high capacitive devices because of high dielectric constant. We chose hot-pressed $BaTiO_3$ with its size 1㎛ that has an εr value of around 6000 at room temperature because the permittivity of ceramic $BaTiO_3$ strongly depends on the grain size [1]. Dicyandiamide (DICY) was used for curing and methyl/ethyl/ketone (MEK) was used as solvent.

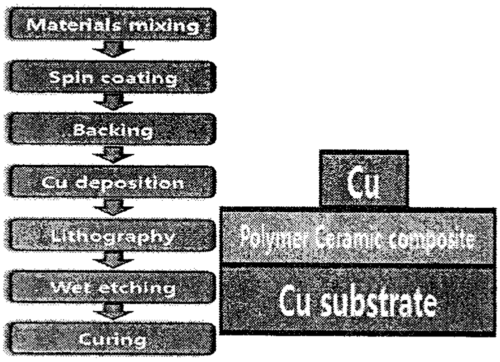


Fig 1. Fabrication process steps of integrated capacitor

To obtain proper combination of materials, the followings are simultaneously considered; uniformity in the thin film, volume fraction of ceramic mixed with dielectric polymer. Integrated capacitor fabrication steps are briefly described in figure 1.

2.2 Experimental Design

In order to determine the best operating condition of the belt furnace for a good contact formation, statistical design of experiment (DOE) was used.

A fractional factorial design includes selected combinations of factors and levels. It is a carefully prescribed and representative subset of a full factorial design. The advantage in this method is the number of experiment half of the full factorial design [2][3]. So we used the fractional factorial design in this paper. Four input factors with two levels of each factor were considered: Bisphenol-A, Solvent (methyl/ethyl /ketone and Toluene), $BaTiO_3$ and DICY. Range of each factor is presented in table 1.

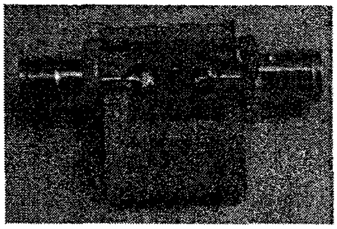
Table 1. The parameters of ceramic filled polymer composite

Parameter	Range (g)
Bisphenol-A	0.5 - 1.5
Solvent	8 - 12
BaTiO3	8 - 12
DICY	0.05 ~ 0.15

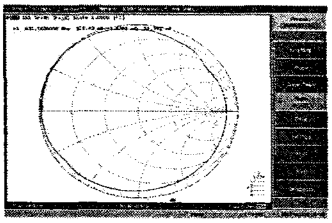
III. Results

The samples were measured using Agilent (E5071A) Network Analyzer. Frequency range is from 300 khz to 1 GHz. The sample and result of measurement are shown in figure 2. The (b), (c) and (d) of the figure 2 show the two self resonance frequencies of one of the samples at 324MHz and 632MHz, respectively. The value of capacitance is about 87nF in this range.

The result of the recipe for volume fraction of ceramic filled dielectric polymer is shown in table 2.

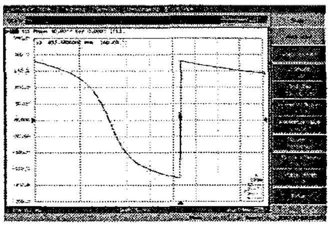


(a) Sample picture



(b) Smith chart result

(c) Magnitude result



(d) Phase result

Fig. 2. Sample and result of measurement

Table 2. Recipe of volume fraction of ceramic filled dielectric polymer

Parameter	Range (g)
Bisphenol-A	1.5
MEK	2.9
Toluene	7.28
$BaTiO_3$	9.6
DICY	0.15

Ⅳ. Conclusion

The optimization of polymer ceramic composite on the Cu substrate was demonstrated in this paper. We found the best recipe that has maximum capacitance under the given range using fractional factorial design. It is very important to obtain the volume fraction of ceramic filled dielectric polymer to make capacitor. However, there are other factors affecting capacitance value in process. So, future research will be performed on optimized process conditions.

Acknowledgment

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Reference

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