Correspondence

Some Clarifications on "Compact Modeling and Analysis of Through-Si-Via Induced Electrical Noise Coupling in Three-Dimensional ICs"

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***Abstract*—The following clarifications are offered to allow the readers to easily understand some of the results in the authors' previous paper "Compact Modeling and Analysis of Through-Si-Via Induced Electrical Noise Coupling in Three-Dimensional ICs."**

***Index Terms*—Active region, body effect, compact model, coupling coefficient, impedance, noise, Through-Silicon-Via (TSV), 3-D integrated circuit.**

I. About the Body-Effect Parameter in [1]

In [1, Sec. III.A], the body-effect parameter γ is obtained from the SPICE parameters in a predictive technology model [2] in 22-nm high-performance bulk CMOS and

$$\gamma = \sqrt{2q\varepsilon_{\rm Si}N_{\rm body}} \cdot EOT/\varepsilon_{\rm ox} \qquad (1)$$

where q is the elementary charge; $\varepsilon_{\rm Si}$ and $\varepsilon_{\rm ox}$ are the permittivity values of Si and SiO_2, respectively; $N_{\rm body}$ is the body doping concentration in nMOSFET ($N_{\rm body} = 5.5 \times 10^{18}$ cm^{-3}); and EOT is the equivalent oxide thickness ($EOT = 1.05$ nm), including both the contributions from high-κ dielectric (0.8 nm) and the inversion layer (0.25 nm). Therefore, $\gamma = 0.414$ V$^{1/2}$.

II. About Equation (4) in [1]

This equation is derived under three assumptions: 1) well conductivity $\sigma_{\rm well}$ is much higher than substrate conductivity $\sigma_{\rm sub}$; 2) there are plenty of V_{DD}/V_{SS} lines; 3) through-silicon via (TSV) has a high aspect ratio (AR). From assumptions 1) and 2), the wells can be treated as a ground plane for the purpose of calculating the admittance due to the conductive and capacitive substrate Y_2 and total TSV self-impedance Z_{11}. The resistance network in the wells can be ignored since it is small.

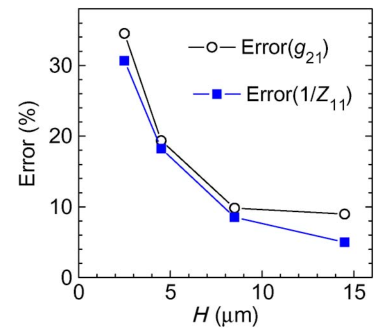

Fig. 1. Calculation error of our analytical model for $1/Z_{11}$ and g_{21} at 10 GHz. All the geometrical and material parameters are kept the same as those in [1, Fig. 6], except that we vary the substrate height H (see [1, Fig. 1(a)]).

In practical situations, the current source is at the surface of the TSV metal. However, from assumption 3), the scalar potential distribution in bulk Si can be treated as due to the current source at the *centerline* of TSV (called line-current-source approximation in [1]). This is similar to the treatment in [3, Sec. III.C], where the vector potential distribution outside a TSV due to the current inside the TSV is treated as due to a *line current* at the center of the TSV.

To demonstrate the accuracy of the line-current-source approximation, we show the calculation error of $1/Z_{11}$ and the noise coupling coefficient g_{21} at 10 GHz in Fig. 1. All the geometrical and material parameters are kept the same as those in [1, Fig. 6], except that we vary the substrate height H (see [1, Fig. 1(a)]), which indicates the AR of the TSV. The result shows that our model becomes less accurate when the AR of the TSV becomes smaller. In other words, for higher AR, the line-current-source approximation is more accurate.

III. About the Definition of $\delta(r)$ and Equation (15) in [1]

In cylindrical coordinate, the radius r ranges from 0 to $+\infty$. $\delta(r)$ is defined as

$$\delta(r) = \begin{cases} +\infty, & r = 0 \\ 0, & r > 0 \end{cases} \text{ and } \int_0^{+\infty} \delta(r){\rm d}r = 1. \qquad (2)$$

Equation (15) in [1] implies that the current density distribution $J_{4z}(r)$ injected into the p+ buried layer is a sharp function of r and its entire surface integral is equal to I_4, the total current injected into the p+ buried layer, i.e.,

$$\int_0^{+\infty} 2\pi r J_{4z}(r){\rm d}r = I_4. \qquad (3)$$

The sharpness is satisfied by $|L_D| \gg H_4$, where L_D is the current-spreading parameter (length), as defined in [1, eq. (14)].

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IV. About R and Z_{22} in [1]

Z_{22} and R are the impedance and the dc resistance from the body of the active region (MOSFET) to the body contact, respectively. Z_{22} is weakly dependent on frequency, and thereby, $Z_{22} \approx R$. Z_{22} and R include both the well sheet resistance and the well contact resistance.

V. Minor Correction

In our paper [1], there was a typo in the interpretation of Fig. 15(b) on page 4032, column 1, lines 3–8. For $f_T = f_{\text{clk}} = 5$ GHz, the characteristic distance should be calculated as 14.1 μm. For $f_T = f_B = 60$ GHz, the characteristic distance should be calculated as 9 μm.

Acknowledgment

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