저가형 유기 SOP 적용을 위한 저온 공정의 $BaTiO_3$ 임베디드 커패시터 설계 및 제작

이승재, 박재영, 고영주*
마이크로/나노 소자 및 패키징 연구실, 전자공학과, 광운대학교, 서울 *대덕전자, 안산시, 경기도

Design and Fabrication of Low Temperature Processed $BaTiO_3$ Embedded Capacitor for Low Cost Organic System-on-Package (SOP) Applications

Seung J. Lee, Jae Y. Park, Yeong J. Ko*
Micro/Nano Devices & Packaging Lab. Department of Electronic Engineering, Kwangwoon University, Seoul
*Daeduck Electronics, Ansan-City, Kyonggi-do

Abstract - In this paper, PCB (Printed Circuit Board) embedded $BaTiO_3$ MIM capacitors were designed, fabricated, and characterized for low cost organic SOP applications by using 3-D EM simulator and low temperature processes. Size of electrodes and thickness of high dielectric films are optimized for improving the performance characteristics of the proposed embedded MIM capacitors at high frequency regime. The selected thicknesses of the $BaTiO_3$ film are 12μm, 16μm, and 20μm. The fabricated MIM capacitor with dielectric constant of 30 and thickness of 12μm has capacitance density of 21.5 pF/mm^2 at 100MHz, maximum quality factor of 37.4 at 300 MHz, a quality factor of 30.9 at 1GHz, self resonant frequency of 5.4 GHz, respectively. The measured capacitances and quality factors are well matched with 3-D EM simulated ones. These embedded capacitors are promising for SOP based advanced electronic systems with various functionality, low cost, small size and volume.

1. Introduction

Recent developments of IT industry demands advanced wireless and mobile electronic systems with small volume, low profile, light weight, low cost, excellent performance, and multi-functionality [1], [2]. SOP (System on a Package) is considered as one of the most challenged and exciting research areas for realizing the advanced electronic systems. Embedded Passive Components (EPC) is the most attractive research area in SOP technologies, because the number of the passive components and IC chips are steadily increasing as the advanced electronic systems towards for higher and multi functionality. Currently, these passive components are being surface-mounted on a substrate as discrete form. Thus, they take up a large area of the package substrate and have lower electrical performance and reliability due to long interconnection length and many solder joints, respectively. Among these passive components, special interest is given to capacitors, because they are used in a large number for various functions, such as decoupling, bypassing, filtering, and timing capacitors [3]. Several studies about the embedded capacitors and high Dk materials have been performed for RF and microwave SOP[3], [4], [5]. LTCC (Low Temperature Co-fired Ceramic) has been widely studied [6], [7], but it requires high temperature process that causes material shrinkage. Thus, it prevents the product reliability and drops the component yield. It is also limited to large area manufacturing.

In this paper, the embedded $BaTiO_3$ capacitors are investigated into a PCB (Printed Circuit Board) substrate for low cost RF SOP applications. For achieving a high density of capacitance, the applied high dielectric composite film is comprised of barium titanate ($BaTiO_3$) powder and epoxy resin. The utilized PCB substrate fabrication processes have been verified about reliability, mass manufacturing, and stability for a long time. The embedded MIM (Metal-Insulator-Metal) capacitors are designed and compared for verifying their applicability by using 3D EM simulator.

2. Desgin and Fabrication

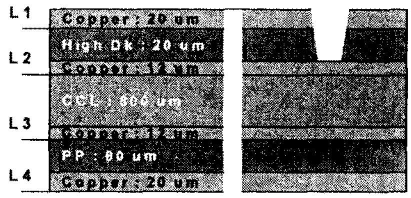
Figure 1 shows a schematic drawing of proposed PCB embedded MIM capacitor. It is simulated by using 3D EM simulator. The capacitance is calculated by using the following equation (1)

$$C = \epsilon_0 \epsilon_r S^2 / d^2 \qquad (1)$$

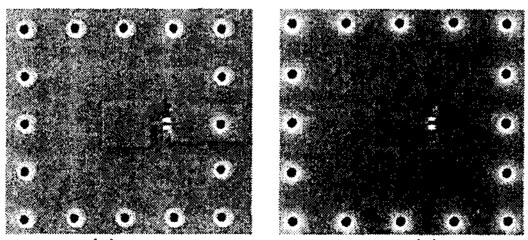
where S is the width of the MIM capacitor and d is thickness of the high Dk material. The designed PCB embedded MIM capacitors have capacitance ranged from 1pF to 15pF for low cost RF SOP applications. For reducing the size of the embedded capacitors by increasing the capacitance density, the used high dielectric composite material is comprised of barium titanate ($BaTiO_3$) powder and epoxy resin. It has relative dielectric constant in the range of 28 to 31 and tangent loss in the range of 0.002 to 0.0035. The fabricated MIM capacitors located on 1st layer have the cured high Dk material with thickness of 12μm, 16μm, and 20μm, and electrode sizes of 450 x 450μm^2, 600 x 600μm^2, and 720 x 720μm^2. All of their bottom electrodes are grounded to make a one port device.

Figure 2 shows a cross-sectional view of 4 layered PCB standard process for fabricating the MIM embedded capacitor. The embedded capacitors are fabricated on 1st layer of PCB. As shown in Figure 2. the utilized 4 layered PCB is comprised of a resin coated copper (4th layer), high DK resin coated copper (1st layer), copper clad laminate (2nd and 3rd layer). After fabrication of these embedded capacitors, the PSR (Photo-imageable Solder Resist) was coated and patterned on top of the capacitors. The GSG (Ground-Signal-Ground) test pads are finally formed and via-interconnected with the previously formed ports and ground plane on the 1st layer. Figure 3 (a) and (b) show the fabricated PCB embedded MIM capacitors for low cost RF SOP applications.

<Figure 1> Schematic drawing of proposed PCB embedded MIM capacitor.



<Figure 2> Cross-sectional view of 4 layered PCB standard processes to fabricate the embedded MIM capacitors



(a) (b)

<Figure 3> Photomicrographs of the fabricated PCB embedded MIM capacitors without planar ground (a) and with planar ground (b) for RF SOP applications

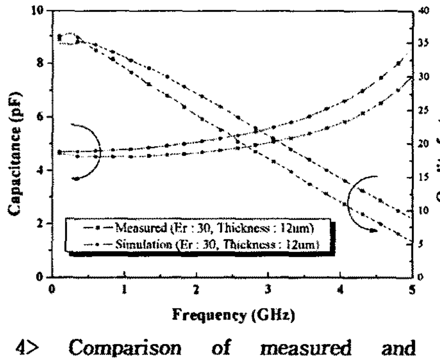
3. Experimental Results and Discussions

The fabricated PCB embedded capacitors have been measured and characterized by using an HP 8510B network analyzer and PICOPROBE coplanar ground-signal-ground (GSG) probes with 250μm pitch size. The measured frequencies are ranged from 0.1GHz to 10GHz for mobile and wireless system applications. Figure 4 shows comparison of measured and simulated performance characteristics of the embedded MIM capacitor with the effective area of 0.216mm^2. As shown in Figure 4, the measured performance characteristics are well matched with simulated ones. Figure 5 shows comparison of quality factors of the fabricated MIM capacitors with the same capacitance designed at different thickness of high Dk material. These measured capacitance and quality factors are calculated by using the following equations (2) and (3) from the measured impedance parameters[1]

$$C = -\frac{1}{2\pi f(im(Z(1,1)))} \tag{2}$$

$$Q = \frac{1}{\omega cR} = \frac{1}{2\pi f(re(Z(1,1)))} \tag{3}$$

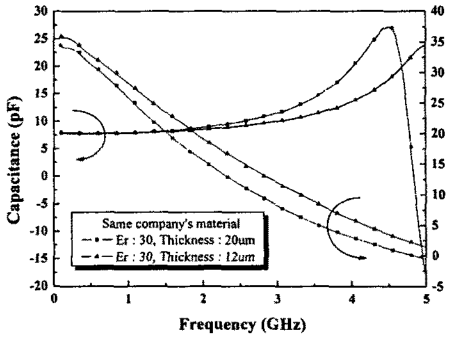
These MIM capacitors have the same dielectric constant of 30. The capacitor with thickness of 20μm and size of 750 x 750μm^2 has capacitance of 7.94pF and quality factor of 25.2, while the capacitor with thickness of 12μm and size of 580 x 580μm^2 has capacitance of 79.7pF and quality factor of 27.7 at 1GHz. As shown in Figure 5, the capacitor with thickness of 12μm has higher self resonance frequency (SRF) and higher quality factor than the capacitor with thickness of 20μm. A thicker high dielectric material may need larger electrode area for representing the same capacitance. The measured loss tangent is ranged from 0.025 to 0.035. Figure 6 shows comparison of the measured values of capacitances and quality factors of the fabricated MIM capacitors with same high dielectric constant and thickness but different top electrode area. The fabricated capacitors have the dielectric thickness of 12.29μm and the effective areas of 0.216mm^2, 0.376mm^2 and 0.544mm^2. The measured quality factors are 30.9, 27.7, and 23.9 at 1 GHz. The measured capacitances are 4.64pF, 8.08pF, and 11.66pF at 100MHz. The calculated capacitances are 4.68pF, 8.13pF, and 11.76pF. The calculated capacitance well matched with measured ones. Thus, these embedded capacitors can be easily designed and applied for low cost RF SOP applications.



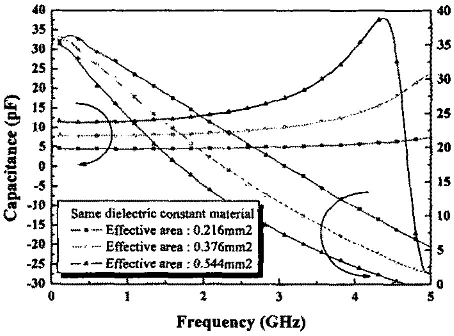
<Figure 4> Comparison of measured and simulated performance characteristics of the fabricated PCB embedded MIM capacitor with effective area of 0.216mm^2.

<Table 1> Comparison of calculated and measured capacitances of the PCB embedded MIM capacitors.

Target capacitance (pF)	Fabricated capacitors			
	Effective area (mm^2)	Dielectric thickness (μm)	Calculated capacitance (pF at 100MHz)	Measured capacitance (pF at 100MHz)
5	0.216	12.29	4.68	4.64
9	0.376	12.29	8.13	8.08
13	0.544	12.29	11.76	11.66



<Figure 5> Comparison of quality factors of the fabricated PCB embedded MIM capacitors with similar capacitance and different thickness.



<Figure 6> Comparison of capacitance and quality factor of the fabricated PCB embedded MIM capacitors with different effective areas.

4. Conclusions

The PCB embedded capacitors were designed, fabricated and characterized by using 3D EM simulator and 4 layered PCB standard process. As the measured performance characteristics of the fabricated embedded passive components are well matched with the simulated ones, 3D EM simulation is confirmed as a promising method to design the embedded capacitors for RF SOP applications. And the fabricated BaTiO3 embedded capacitor has good performance characteristics which are applicable to embedded matching circuits, filter, and diplexer devices. The embedded capacitors are necessary to develop the advanced electronic systems with various functionalities, lower cost, lower profile, smaller size and volume.

[Reference]

[1] J. Prymark, S. Bhattacharya, and K. Paik, "Fundamentals of passives: discrete, integrated, and embedded," in *Fundamentals of Microsystems Packaging*, R. R. Tummala, Ed. New york: McGraw-Hill, 2001, ch. 11.

[2] J. Rector, "Economic and technical viability of integral passives," in *Proc. 48th Electron. Comp. Technol. Conf.*, 1997, pp. 218-224.

[3] Sung-Dong Cho, Kyung-Woon Jang, Jin-Gul Hyun, Sangyong Lee, Kyung-Wook Paik, Hyungsoo Kim, and Joung-Ho Kim, "Epoxy/BaTiO3 Composite Films and Pastes for High Dielectric Constant and Low-Tolerance Embedded Capacitors Fabrication in Organic Substrates" in *IEEE Transaction on Electronics Packaging Manufacturing, vol. 28, no. 4*, 2005, pp. 297-303

[4] Yang Rao, Jireh Yue, C.P.Wong, "Material Characterization of High Constant Polymer-Ceramic Composite for Embedded Capacitor to RF Application," *2001 International Symposium on Advanced Packaging Materials.*

[5] Lixi Wan, P. Markondeya Raj, M. Swaminathan, and R. Tummala, "Design, Simulation and Measurement Techniques for Embedded Decoupling Capacitors in Multi-GHz Packages/PCBs," *2005 6th International Conference on Electronic Packaging Technology.*

[7] R. L. Brown and P. W. Polinski, "The integration of passive components into MCM's using advanced low-temperature cofired ceramics," *Int. J. Microcircuit Electron. Packag., vol. 16, no. 4*, 1993, pp.328-338

[8] William Bllod, Feng Ling, Telesphor Kamgaing, Thomas Myers, and Michael Petras, "Simulation, Modeling, and Testing Embedded RF Capacitors in Low Temperature Cofired Ceramic," *Electronic Components and Technology Conference*, 2001