A High-Performance Global Eletromagnetic Noise Suppression Method for 3D TSV SiP

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***Abstract*—In this paper, we propose a high-performance method to suppress global electromagnetic noise coupling in 3D through silicon via (TSV) system in package (SiP). This technique needs to form a periodic shielding structure in 3D SiP, which consists of contact arrays, grid ground planes and ground TSV array. Contact arrays and grid ground planes can suppress noise coupling in the shallow substrate and ground TSV array suppresses noise coupling in the deep substrate. This method is practical for noise suppression in 3D SiP with heterogeneous integration. Results show that it has a better performance when it is compared to the guard ring method even the working frequency reaches 50 GHz.**

Keywords—Noise coupling suppression; 3D SiP (system in package); dispersive shielding; ground TSV (through silicon via) array.

I. Introduction

In recent years, the appearance of three-dimensional system in package (SiP), which is based on through silicon via (TSV) technology, not only facilitates high-density heterogeneous integration, but also has shorter interconnection length which can reduce the influence on device performance caused by interconnection delay.

However, the electrical analysis and design of 3D SiP are more challenging. In 3D SiP, as the working frequency increases, more noise from active circuits or signal TSVs will inject into the substrate and propagate in the way of electromagnetic coupling. Noise's propagation way includes compact three-dimensional horizontal and vertical electro-magnetic coupling. For the integrated design of mixed-signal IC, it is necessary to take effective noise isolation measures to ensure each IC can work normally.

At present, conventional guard ring method has been widely used in various noise isolation situation of ICs. Besides, there are some other noise isolation methods including silicon on insulator (SOI), high resistive substrate, deep N-well, deep trench isolation (DTI) and so on [1,2]. However, these methods have great defects when they are applied in 3D SiP because they can't effectively suppress noise propagated vertically. In our previous work, a noise suppression method which applies grid ground planes and contact arrays had been proposed and its effectiveness was verified [3]. But the noise suppression effect of this method will greatly decrease when the working frequency reaches more than 10 GHz.

In order to improve the noise suppression effect at high frequency, ground TSV array is introduced into this method. Finally, a periodic three-dimensional electromagnetic shielding structure is developed by the way of combining contact arrays, grid ground planes and ground TSV array. This structure is applied into substrate noise suppression between different dies in 3D SiP. We discuss the noise suppression effect in three cases based on the difference of aggressor and victim. It's proved that our method is more efficient in noise suppression when it is compared with the guard ring method. Its noise suppression stability and performance at high frequency is also better than that of our previous method.

II. Ground TSV Array, Contact Array and Grid Ground Plane

A. *Ground TSV Array*

Ground TSV array is composed of a series of TSVs distributed in the SiP periodically. All TSVs of the ground TSV array are evenly spaced and connect grid ground planes on different dies together to form a three-dimensional electromagnetic shielding structure. On the one hand, ground TSV array can provide nearby good return path for signal TSVs, which can effectively reduce the influence of electromagnetic interference caused by bad return path. On the other hand, ground TSV array can provide vertical return path to absorb substrate coupling noise so that it won't further spread and affect other circuits.

Conventional noise isolation method is not effective to suppress coupling noise propagated in vertical direction. But ground TSV array cross substrates of each dies vertically, which makes it easier to absorb coupling noise propagated vertically. The density of ground TSV array is adjustable, which depends on the design requirement. Generally, if the density of ground TSV array is higher, the noise suppression effect is better.

B. *Contact Array and Grid Ground Plane*

It's proved in [3] that the contact array can obtain a better noise suppression performance when it is compared to the guard ring method with the same cost of wiring space.

Using contact arrays and grid ground planes to suppress noise propagation is based on the theory of dispersive shielding. At low frequency, the impedance of oxide layer is very large which makes it's conductivity is poor. Thus contact arrays which directly contact with substrates mainly work to absorb noise at low frequency. At high frequency, the oxide layer will become more conductive which allows noise cross the oxide layer and flow back to grid ground planes.

III. Performance Comparision

In the design of 3D SiP, it's necessary for us to concern about the coupling noise propagated between different substrates in the vertical direction. As shown in Fig. 1, noise suppression methods are applied to a case of a three-layer stacked SiP. In this case a polymer material called benzocyclobutene (BCB) is used to form insulation layers between different dies. BCB is common in the application of wafer bonding technology because it not only has good stability and adhesion but also can be excellent passivation material [4].

For considering the cases of suppressing the noise coupling from pad to TSV (Pad-TSV) and from TSV to TSV (TSV-TSV), as shown in Fig. 2, aggressor and victim are changed. When our method is applied in two-layer SiP or SiP with more than three layers, the noise suppression structure can be modified in the similar way which is shown in Fig. 1.

Both the proposed method and guard ring method applied in three cases descripted above are simulated by 3D EM field solver, HFSS [5]. All simulation results are shown in Fig. 3.

For the case of Pad-Pad, the noise suppression performance of guard ring method is good enough, which can be concluded by comparing the noise transfer function curve of reference case and the case applied guard ring method. Our previous method without using ground TSV array has a better performance than that of guard ring method in the frequency range from about 1 GHz to 40 GHz. However, as the frequency increases, the noise suppression performance of the previous

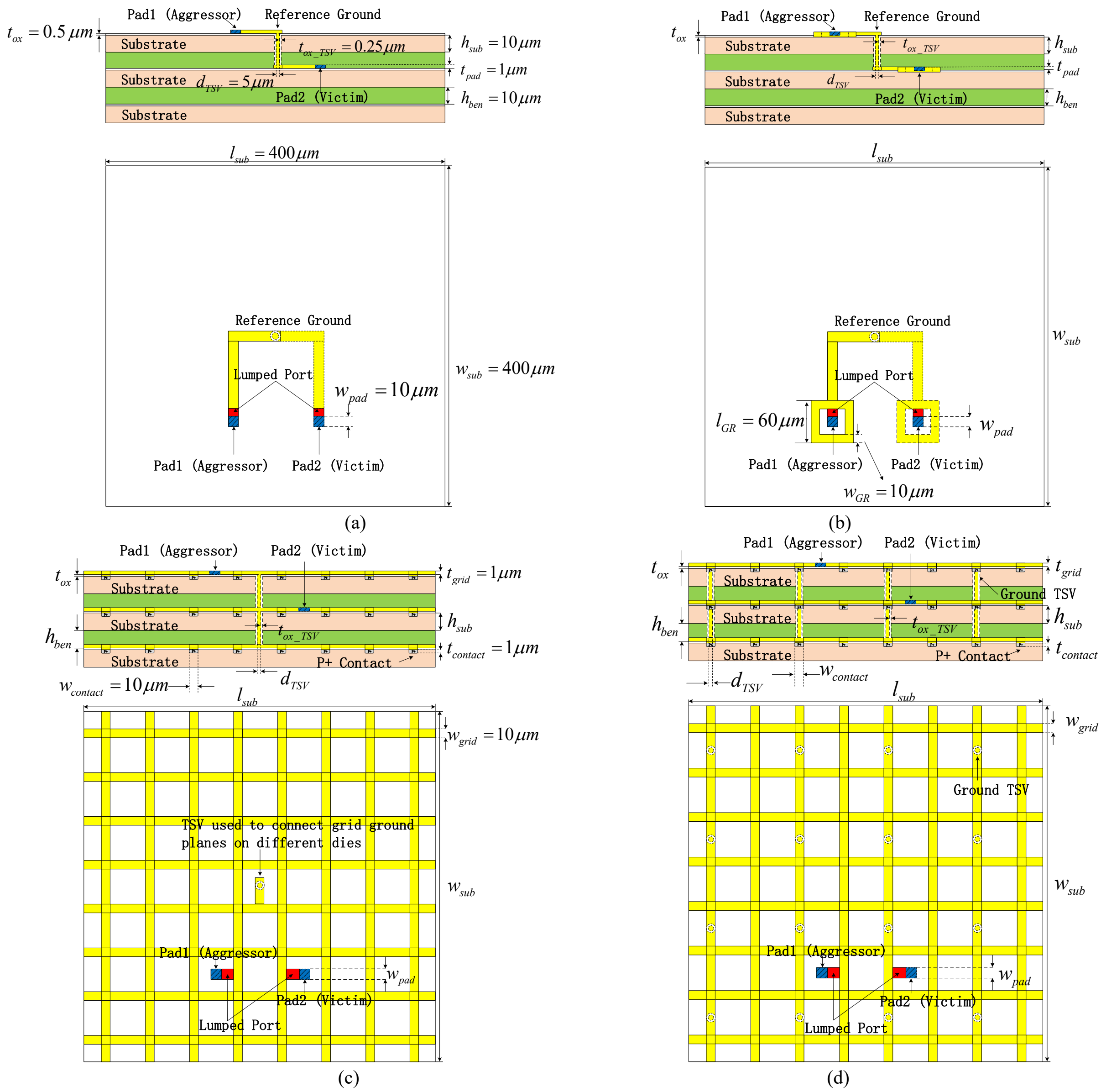
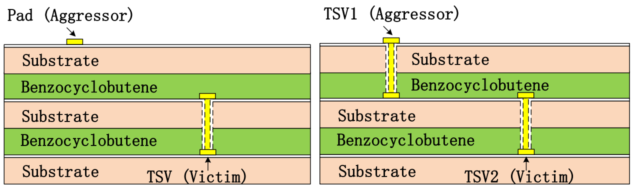
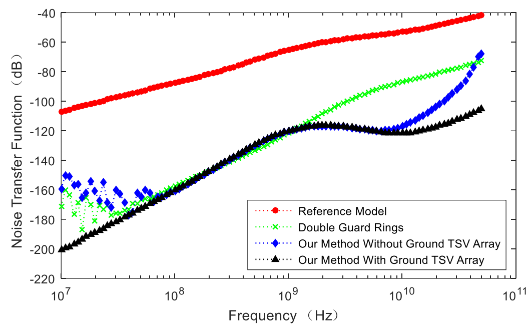


Fig. 1. Noise isolation methods for three-layer 3D SiP: (a) reference model, (b) double guard rings method, (c) our previous method without ground TSV array, (d) our method with ground TSV array. All the structures only shows the case of coupling noise isolation between pad and pad.

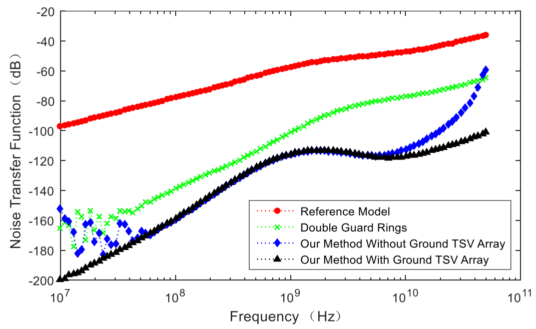


(a) (b)

Fig. 2. Settings of aggressor and victim for two-layer model when considering the suppression of noise from (a) pad to TSV, and (b) TSV to TSV.



(a)



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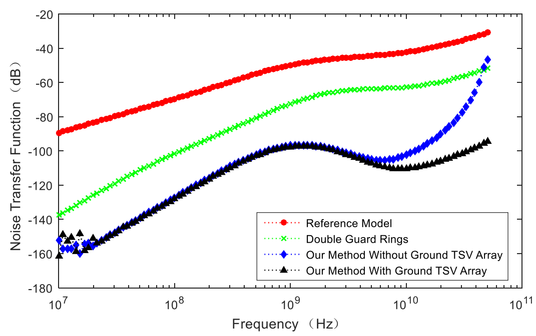

(c)

Fig. 3. Noise suppression performance comparison among the reference model, double guard rings, our previous method with only P+ contact array and grid ground plane, and our method with P+ contact array, grid ground plane and ground TSV array for three cases. (a) Pad-Pad, (b) Pad-TSV, (c) TSV-TSV.

method without ground TSV array decreases quickly. That's because at such a high frequency, more coupling noise inject into the depth of substrate which guard ring method and the previous method could not suppress effectively.

To resolve this problem, a vertical shielding structure is needed, which can be realized in the SiP by building ground TSV array. As shown in Fig. 3(a), when our method with 4×4 ground TSV array is applied, the noise isolation effect is improved in the frequency range from 6 GHz to 50 GHz.

For the case of Pad-TSV, as shown in Fig. 3(b), our previous method's noise suppression performance also decreases significantly when frequency is higher than 10 GHz. It's obvious that when our method with 4×4 ground TSV array is applied, this problem can be resolved and the best noise suppression effect is obtained, which at least has a suppression effect of 57 dB.

For the case of TSV-TSV, as shown in Fig. 3(c), it's obvious that our previous method has a better noise isolation effect than that of the guard ring method. In this case, both aggressor and victim are TSV which means that the noise coupling path is more dispersive and our method based on the theory of dispersive shielding is better. Similarly, the noise suppression effect of both our previous method and guard ring method degrades when the frequency goes to near 50 GHz. But for our improved method with ground TSV array, the shielding structure has at least 45.7 dB suppression in the whole simulation frequency range from 10 MHz to 50 GHz. At 50 GHz, the noise suppression effect even reaches 63.5 dB.

Thus, no matter for which cases, the improved method with contact array, grid ground plane and ground TSV array structure has the best noise isolation effect when it is compared with the guard ring method and our previous method. Our previous method is not good enough because its performance at high frequency degrades obviously which makes it not stable. Because ground TSV array is a vertical structure, it can improve the shielding structure's ability of absorbing noise in the depth of substrate.

IV. Conclusion

In this paper, a high-performance global electromagnetic noise suppression method for 3D TSV SiP is proposed. This method needs to build a three-dimensional global electromagnetic noise suppression structure which consists of contact arrays, grid ground planes and ground TSV array in SiP. It can effectively suppress the propagation of coupling noise. We apply this method to 3D TSV SiP design, to investigate its performance in the frequency range from 10 MHz to 50 GHz, and compared it with the conventional guard ring method. Results show that our new method has the best isolation effect and keep stable in the wideband.

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