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유기 패키징 기판에서의 BTO 기반의 임베디드 MIM 커패시터의 특성 분석

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Characterization of BTO based MIM Capacitors Embedded into Organic Packaging Substrate

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Abstract - In this paper, fully embedded high Dk BTO MIM capacitors have been developed into a multi-layered organic package substrate for low cost RF SOP (System on Package) applications. These embedded MIM capacitors were designed and simulated by using CST 3D EM simulators for finding out optimal geometries and verifying their applicability. The embedded MIM capacitor with a size of 550 x 550 um^2 has a capacitance of 5.3pF and quality factor of 43 at 1.5 GHz, respectively. The measured performance characteristics were well matched with 3D EM simulated ones. Equivalent circuit parameters of the embedded capacitors were extracted for making a design library.

1. Introduction

As IT industry demands advanced electronic systems with small volume, low profile, light weight, low cost, excellent performance and multi-functionality, passive components integration is considered as one of exiting research areas, because the number of passive components is steadily increasing as the electronic systems towards for higher functionality [1]. Passive components are currently being surface-mounted on substrate as discrete form. They take up large area of a package substrate and lower electrical performance and reliability due to longer interconnection length and more solder joints, respectively. Thus, SOP (System on Package) is drawing attractions, since it can reduce system cost, size, and time-to-market. SOP is being considered as one of the challenging and exciting research areas to realize advanced electronic micro-systems [2].

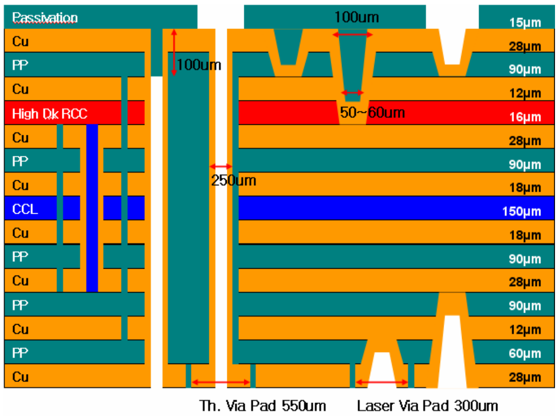
In particular, EPD (Embedded Passive Devices) is the attractive research area for RF SOP applications. Among these passive devices, special interest in given to capacitors, because they are used in large numbers for various functions, such as de-coupling , by-passing, filtering, and matching circuits. So far, LTCC has been widely studied for SOP applications, since LTCC materials have low loss tangent, which it allows to make high Q embedded passive components [3]. However, they are limited to mass production and low cost due to the small size and the shrinkage of the ceramic substrate occurred during the firing process. Therefore, organic substrate based embedded passive devices have been widely studied for low cost RF SOP applications [4]. However, these devices have poor performance characteristics and large sizes compared with the LTCC based ones.

In this paper, fully embedded high Q MIM (Metal-Insulator-Metal) capacitor is designed, fabricated, and characterized into a multi-layered organic package substrate for low cost RF SOP applications. The embedded capacitor is designed and simulated by CST 3D EM simulator to find optimized structural geometries. High dielectric composite films with various thicknesses are investigated for embedded high Q capacitors at high frequency regime, which are comprised of barium titanate ($BaTiO_3$) powder and epoxy resin.

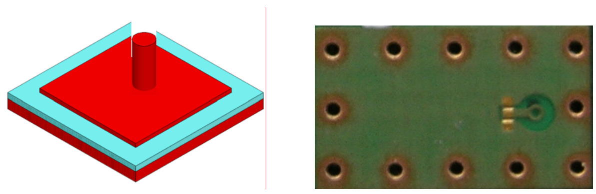
2. Design and Fabrication

The embedded one-port MIM capacitor has a perfect square shape. Input signal via located center of the top electrode. The designed PCB embedded MIM capacitors have capacitance ranged from 1 to 10pF for applying commercially applicable RF SOP products. The one-port MIM capacitors designed on the 2nd and 3rd layer have the cured high dielectric material with thickness of 8μm, 12μm, 16μm and electrode sizes ranged from 400 x 400μm^2 to 800 x 800μm^2. All of their bottom electrodes are grounded to make one - port devices.

Figure 1 shows a cross-sectional view of 8-layered organic package substrate to fabricate embedded MIM capacitors. As shown in Figure 1, the 8-layered organic package substrate is comprised of a prepreg with copper (1st, 3rd, 6th, 7th and 8th layers), high Dk resin coated copper (2nd layer), and copper clad laminate (4th and 5th layers).High Dk materials are composed of barium titanate ($BaTiO_3$, BT) powder and epoxy resin. The prepreg, CCL, and high Dk RCC materials have a dielectric constant of 4.1, 4.4, and 30 and a loss tangent of 0.016, 0.03, and 0.025, respectively. After fabricationof these embedded passive components, the PSR (Photo-imageable Solder Resist) was coated and patterned on top of the components. The GSG (Ground-Signal-Ground) test pads are finally formed and via-interconnected with the previously formed input / output ports and ground plane on the 1st layer by electroplating copper, nickel, and gold metals. Figure 2 shows 3D schematic drawing and photomicrograph of the fabricated embedded MIM capacitors into the 8-layered organic package substrate for low cost RF SOP applications.



<Figure 1> A cross-sectional view of 8-layered organic package substrate to fabricate embedded passive circuits with MIM capacitors.



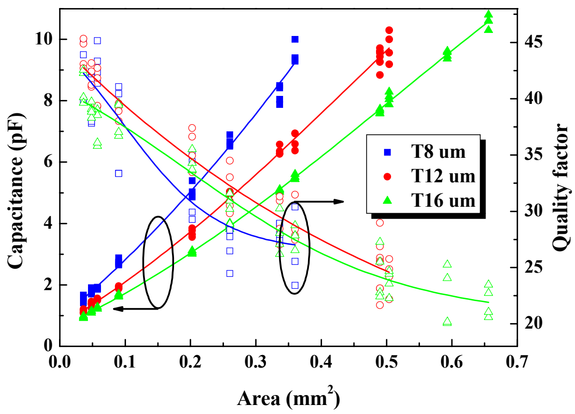
(a) **(b)**

<Figure 2> 3D schematic drawing (a) and photomicrograph (b) of the fabricated embedded MIM capacitors.

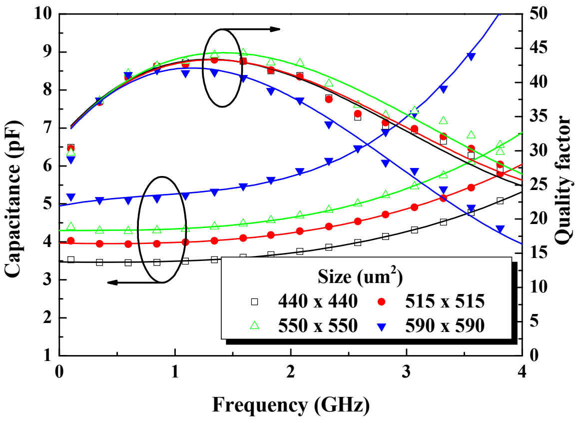
3. Experimental Results and Analysis

The fabricated MIM capacitors have been measured and characterized by using a HP 8510B network analyzer and PICOPROBE coplanar GSG probes with a 250μm pitch size. The measured frequencies are ranged from 0.1GHz to 10GHz for commercial RF applications.

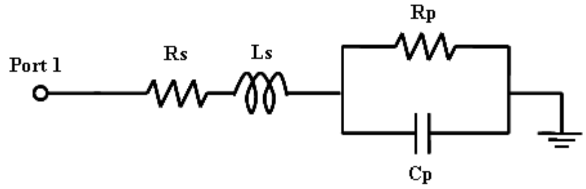
$BaTiO_3$ high dielectric films with three different thicknesses were selected to fabricate the embedded MIM capacitors with high capacitance density. The thicknesses of the high dielectric films are 8um, 12um, and 16um. Figure 3 shows measured capacitance and quality factor of the fabricated MIM capacitors at 2GHz. The measurements have been peformed by varying the thicknesses and sizes of the capacitors. As expected, the results show that the thinner the thickness is, the higher capacitance density and quality factor are. However, the thinner the thickness is, the lower the yield is due to the process tolerance during the fabrication. Figure 4 shows comparison of capacitances and quality factors of the fabricated capacitors with different sizes at the same thickness of the high Dk sheet. These embedded capacitors have capacitance values ranged from 3.71 to 5.77pF and maximum quality factors ranged from 42 to 37 at 2GHz. Figure 5 (a) shows equivalent circuit model of the embedded MIM capacitor. Rs and Ls are parasitic resistance and inductance values of the feed line and top electrode. Cp is an effective capacitance value and Rp is a parasitic resistance value which is purely dielectric loss. Figure 5 (b) shows the measured and the fitted impedance and phase characteristics. Series connected parasitic resistance and inductance values are ranged from 0.17 to 0.25nH and from 0.45 to 0.32 Ohms, respectively. Parallel connected parasitic resistance and effective capacitance values are ranged from 5100 to 3010 Ohm and from 2.07 to 8.16pF, respectively. These values are dependent on the size of the embedded capacitors. They can be useful for designing embedded passive circuits and modules.



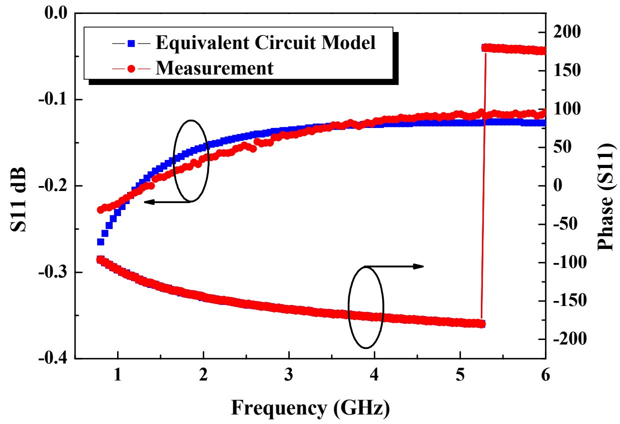
<Figure 3> Comparison of capacitance and quality factor at 2GHz of the embedded capacitors with different heights and effective areas.



<Figure 4> Comparison of capacitance and quality factor of the embedded capacitors with different effective areas at the same height (ε_r : 30, T 16um).



(a)



(b)

<Figure 5> Equivalent circuit model of embedded MIM capacitor with one port termination to ground (a) and comparison of measured and simulated impedance characteristics of the embedded capacitor (b).

4. Conclusions

Fully embedded MIM capacitors into 8-layered organic package substrate have been designed, fabricated, and characterized for low cost RF SOP applications. $BaTiO_3$ dielectric films with different thicknesses have been applied to fabricate MIM capacitors to achieve higher quality factors and reduce their sizes. It has good performance characteristics at high frequency regime. The measured performance characteristics were well matched with CST 3D EM simulated ones. The developed MIM capacitors can be useful for advanced SOP products with various functionalities, lower cost, lower profile, smaller size and volume.

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