Student Paper

The Incorporation of Electromagnetic Effects on Through Silicon Vias in TCAD Simulation

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***Abstract*－Self inductance and skin effect are included based on 3D EM simulation tools, Q3D and HFSS. The results of modified mix-mode TCAD simulation highly agree with the EM simulation results. When these EM effects are incorporated in the TCAD simulation for a 10GHz signal input, the error of the insertion loss has been reduced from ~10% to 3% and the error of the noise transfer function has been lowered to 4.7%.**

I. Introduction

TSV is one of the 3D IC technologies that enlarges the density of the devices and is a promising candidate to solve the rising economic issue of the future CMOS industry. The behaviors of a TSV signal-ground pair and the coupling effect between TSV signal-ground pairs play important roles in the circuit design. Previous work shows that to meet with the active demand of accurate electrical modeling of TSVs, the semiconductor effects such as depletion region and deep depletion in C-V characteristic have to be considered [1]. In EM simulation, depletion region can be regarded as a region which has zero conductivity to improve the accuracy. However, other semiconductor effects such as D_{it} and mobility degradation are very difficult to be added in. In TCAD simulation, most of the semiconductor characteristics can be included, but electromagnetic effects such as self-inductances and the skin effect induced by Eddy current are neglected, where a high frequency input signal causes considerable errors. In this work, self-inductances of a TSV signal-ground pair are added in mix-mode TCAD simulations, a part of the metal region of the TSV has been blanked properly to include the impacts of skin effect.

II. Simulation and Discussions

Fig. 1 shows our TSV simulation structures in TCAD and HFSS, respectively. The substrate is boron-doped p-type silicon with a carrier concentration equals to $1\text{x}10^{15}$ cm^{-3}. The TSV is filled by Cu, which has radius of 5um and length of 35um. There is a 100nm depth STI which is 2.5um wide. A P^+ guard ring with 1um wide and 1um away from the edge of the STI. The input signal is a DC voltage source of 1.2V with an ac sinusoidal term which amplitude equals to 0.05V. **Fig. 2** shows the values of skin depth in Cu under different signal frequencies. The values of skin depth under signal less than 100MHz are not shown since they are larger than the radius of Cu. The value can be approximated by analytic equation:

$$\delta_s = \sqrt{\frac{\rho}{\pi f \mu}} = \sqrt{\frac{2}{\omega \mu \sigma}}$$

The parameters of self-inductance can be extracted from Q3D simulation and are shown in **Fig. 3**. , and are used in the equivalent circuit of the TSV signal-ground pair.

Fig. 4 indicates the relationships between insertion loss and input signal frequency. For input signal frequency lower than 2 GHz, both TCAD simulations with and without considering skin effect and self-inductance are similar to EM simulation. The dominating loss mechanism at this frequency is dielectric loss [2] and it shows little dependency with skin effect. For 5GHz and 10 GHz input signals, the differences become observable. For a 10GHz input signal, the TCAD simulation without considering skin effect and self-inductance has nearly 10% error, the error becomes 3% under the consideration of skin effect and self-inductance.

Based on the above results, the simulation structure for coupling effect was built up considering skin effect under different input signal frequencies. All of the TSVs has a part of metal been blanked **(Fig.**

5). The simulation results of noise transfer function are shown in **Fig. 6**; an error down to 4.7% is achieved.

III. Conclusions

The electromagnetic effects on TSV at high-frequency are studied. In the simulation without considering skin effect and self-inductance, the insertion loss is underestimated and cause a ~10% error. By properly blanking a part of the metal of each TSV, the impact of skin effect can be included. At a 10GHz signal input, the error of the insertion loss has been reduced from ~10% to 3% and the error of the noise transfer function has been lowered to 4.7%**.**

Acknowledgment

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References

[1] T. Bandyopadhyay, R. Chatterjee, D. Chung, M. Swaminathan, and R. Tummala, “Electrical modeling of through silicon and package vias,” in Proc. IEEE Int. Conf. 3D Syst. Integr., Sep. 2009, pp. 1–8.

[2] Pak J. S., et al., “Slow wave and Dielectric Quasi TEM Modes of Metal-Insulator-Semiconductor (MIS) Structure Through Silicon Via (TSV) in Signal Propagation and Power Delivery in 3D Chip Package”, Electronic Components and Technology Conference, June 1-4, 2010, Las Vegas, USA.

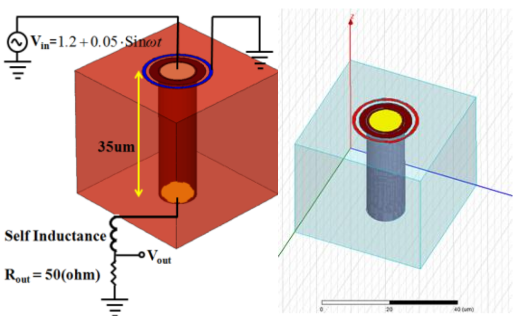
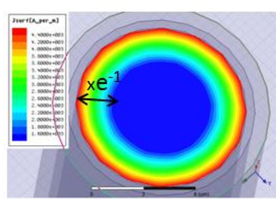
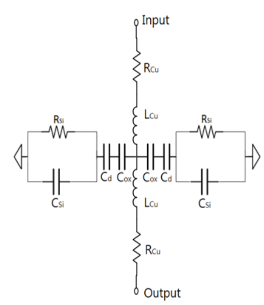


Fig. 1 The insertion loss simulation structure of a TSV signal-ground pair in mix-mode TCAD and EM simulator HFSS. A P+ guard ring is 1um wide and 1um away from the edge of the STI. The input signal is a DC voltage source of 1.2V with an ac sinusoidal term which amplitude equals to 0.05V.



Frequency	Skin depth
100MHz	6.540um
200MHz	4.624um
500MHz	2.955um
1GHz	2.068um
2GHz	1.478um
5GHz	0.935um
10GHz	0.654um

Fig. 2 Skin depths in Cu under different input signal frequencies. The parameters of skin depth are extracted from HFSS. Top views of TCAD simulation structure are shown for 200MHz, 2GHz and 10GHz input, respectively. A part of the metal region (the orange circle) has been blanked according to the skin depths.



Frequency	Inductance
10MHz	13.63pH
20MHz	13.45pH
50MHz	13.11pH
100MHz	12.75pH
200MHz	12.28pH
500MHz	11.53pH
1GHz	10.91pH
2GHz	10.3pH
5GHz	9.67pH
10GHz	9.36pH

Fig. 3 The values of self-inductance of a TSV signal-ground pair under different input signal frequencies. The self-inductances are extracted from Q3D simulation and have been considered in the equivalent circuit of the TSV signal-ground pair.

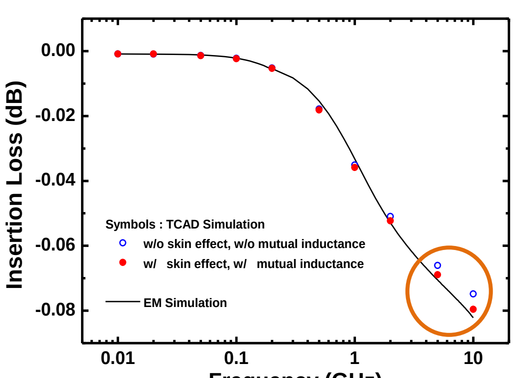


Fig. 4 The insertion loss of a TSV signal-ground pair in mix-mode TCAD simulation and the EM simulator HFSS. The solid line is the simulation result of HFSS. The empty circle represents TCAD simulation without skin effect and self-inductance. The solid circle represents TCAD simulation with skin effect and self-inductance. Under a 10GHz signal input, the error of the insertion loss has been reduced from ~10% to 3%.

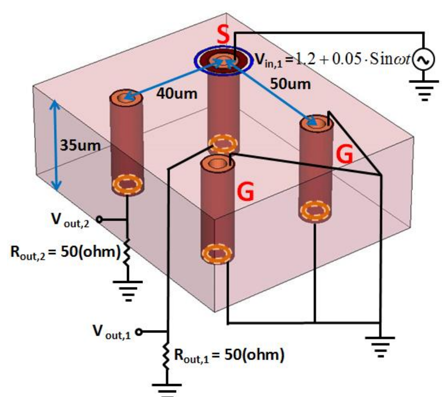


Fig. 5 The coupling effect simulation structure of TSV signal-ground pairs in mix-mode TCAD. One of the signal ports has a P+ guard ring with characters mentioned above.

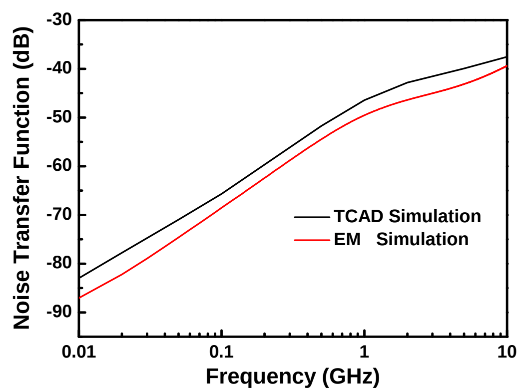


Fig. 6 The noise transfer function of a TSV signal-ground pairs in mix-mode TCAD simulation and the EM simulator HFSS. The black line represents the simulation result of TCAD considering skin effect and the red line shows the results of HFSS, Under 10GHz input signal, the error is down to 4.7%.