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Analysis and Optimization of Corner Effect of TSV Array in 3D Integrated Circuits

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Abstract

Crosstalk of high density Through Silicon Via (TSV) array is one of the major problems in 3-D Integrated Circuits (3D-IC). In this paper, the corner effect of a TSV array is analyzed by coupling capacitance and S parameter. The 6C static shielding method is modified at array corners according to our calculation. At last, we proposed and evaluated three crosstalk suppression schemes to achieve a better signal integrity.

1. Introduction

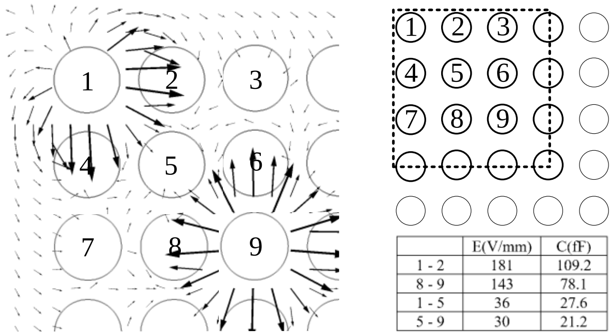
TSV has been widely used in 3D-IC due to its advantages of low latency, high integration, and low power consumption [1]. However, due to the repaid increase in integration scale, crosstalk is becoming crucial as TSV size and pitch shrinks, and can result in serous signal integrity issues including the rise of noise margin and bit error rate.

A straightforward solution to suppress crosstalk is to insert ground TSVs in the array for screening. However, this may increase the package area remarkably [2]. Since the electromagnetic coupling between TSVs at high frequency are localized [3], several crosstalk avoidances codes [4, 5] and layout shielding scheme [6] based on adjacent coupling capacitance are proposed to achieve better full chip signal integrity. However, none of those codes and schemes takes the corner effect into account.

In this paper, the corner effect of a TSV array is investigated and ground TSV based optimization schemes are proposed to suppress the corner electromagnetic coupling.

2. Analysis of the Corner Effect

In order to investigate the corner effect of an interposer, a 5×5 TSV array on a 10^{15}cm^{-3} doped P-substrate is simulated by a Finite Element Method (FEM) tool, to analyze the electromagnetic coupling mechanism on the corner. The diameter is 10um, pitch 15um, and depth 60um. As is shown in Fig. 1, the electromagnetic field distribution and intensity of the corner TVS significantly differ from those internals, which leads to a reinforced coupling capacitance on the corner, especially between the corner TSVs and their nearest neighbors (e.g. TSV1-2). Whereas the coupling between nearest diagonals (e.g. TSV1-5) are much weaker. For instance, the electric field at the midpoint between TSV 1 and 2 is 27% larger than that between 8 and 9, and the coupling capacitance is even 40% higher at 1G Hz. On the other hand, the electric field and coupling capacitance between TSV 1 and 5 are 20% and 31% larger than those between TSV 5 and 9. However, the coupling capacitance between TSV 1 and 5 is only 25.3% of that between 1 and 2, which has a good agreement with the 6C static shielding method [5].



	E(V/mm)	C(fF)
1 - 2	181	109.2
8 - 9	143	78.1
1 - 5	36	27.6
5 - 9	30	21.2

Fig. 1 Illustration of a TSV array's corner effect

On account of this, letting C_i *(i=1,2,3……)* denotes the average coupling capacitance with its nearest neighbors, and discards the nearest diagonals. C_1/C_9 can represent the magnitude of corner effect, namely the corner ratio, and $C_{2,3}/C_9$ the edge ratio. Fig. 2 is the comparison the $C_{1,2,3}/C_9$ as frequency changes. At 100M Hz, the corner ratio can reach 1.8. Whereas as frequency increases, it decreases to 1.3 due to the attenuation of the electromagnetic wave with higher frequency in the substrate. The edge ratios start from 1.52 and 1.4 at 100M Hz, and both converge to 1.2 at high frequencies. It can be seen the corner TSVs suffer the most severe crosstalk in the interposer.

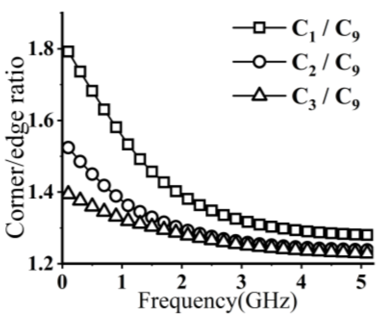
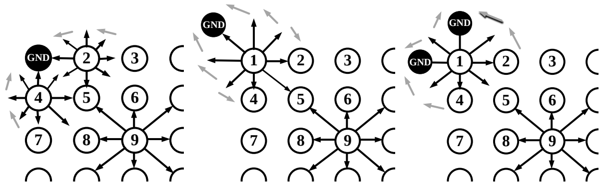


Fig. 2 Corner/edge ratio at different frequencies

The widely adopted 6C static shielding method, in which neighboring coupling capacitance is normalized to *C*, and the diagonal ones *0.25C*, has to be modified at the corner for a better estimation. In the view of the common working frequency of the 3D-IC, as well as for simplicity, the nearest neighbors' coupling capacitance should be modified to *1.5C*, and nearest diagonals *0.33C.*

3. Optimization and Evaluation

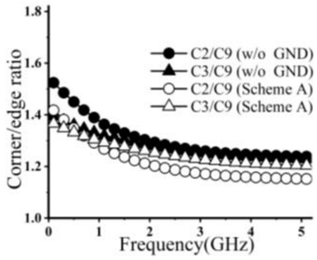
Based on the analysis of corner effect, we proposed three schemes in Figure 3 to optimize corner electromagnetic coupling in TSV array with minimal ground TSVs. In scheme A, the corner signal TSV is replaced by a ground one, and one or two ground TSVs are inserted by the corner in scheme B and C respectively.



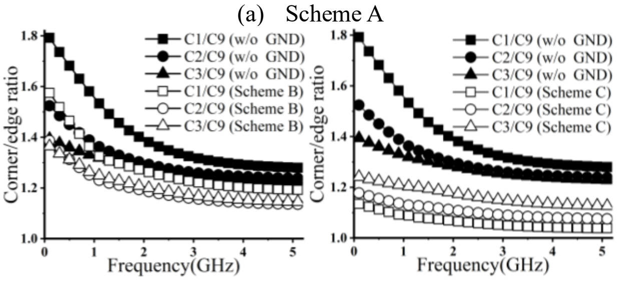
(a) Scheme A (b) Scheme B (c) Scheme C

Fig. 3 Three schemes for adding ground TSV

Figure 4 evaluates the three proposed schemes in frequency domain. The solid lines are the corner ratio (C_2/C_9 for scheme A) without introducing shielding ground TSVs as references for future evaluation. From the perspective of TSV2, Scheme A and B provides similar crosstalk suppression, but the corner ratio still reaches 1.6 in scheme B at low frequency. It is obvious that scheme C offers much better shielding at the entire frequency domain, because there are two closer ground TSVs on the neighboring position. Nevertheless, Scheme A offers a better area overhead with acceptable corner crosstalk. For the scheme C for high frequency purposes, the 6C static shielding method approximately holds at array corners.



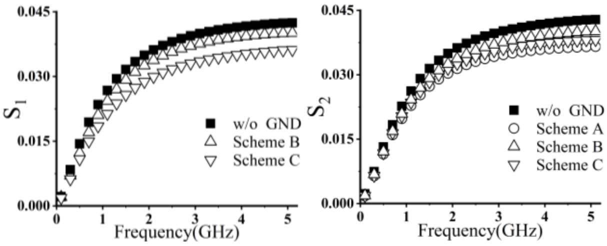
(a) Scheme A



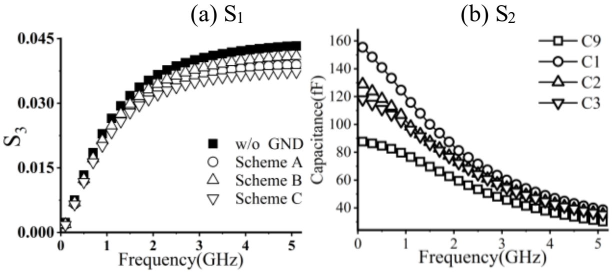
(b) Scheme B (c) Scheme C

Figure 4. Corner/edge effect evaluation for the three schemes

From the view of electromagnetic fields, the scattering parameter for TSV 1 and 2, namely the ratio of crosstalk energy and input energy, is plotted in Fig. 5 (a,b,c) for further comparison of the three schemes. As expected, Scheme C generally offers the best shielding effect, especially for TSV1 and 3. However, the coupling noise of TSV2 is reduced by 19% in scheme A, which is better than scheme C, because of its neighboring TSV1 is grounded and thus offers better local screening. The scattering parameters show reversed frequency responses with respect to the average coupling capacitance in Fig. 5 (d), because they are inversely proportional to the rising time of signals.



(a) S_1 (b) S_2



(c) S_3 (d) coupling capactiance

Figure 5. S parameter and average coupling capacitance for TSV 1, 2 and 3

From the above evaluation, Scheme C offers the best crosstalk suppression, but scheme A can achieve a better tradeoff between area overhead and signal integrity. In addition, sharp TSV array corners should be avoided in the interposer layout.

4. Summary

In this paper, we analyzed corner effect in a 5×5 TSV array by introducing a parameter corner ratio. At low frequencies, the corner effect is severe, and may cause the coupling at the corner 1.8 times larger than that in the center. The 6C static shielding method is modified at the corners based on our simulation. Moreover, three crosstalk suppression schemes based on minimal ground TSV numbers are proposed, compared, and characterized.

Acknowledgement

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