실리콘에 기초한 새로운 크로스바 구조의 손실있는 대칭 결합선로에 대한 유한차분법을 이용한 해석

Analysis of Symmetric Coupled Line with New Crossbar Embedded on Si-based Lossy Structure using the FDTD Method

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ABSTRACT

A characterization procedure for analyzing symmetric coupled MIS(Metal-Insulator- Semiconductor) transmission line is used the same procedure as a general single layer symmetric coupled line with perfect dielectric substrate from the extraction of the characteristic impedance and propagation constant for even- and odd-mode. In this paper, an analysis for a new substrate shielding symmetric coupled MIS structure consisting of grounded crossbar at the interface between Si and SiO2 layer using the Finite- Difference Time-Domain(FDTD) method is presented.

In order to reduce the substrate effects on the transmission line characteristics, a shielding structure consisting of grounded crossbar lines over time-domain signal has been examined. Symmetric coupled MIS transmission line parameters for even- and odd-mode are investigated as the functions of frequency, and the extracted distributed frequency- dependent transmission line parameters and corresponding equivalent circuit parameters as well as quality factor for the new MIS crossbar embedded structure are also presented. It is shown that the quality factor of the symmetric coupled transmission line can be improved without significant change in the characteristic impedance and effective dielectric constant.

Key words : FDTD technique, Embedded and Crossbar Structure, Even- and Odd-mode, Attenuation constant, Characteristic impedance.

1. INTRODUCTION

Silicon-based technology is increasingly and widely used for RF and microwave integrated circuits because of the distinct advantages of low cost and well developed fabrication techniques. Interconnects in silicon-based ICs can be classified as Metal-Insulator-Semiconductor(MIS)

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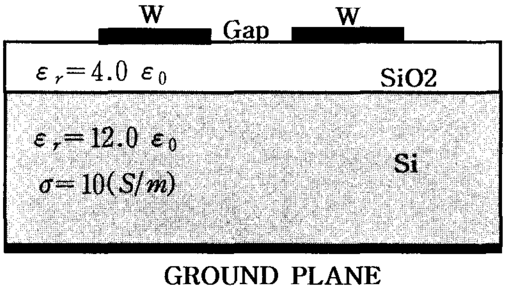
transmission lines, which consist of metal lines on semiconducting substrates, isolated by a thin SiO_2 oxide layer. As previous work, many researchers have reported the transmission properties of such structures including the analysis based on a parallel-plate waveguide approach of MIS microstrip lines[1~11].

Microstrip structures realized on a Si-SiO2 substrate are known to be quite sensitive to the conductive properties of Si because of the particular field configuration. Multi-layer multi-conductor configurations form a part of most of the high-speed circuits. More recently accurate characterization of Si-based lossy MIS structure including a single microstrip line with crossbars embedded MIS structure and multiple coupled lines on the single and multi-layered dielectric media using the Finite-Difference Time-Domain method has been presented by Kim[12~14].

In this paper, symmetric coupled MIS transmission line structure on Si-SiO2 substrates as shown in Fig. 1 is analyzed using the FDTD method. Then, a new substrate shielding structure consisting of grounded crossbars is examined, and microstrip characteristics for the symmetric coupled line over the crossbar shielding structure is presented. The substrate-shielded microstrip structure is essentially a two-layered microstrip line with a series of crossbar conductors at the interface between Si and SiO2 layer. The crossbar conductors are perpendicular to the main transmission line strip conductors and are assumed to be at ground potential. A full-wave analysis of the crossbar structure is carried out using FDTD. Equivalent circuit parameters are extracted for substrate-shielded microstrip structures from the FDTD simulations, and a comparison is made with the two-layered microstrip structure without substrate shield.



[Fig. 1] Symmetric coupled line of Si-based MIS structure.

2. SYMMETRIC COUPLED LINE MIS STRUCTURE

The symmetric coupled microstrip line is very useful for the design of various directional couplers.Basically, there are two fundamental quasi- TEM modes of propagation. The even mode is the mode corresponding to both microstrip conductors being at the same potential V and having equal currents. The odd mode corresponds to the microstrip conductors being at opposite potentials, -V and V, with respect to the ground plane. For the odd mode the currents on the two conductors are also equal in amplitude but of opposite direction.

The important parameters describing the quasi-TEM mode properties of the coupled microstrip line are the even- and odd-mode effective dielectric constants, and the even- and odd-mode characteristic impedances. The line parameters such as effective dielectric constants, $\varepsilon_{effe}(\omega)$ and $\varepsilon_{effo}(\omega)$, characteristic impedances $Z_{oe}(\omega)$ and $Z_{oo}(\omega)$ and propagation constants, $\gamma_e(\omega)$ and $\gamma_o(\omega)$ are calculated using equations (1) to (3) of the even- and odd-mode approach for the symmetric coupled line.

$$\gamma(\omega) = \frac{1}{L}\left(\ln\frac{V(z,\omega)}{V(z+L,\omega)}\right) \tag{1}$$

$$Z_0(\omega) = \frac{FFT\left\{\int_d^0 \vec{E}\cdot\vec{dl}\right\}}{FFT\left\{\oint_c \vec{H}\cdot\vec{dl}\right\}} \tag{2}$$

$$\varepsilon_{eff}(\omega) = \frac{1}{\omega^2\mu\,\varepsilon_0}\cdot\left\{\frac{1}{L}Im\left[\ln\left(\frac{V(z,\omega)}{V(z+L,\omega)}\right)\right]\right\}^2 \tag{3}$$

Where L is the length between the two monitored voltage points over the time domain simulations and FFT means the Fast Fourier Transforms, $\vec{E}$ and $\vec{H}$ also represent electric and magnetic field intensity, respectively.

Theoretically, the effective dielectric constant for the odd mode is smaller than that for the even mode because a larger percentage of the electric field energy is located in the air region. The capacitance between closely spaced parallel signal conductors at opposite potentials is large, so that the characteristic impedance of the odd mode is smaller than that for the even mode.

The attenuation constant for symmetric coupled microstrip lines is comparable to that for the microstrip line. For closely spaced conductors the increased concentration of the current near the two inner edges for the odd mode, along with the smaller characteristic impedance, increases the attenuation constant of this mode relative to that for the even mode.

For the odd mode the attenuation caused by dielectric loss will be less than that for the even mode since the electric field energy is more evenly distributed between the air region and the substrate region for this mode.

Using following equations (4) and (5), the even- and odd-mode parameters $L_e(\omega)$, $G_e(\omega)$ and $C_e(\omega)$ and $L_o(\omega)$, $G_o(\omega)$ and $C_o(\omega)$ for the symmetric coupled MIS structure can easily be calculated from equations (1) and (2) for each modes. And also the quality factors of symmetric coupled microstrip line for each modes can be calculated from propagation constant $\gamma_{e,o}(\omega)$ of transmission line shown in equation (6).

$$\gamma_{e,o}(\omega)\,Z_{oe,o}(\omega) \equiv R_{e,o}(\omega) + j\omega\,L_{e,o}(\omega) \tag{4}$$

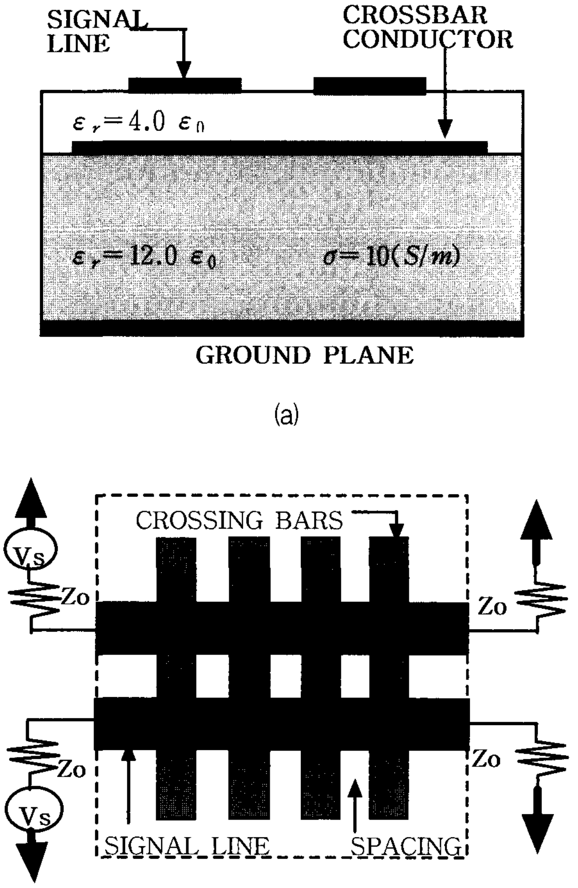
$$\frac{\gamma_{e,o}(\omega)}{Z_{oe,o}(\omega)} \equiv G_{e,o}(\omega) + j\omega\,C_{e,o}(\omega) \tag{5}$$

$$Q_{e,o}(\omega) = \frac{\beta_{e,o}(\omega)}{2\,\alpha_{e,o}(\omega)} \tag{6}$$

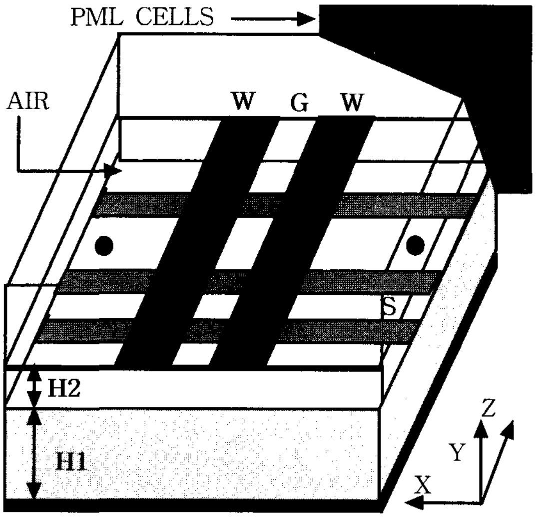
3. SYMMETRIC COUPLED MIS LINES WITH SUBSTRATE SHIELDING

Figures 2 and 3 show side and top view for a symmetric coupled line MIS structure and entire computational domain with embedded grounded crossbar for substrate shielding, respectively. The conductor lines are simulated on an $N_x\Delta x$ by $N_y\Delta y$ by $N_z\Delta z$ computational domain with Δx =10 μm, Δy=12.5 μm and Δz=20 μm. This corresponds to conductor widths W1=W2=5 Δx for the signal lines, a gap size between the two signal lines of G=5 Δx, a crossbar conductor width of Wc=2 Δz, and spacings S=3 Δz and 6 Δz between the crossbar, respectively. The substrate heights are H1=16 Δy and H2=2 Δy.

The entire computational domain including the PML boundary of 8 cells is divided into 78 by 50 by 280 grid cells. In the FDTD simulation, the time step of Δt=0.0218 ps is used and the total number of time steps is 2700. The input is excited with a Gaussian pulse with T=2.33 ps and t_0=6.98 ps.



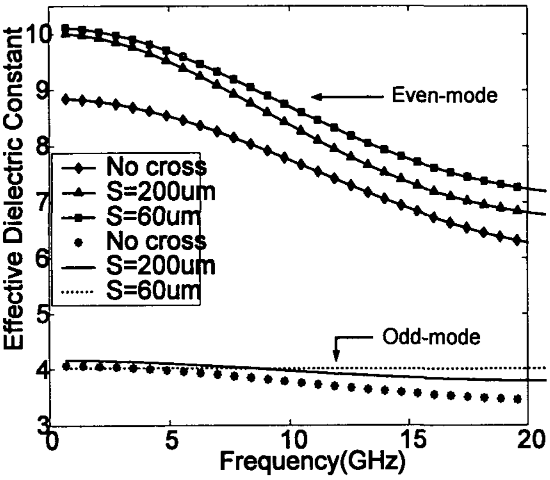
[Fig. 2] (a) Side view and (b) top view of symmetric coupled microstrip MIS line structure with embedded grounded crossbar for substrate shielding.



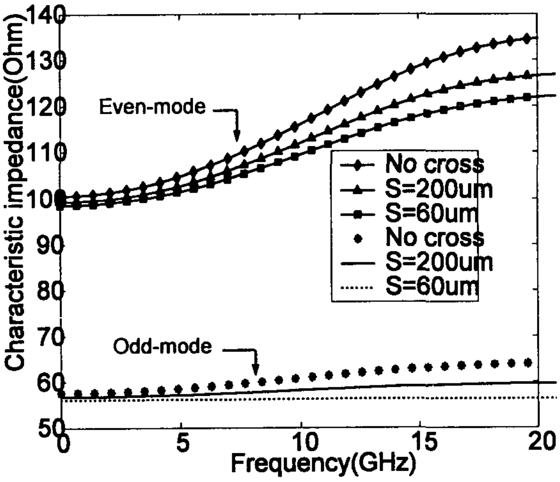
[Fig. 3] Entire computational domain for FDTD simulation of symmetric coupled lines with the crossbar shielding structure.

4. SIMULATION RESULTS FOR THE PROPOSED STRUCTURE

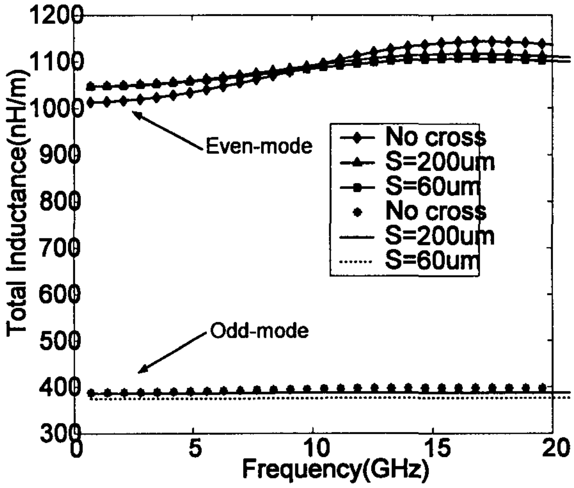
Figures 4 and 5 show the frequency-dependent effective dielectric constant $\varepsilon_{eff}(\omega)$ and characteristic impedance $Z_o(\omega)$ for the even- and odd-modes for the symmetric coupled lines with the embedded grounded crossbar



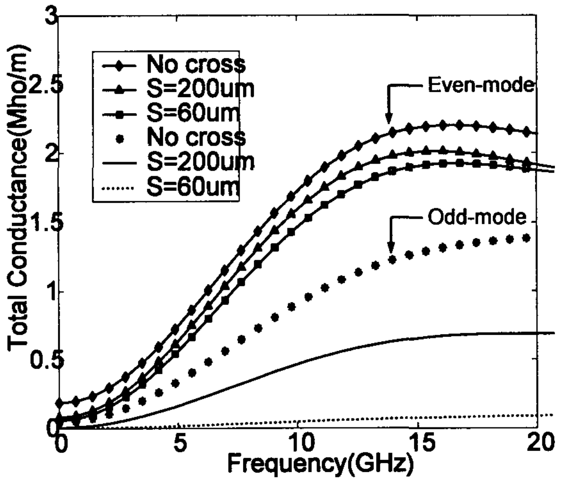
[Fig. 4] Effective dielectric constant of even- and odd-mode for the symmetric coupled lines with the crossbar shielding structure.



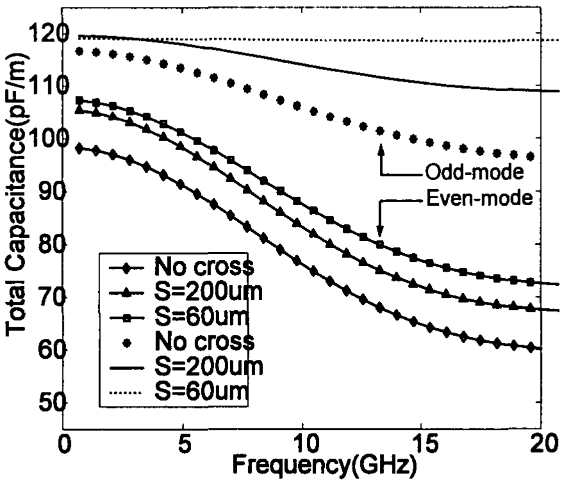
[Fig. 5] Characteristic impedances of even- and odd-mode for the symmetric coupled lines with the crossbar shielding structure.



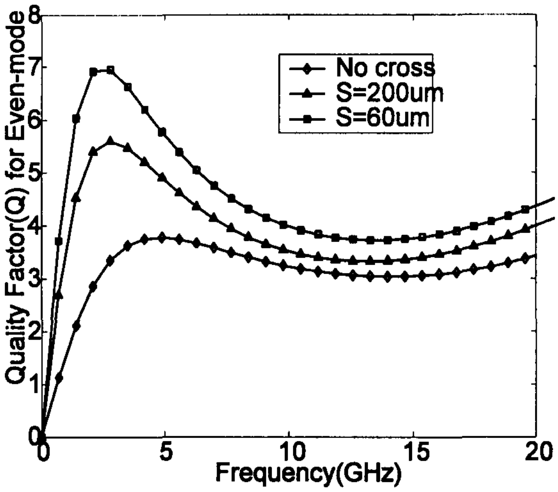
[Fig. 6] Total inductances of even- and odd-mode for the symmetric coupled lines with crossbar shielding structure.



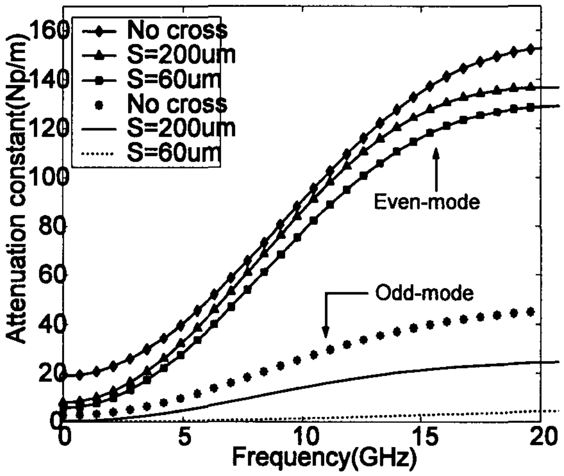
[Fig. 7] Total conductances of even- and odd-mode for the symmetric coupled lines with the crossbar shielding structure.



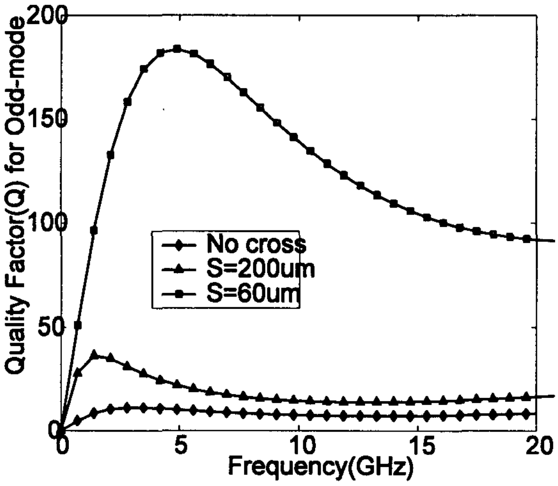
[Fig. 8] Total capacitances of even- and odd-mode for the symmetric coupled lines with the crossbar shielding structure.



[Fig. 10] Quality factors of even-mode for the symmetirc coupled lines with the crossbar shielding structure.



[Fig. 9] Attenuation constants of even- and odd-mode for the symmetric coupled lines with the crossbar shielding structure.



[Fig. 11] Quality factor of odd-mode for the symmetric coupled lines with the crossbar shielding structure.

structure for different spacings of the crossbar conductors and for substrate conductivity, σ=10 (siemens/m). The overall inductance, conductance, capacitance, attenuation constant and quality factor for even- and odd-mode are shown in Figures 6 to 11, respectively. It can be seen that as expected, the even mode attenuation characteristic is significantly higher than that for the odd mode due to the stronger field concentration in the substrate for the even mode.

In general, the even mode exhibits stronger frequency dependence. And also, it can be seen that as in the single line case, the crossbar shielding structure significantly reduces the shunt conductance and attenuation without significantly affecting the characteristic impedance.

5. CONCLUDING REMARKS

In this paper, the Finite Difference Time Domain(FDTD) method has been applied to investigate the frequency- dependent propagation characteristics of Si-based multilayer symmetric coupled line MIS structure with crossbar embedded between Si and SiO2 layer from the propagation constants and characteristic impedances.

The results show that the transmission line characteristics are strongly influenced by the lossy nature of the silicon substrate. In order to reduce the substrate effects on the transmission line characteristics, a shielding structure consisting of grounded crossbar conductor lines has been examined.

The extracted distributed transmission line parameters and corresponding equivalent circuit parameters as well as quality factor have been examined as a function of frequency. It was found that the quality factor of the symmetric coupled transmission lines can be improved without significant change in the characteristic impedance and effective dielectric constant.

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