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A Novel hybrid strategy of via-first bare TSVs for enhanced signal integrity in 3-D integrated systems

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Abstract

In this paper, a hybrid strategy of via-first bare TSVs is proposed and analyzed aiming at mitigating noise coupling problems in 3-D integrated systems. With the proposed strategy, the noise coupling of the 3-D integrated systems is significantly reduced. Also, the proposed bare TSV streamlines process of conventional TSVs, for it eliminates insulation layer process in conventional TSVs.

1. Introduction

Three-dimensional (3D) integration technology is deemed the most promising solution for future integrated systems because of its reduced size, enhanced performance and hetero-integration capacity. Through silicon vias(TSV) are the key infrastructure in 3D integrated systems. In scenarios of advanced technology nodes, such as 20/14 nm, the via-first TSVs are more advantageous to the system compared with conventional via-last TSVs, for it demands less area, and thus allow an increased density of I/Os. However, these crowded TSV are beset with issues of signal integrity. In this paper, a novel hybrid strategy of via-first bare TSVs for enhanced signal integrity in 3-D integrated systems is proposed and analyzed. With the proposed strategy, the noise coupling of the 3-D integrated systems is significantly reduced, and the TSV process is simplified by eliminating insulation layer in conventional TSV structure.

2. The hybrid strategy of via-first bare TSVs

For via-first process, polysilicon is the usual choice of filling material in TSVs. In the proposed strategy, TSVs are without insulation layers (so-called bare TSVs), and are divided into two types, i.e. signal TSVs and ground TSVs. For signal TSVs, the polysilicon is doped with N-type impurities; for ground TSVs, the polysilicon is doped with P-type impurities. Then a thermal driven is followed to activate the doped ions, and to form ohmic contact between ground TSVs with P-type substrate. At the same time, a space charge region is formed in P-type substrate around N-type signal TSVs. The comparison of the proposed hybrid strategy with conventional strategy for the typical SGS(Signal-Ground-Signal) configuration is shown in fig.1. Note that in the conventional strategy, the depletion capacitance is formed due to the MOS (Metal-Oxide-Semiconductor) effect, while in the hybrid strategy, the junction capacitance is solely formed by the P-N junction. The signal TSV is insulated from substrate because of the reversely biased P-N junctions. Meanwhile, the ground TSV directly contact with substrate without an insulation layer pinned down the substrate potential to ground more effectively, which can help with noise absorbing and shielding.

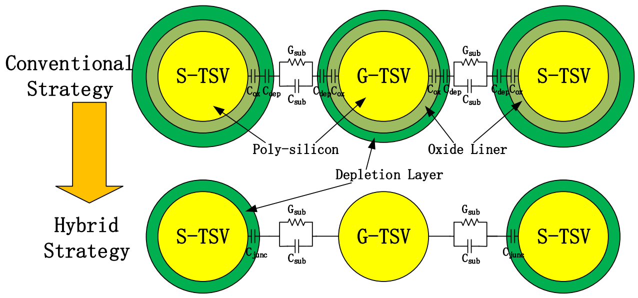

Fig.1 Comparison between conventional strategy and the proposed hybrid strategy

3 Noise coupling between signal TSVs

The hybrid strategy is generally composed of bare signal TSVs and bare ground TSVs. For bare signal TSVs, a cylindrical P-N diode is formed between TSV and the substrate. The P-N junction width, W_{junc}, is derived by solving cylindrical Poisson equations and applying charge conservation condition to the junction space[1]. The solving of W_{junc} enables the study of the hybrid strategy by method of 3D electromagnetic modeling and analysis. Table.1 shows the structural and material parameters submitted to the EM simulation.

It should be noted that, in a reversely biased P-N diode, the amount of reverse saturation current and reverse generation current density are about 10^{-7}A/cm^2, which is several pico-amps for each TSV. In this case, the reverse current can be regarded as negligible leakage current as with in conventional TSVs[2].

In order to demonstrate the advantages of the proposed hybrid strategy for noise reduction, a 3D full-wave electromagnetic field solver was applied to obtain the noise coupling coefficient for different scenarios based on parameters listed in Table I. As shown in fig.2, two lumped port was applied to the two signal TSVs respectively to extract S21 parameters as noise coupling coefficient between bare TSVs in SGS configuration.

Fig. 3 shows the extracted noise coupling coefficient of different strategies. First of all, the equality of bare signal TSV and conventional signal TSV is demonstrated. For bare signal TSV, the calculated junction width is 0.87μm and 1.29μm for quiet signal TSVs and aggressor signal TSVs respectively. For conventional TSVs, the calculated MOS depletion region is 0.72μm and 0.20μm for aggressor signal TSVs and ground/quiet signal TSVs. The simulation results shows that the noise coupling for bare TSVs and conventional TSVs in a dual-signal configuration are almost the same from 0.1-50GHz, as shown in fig.3. Then a ground TSV is inserted between two signal TSVs. The effectiveness of conventional ground TSVs and bare ground TSVs has been thoroughly investigated in [3,4]. The results shows that the application of bare TSVs in SGS configuration resulted in −27.76dB at 0.1GHz and −8.81dB at 10GHz of increased noise isolation over the conventional TSVs, respectively.

Table I structural and material parameters

Parameter	Description	Value
h_{TSV}	TSV height	10μm
r_{TSV}	TSV via radius	1μm
p_{GTSV}	Pitch between S-G TSVs	4μm
p_{STSV}	Pitch between S-S TSVs	8μm
t_{ox}	Thickness of TSV insulation layer	0.1μm
Na_{sub}	Doping concentration of P-type substrate	1.2e15cm^{-3}
Na	Doping concentration of P-type G TSV	1.0e20cm^{-3}
Nd	Doping concentration of N-type signal TSV	1.0e20cm^{-3}
W_{dep}	Thickness of depletion layer in TSV	0.72μm
W_{junc}	Thickness of junction in bare TSVs	0.87μm
Vdd	System supply voltage	1.2V

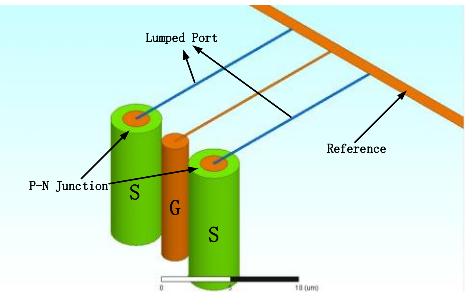

Fig.2 simulation configuration of noise coupling between signal TSVs

3. The bare TSV process flow

Another major advantage of the hybrid strategy is the elimination of insulation layer process in conventional TSVs. The general process flow utilizing the hybrid strategy is illustrated in fig.4. For via-first polysilicon TSVs, chemical vapor deposition processes are usually used for via filling [5]. After the filling of different types of heavily doped polysilicon, a thermal drive-in is then followed to ensure proper dopant diffusion and activate the doped ions. In general, the application of the proposed strategy only entails several additional steps that fills the signal and ground vias with different doped polysilicon. Therefore, the original circuit design, placement and routing are kept unaffected by the adoption of the hybrid strategy.

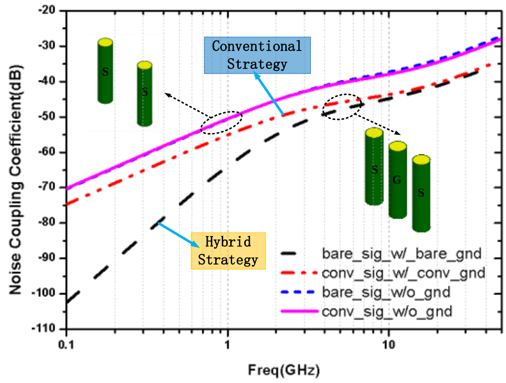

Fig.3 the noise coupling coefficient of different strategies.

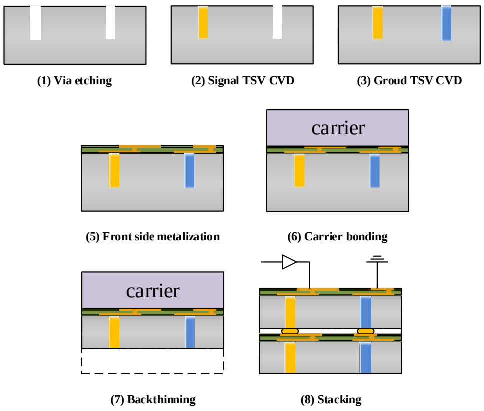

Fig.4 the general process flow of bare TSVs for hybrid strategy

4. Conclusions

In this paper, a novel hybrid strategy of via-first bare TSVs for enhanced signal integrity is proposed and analyzed by the 3D electromagnetic solver. The results show that, with the proposed strategy, noise coupling coefficient between signal TSVs is significantly reduced. Also, the proposed bare TSV streamlines process of conventional TSVs, for it eliminates insulation layer process in conventional TSVs.

Acknowledgements

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