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Integration of MIM Capacitors on BCB with Thin-Film MCM-D Technology

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1. Introduction

Integration of capacitors is one of the key technologies for system-on-package (SOP) to realize its full potential. One major advantage that embedded capacitors have over their surface mount counterparts is much lower parasitic inductance [1]. This means they are directly useful in decoupling of high-power chips [1]. While much efforts are put on embedding capacitors throughout different SOP areas such as organic-based (MCM-L), ceramic-based (MCM-C) and thin-film-based (MCM-D), MCM-D shows the best suitability in terms of obtaining high capacitance density needed for decoupling in RF and millimeter wave applications. This can be attributed to the controllability of layer thickness and feature dimensions in MCM-D [2].

In the thin-film MCM-D architectures, capacitors are usually embedded on the substrate and multilayer benzocyclobutene (BCB) is stacked above [3], [4], thereby necessitating multilayer via interconnection. However, when the structure bears a thick BCB layer (>10 ㎛), large vias are needed since the aspect ratio of standard photo-BCB vias is about 1:4 [5], which lowers the compactness of the system. If MIM capacitors can be integrated directly on BCB, several via process steps can be reduced.

On the other hand, BCB has excellent planarization property [6]. If MIM capacitors can be reliably stacked on BCB, embedded capacitors based on thin-film process can also be realized on organic or ceramic substrates with surface roughness, utilizing BCB film as surface planarization layer.

In this work, MIM capacitors were integrated directly on the BCB layer coated over the silicon substrate. Large capacitance was aimed for decoupling purpose. The fabrication process of proposed MIM capacitors is presented and the performance of such capacitors is analyzed in the following.

2. Dielectric film properties

One of the governing factors that determines the I-V breakdown and reliability of MIM capacitor is dielectric film quality [7]. Prior to the fabrication of MIM capacitor, intensive experiments were conducted to obtain improved dielectric film quality with in-house remote plasma-enhanced chemical vapor deposition (RPECVD) system [8]. SiN_x was used as dielectric film since it is most cost effective [7] and compatible with our process. By optimizing various deposition parameters such as RF source power, pressure, and gas flow ratio that affect the properties of deposited films, we obtained SiN_x film with excellent breakdown field strength of larger than 7.4 MV/cm in Silicon MIS structure [8], when 600Å SiN_x is deposited at 190 ℃ over 300×300 ㎛^{2} pattern.

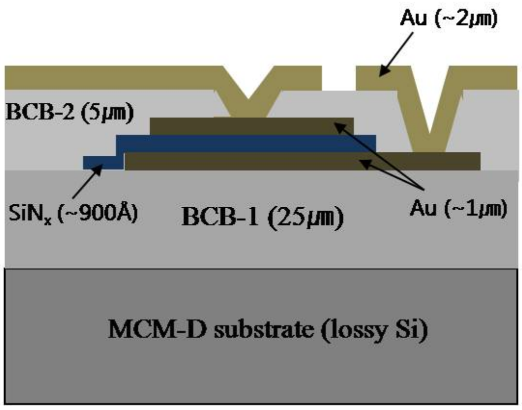

Fig. 1 Structure of MIM capacitor on BCB layer stacked over MCM-D substrate.

3. Fabrication of MIM capacitors

Fabrication of MIM capacitors in this work is based on the multilayer thin-film MCM-D technology. Figure 1 shows the structure of the fabricated MIM capacitor.

BCB layer of ~25 ㎛ was spin-coated over a typical low-cost lossy Si substrate (20 Ω·cm) and cured at 250 ℃ for 60 minutes. Curing temperature was determined in consideration of both the transition temperature of BCB and the deposition temperature of SiN_x. On top of the first BCB layer, bottom plate metal of ~1 ㎛ was formed by typical Ti/Au evaporation and lift-off process. Using optimized deposition condition mentioned in the earlier section, 900Å RPECVD SiN_x film was deposited as an MIM dielectric layer. Top plate metal of ~1 ㎛ was formed using the same process as the bottom plate metal and above which the second BCB layer of ~5 ㎛ was spin-coated and cured. For interconnection with signal line, vias were formed by O_2/SF_6 plasma etching and Ti/Au of ~2 ㎛ was evaporated as signal line.

In order to investigate the scalability of capacitance, capacitor size was varied as 100×100 ㎛^{2}, 200×200 ㎛^{2}, 500×500 ㎛^{2}, and 1×1 mm^2. All the capacitors were fabricated as CPW type.

4. Results and discussion

Breakdown voltage of fabricated MIM capacitors was measured with HP 4155A parameter analyzer. Figure 2 shows the measurements result for varying capacitor size. The breakdown voltage ranged from 58 to 92 V, or equivalently, the breakdown field strength ranged from 6.4 to 10.2 MV/cm for capacitor size varying from 1×1 mm^2 to 100×100 μm^2. The appeared breakdown characteristic indicates excellent quality of deposited SiN_x film as well as reliability of the MIM capacitors stacked directly above the BCB layer.

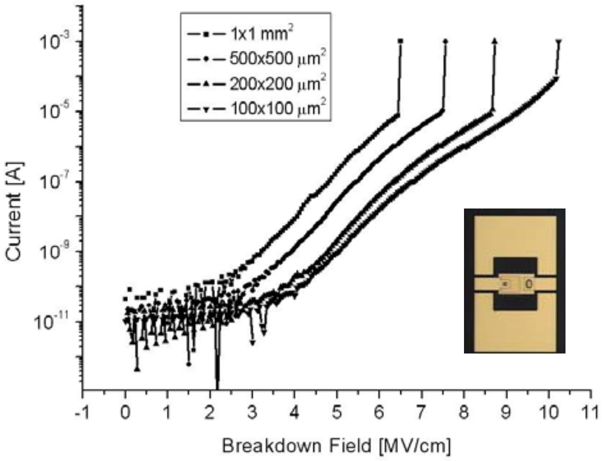

Fig. 2 Measured breakdown field strength of MIM capacitors for varying capacitor size.

To extract intrinsic capacitance of fabricated MIM capacitors, RF measurements were performed with HP 8753D network analyzer. Measured S-parameters (S_{11}) are shown in Fig. 3 for two different capacitor sizes, in which the fabricated MIM capacitors traced ideal loci of capacitor over the entire measurement frequency range.

The extracted values of intrinsic capacitance for varying capacitor size are listed in Table I. Maximum capacitance of 547.8 pF was obtained from 1×1 mm^2 MIM capacitor. This value is considered to be large enough to function as decoupling capacitor in the millimeter wave frequency application. It is also observed that the trend between capacitor size and capacitance value is very consistent throughout the scaling range, yielding an almost constant specific capacitance (capacitance per unit area) of ~540 pF/mm^2 with variation within ± 2 %. This is reasonable capacitance density for MIM capacitors with 900Å SiN_x film deposited as dielectric layer.

Table I. Extracted intrinsic capacitance of MIM capacitors for varying capacitor size.

Size (μm^2)	1000x1000	500x500	200x200	100x100
C (pF)	547.8	135.1	21.2	5.3

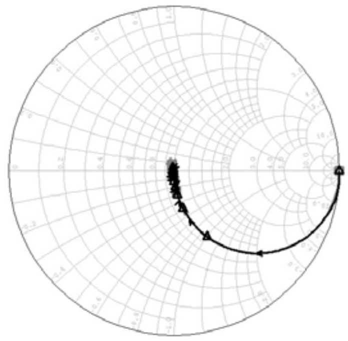

Fig. 3 Measured S-parameter (S_{11}) of MIM capacitors with size of 100×100 μm^2 (line with triangle symbols) and 200×200 μm^2 (line with square symbols).

5. Conclusions

MIM capacitors have been successfully embedded on BCB with RPECVD 900Å SiN_x dielectric layer. Fabricated MIM capacitors span a wide range from ~5 pF to ~550 pF with breakdown field strength of larger than 6.4 MV/cm.

The proposed structure promises the use of thick BCB layer in MCM-D technology with reduced via interconnection.

It is worthwhile to emphasize that the demonstration of stacking MIM capacitors on BCB shows the possibility that embedded capacitors based on thin-film process can also be realized on organic or ceramic substrates with surface roughness, utilizing BCB as surface planarization material.

Acknowledgements

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