논문 2006-43TC-12-11

다양한 손실매질내의 손실특성 개선을 위한 새로운 크로스바 구조의 해석

(Analysis of A New Crossbar Embedded Structure for Improved Attenuation Characteristics on the Various Lossy Media)

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요 약

본 논문에서는 일반적인 손실매질의 다층구조로 이루어진 마이크로 스트립선로의 손실특성의 개선을 위한 새로운 구조를 제안한다. MIS(도체-부도체-반도체) 구조로 된 전송선로를 해석하기 위하여 기본적으로 특성임피던스와 전파상수의 추출에 기초한 일반적인 특성화 절차가 사용되고, Si와 SiO2층 사이에 0전위를 가진 도체를 일정한 간격의 주기적인 배열로 고안된 새로운 모델의 MIS구조에 대한 유한차분법을 이용한 해석방법이 사용된다. 특히 전송선로에 대한 유전체의 영향을 줄이기 위하여 0전위를 가진 주기적인 결합의 도체로 이루어진 구조가 시간영역의 신호를 통해 시험된다. 다양한 손실률을 가진 불완전 유전체에 따른 전압 및 전류의 크기뿐만 아니라 주파수 의존적인 추출된 전송선로 파라미터와 등가회로 파라미터가 주파수 함수로서 나타내진다. 특히 본 논문에서 제안한 새로운 구조의 불완전 유전체에 대한 전송선로 파라미터가 주파수 함수로 구해진다.

Abstract

In this paper, we propose a new cross bar embedded structure for improvement of attenuation characteristics along the different lossy media. A general characterization procedure based on the extraction of the characteristic impedance and propagation constant for analyzing a single MIS(Metal-Insulator-Semiconductor) transmission line used and an analysis for a new substrate shielding MIS structure consisting of grounded crossbars at the interface between Si and Sio2 layer using the Finite-Difference Time-Domain(FDTD) technique is used. In order to reduce the substrate effects on the transmission line characteristics, a shielding structure consisting of grounded cross bar lines over time-domain signal has been examined. The extracted, distributed frequency-dependent transmission line parameters as well as the line voltages and currents, and also corresponding equivalent circuit parameters have been examined as function of frequency. It is shown that the quality factor of the transmission line can be improved without significant changes in the characteristic impedance and effective dielectric constant.

Keywords : Propagation characteristic, MIS(Metal-Insulator-Semiconductor) line, Grounded cross bar conductor

Ⅰ. INTRODUCTION

Silicon-based technology is increasingly used for RF and microwave integrated circuits due to the distinct advantages of low cost and well-developed fabrication techniques. Interconnects in silicon-based ICs can be classified as Metal-Insulator-Semiconductor (MIS) transmission lines, which consist of metal lines on semiconducting substrates, isolated by a thin oxide layer. The semiconducting substrate is characterized by its dielectric constant and conductivity. In the previous work, Guckel et al. investigated the transmission properties of such structures including the analysis based on a parallel-plate waveguide approach of MIS microstrip

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접수일자: 2006년5월17일, 수정완료일: 2006년12월12일

lines[1]. In the early1970s, Hasegawa[2] analyzed theoretically the transmission properties of microstrip lines using a parallel-plate waveguide model with a perfectly conducting line of infinite width for the MIS structure and compared them with experimental results. More recently efficient and versatile methods for the characterization of low-loss MIS structures have evolved[3,4], and G. Ghione studied a lossy quasi-TEM model for multiconductor bus lines on semi-insulating GaAs substrates and analyzed crosstalk, propagation signal delay and pulse distortion in high-speed circuits[5].

Microstrip structures realized on a Si-SiO2 substrate are known to be quite sensitive to the conductive properties of Si due to the particular field configuration. Goel reported a crosstalk analysis for a multi-layer multi-conductor system in the same dielectric[6]. Multi-layer multi-conductor configurations form a part of most of the high-speed circuits. Chan et al. presented the propagation characteristics of waves along a periodic array of parallel signal lines in a multi-layered structure in the presence of a periodically perforated ground plane and the characterization of the discontinuities made of two orthogonally crossed strip lines on a suspended substrate[7]. Recently, some researchers including G. Plaza and F. Medina reported the computation of the propagation constant and the characteristic impedance of the fundamental mode in planar transmission lines with nonperfect conductors printed on layered dielectric and/or semiconductor substrates.[8-10]

In this paper, a new substrate shielding structure consisting of grounded cross-bars is proposed and examined using the FDTD method. The substrate-shielded microstrip structure is essentially a two-layered microstrip line with a series of cross-bar conductors at the interface between Si and SiO2 layer. The crossbar conductors are perpendicular to the main transmission line strip conductor and are assumed to be at ground potential. Microstrip characteristics including the attenuation improvement for the MIS single line over the cross-bar shielding structure are presented.

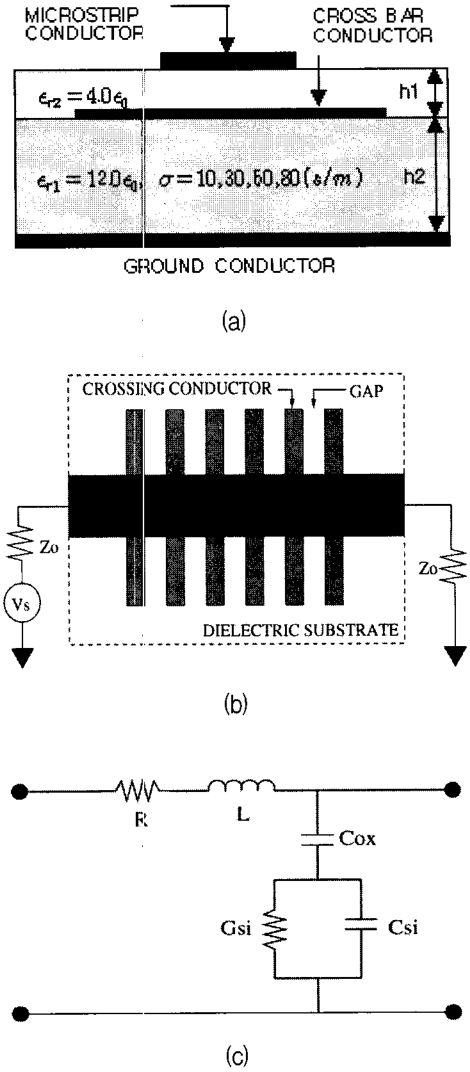

그림 1. 0 전위를 가진 크로스바의 단일 마이크로 스트립 MIS 선로 (a) 옆에서 본 구조 (b) 위에서 본 구조 (c) 분포정수 등가회로

Fig. 1. (a) Side view, (b) top view and (c) its distributed equivalent circuit model of single microstrip MIS structure with embedded grounded cross bars for substrate shielding

Ⅱ. ANALYSIS OF SINGLE MIS LINE WITH SUBSTRATE SHIELDING

Recently, the FDTD method has been widely extended to analyze microstrip based structures. The technique as such is well described by a number of researchers, and hence, not repeated in this paper. Application of the FDTD method to simulate the characteristics of the transmission lines provides broadband frequency information in one time simulation. Basically, in this method, the two Maxwell's curl equations are discretized both in time and space and the field values on the nodal points of the space-time mesh are calculated.

$$\nabla \times \mathbb{E} = -\mu \frac{\partial \mathbb{H}}{\partial t} \quad (1)$$

$$\nabla \times \mathbb{H} = \epsilon \frac{\partial \mathbb{E}}{\partial t} + \sigma \mathbb{E} \quad (2)$$

In the FDTD method, the entire computational domain is discretized into a number of cells of size Δx, Δy and Δz in x, y and z directions, respectively. As an input excitation, a Gaussian pulse is desirable because its frequency spectrum also being Gaussian, provides frequency domain information from DC to the desired cutoff frequency by adjusting the width of the pulse. A Gaussian pulse is defined by

$$g(t) = exp\left(\frac{-(t-t_0)^2}{T^2}\right) \quad (3)$$

where t_0 and T are time delay and gaussian pulse width, respectively. The electromagnetic fields calculated by the FDTD algorithm were used to compare the voltages and currents on microstrip signal line. Voltage and current are defined as

$$I = \int_c \mathbb{H} \cdot d\mathbb{L} \quad (4)$$

$$V = -\int_0^h \mathbb{E} \cdot d\mathbb{L} \quad (5)$$

where c is the transverse contour of a conductor and h is the distance between a conductor and the ground plane.

During the FDTD simulation, the potential is set to be zero for the grid cells containing the cross bar conductors so that all cross bars behave like perfect grounded conductors. The input port of the signal line is excited with a Gaussian pulse and the voltages and currents are recorded at two different locations. The characteristic impedance of the structure is obtained from the ratio of Fourier-transformed voltage and current. The metal strips and the ground plane are assumed to be perfectly conducting and infinitely thin, and are defined by setting the tangential component of the electric field to zero. The conductor line is simulated on computational domain with $\Delta x = 10\mu m$, $\Delta y = 12.5\mu m$ and $\Delta z = 10\mu m$. This corresponds to conductor width W=5 cells of the signal line, a cross bar conductor width of Wc=2 cells, a gap size between the cross bars of S=2 cells respectively, and substrate heights h1=16 and h2=2 cells. The width, N_x, and height, N_y, of the simulation box are chosen to be large enough to not disturb the field distributions near the strips. In all, the entire computational domain including the PML boundary of 8 cells is divided into 58 by 50 by 280 grid cells. A time step of Δt=0.0218 ps is used and the total number of time steps is 2500. The input is excited with a Gaussian pulse with T=2.33 ps and t_0=6.98 ps. A single line MIS structure with an embedded grounded cross bar structure for substrate shielding is shown in Fig. 1(a). The width and spacing of the cross bars are considered to be much smaller than the wavelength so that uniform signal propagation can be assumed along the line. As in the case without substrate shielding, the characteristic impedance $Z_0(\omega)$ and the propagation constant $\gamma(\omega)$ of the signal line are obtained from the ratio of Fourier-transformed voltage and current and the ratio of the voltages taken at two different locations, respectively. The equivalent circuit for a small length of the structure is Fig. 1(c) which consists of series resistance $R(\omega)$ inductance $L(\omega)$, shunt capacitances $C_{ox}(\omega)$ for the oxide layer and capacitance $C_{si}(\omega)$ and conductance $G_{si}(\omega)$ for the silicon layer. It is assumed that the capacitance and the conductance for the silicon layer are related as

$$\gamma(\omega) \cdot Z_0(\omega) \equiv R(\omega) + j\omega L(\omega) \quad (6)$$

$$\gamma(\omega)/Z_0(\omega) \equiv G(\omega) + j\omega C(\omega) \quad (7)$$

$$\frac{C_{si}}{G_{si}} = \frac{\epsilon_{si}}{\sigma_{si}} \tag{8}$$

where ϵ_{si} and σ_{si} are the dielectric constant and conductivity of Si layer, respectively. As mentioned above, the overall admittance $Y(\omega)= G(\omega)+j\omega C(\omega)$ is given. Using equations (3) and (4), the equivalent circuit parameters $C_{si}(\omega)$ for the oxide and silicon layer can be calculated as

$$C_{si}(\omega)= \frac{\sigma\epsilon}{Re\,(Z(\omega))(\sigma^2+\omega^2\epsilon^2)} \tag{9}$$

Ⅲ. SIMULATION RESULTS

Figs. 2 to 10 show the results of the MIS line with the cross bar structure for the same spacing of the cross bar conductors for different substrate conductivity, $\sigma = 10, 30, 50, 80(s/m)$. In Fig. 2, we can see that the magnitudes of monitored voltages over single MIS line with cross bars along the semiconductor resistivity as shown in table 1. In table 1, as we expect, we can easily find decreasing and increasing for voltage and current waveform, respectively.

And Fig. 3 show attenuation constant as a function of frequency. As the result of attenuation characteristics of the various types of semiconductor resistivity, we can see that the magnitudes of four cases of no cross bar are lower than the four cases of cross bar as shown in table 2. Fig. 3 shows that as the values of substrate resistivity are larger and the frequency is higher, the ranges of attenuation rate are much smaller.

표 1. 크로스바를 가진 단일 MIS 선로에서의 전압변화율(단위 : %)

Table 1. Line voltage attenuation of the signal line on a single MIS line with the embedded cross-bar substrate shielding structure(unit : %)

$\sigma = 10(s/m)$		$\sigma = 30(s/m)$		$\sigma = 50(s/m)$		$\sigma = 80(s/m)$	
No Cross	Cross	No Cross	Cross	No Cross	Cross	No Cross	Cross
100	88.18	80.73	72.73	70.0	65.45	63.64	61.09

표 2. 크로스바 유무에 따른 단일 MIS 선로에서의 다양한 전도도에 기인한 손실(단위 : s/m, Np/m)

Table 2. Attenuation constant for the various resistivity, no crossing and with cross-bar of the signal line on a single MIS line at some frequencies(unit : s/m for resistivity and Np/m for attenuation).

Freq.	Cross	$\sigma = 10(s/m)$	$\sigma = 30$	$\sigma = 50$	$\sigma = 80$
10 GHz	CR	25.25(Np/m)	35.46	40.26	43.51
	NOC	23.31	29.34	30.45	33.03
20 GHz	CR	75.34	124.78	141.1	149.76
	NOC	64.65	98.38	101.33	119.1
30 GHz	CR	119	243.76	278.8	290.7
	NOC	98.2	183.37	197.1	212.61

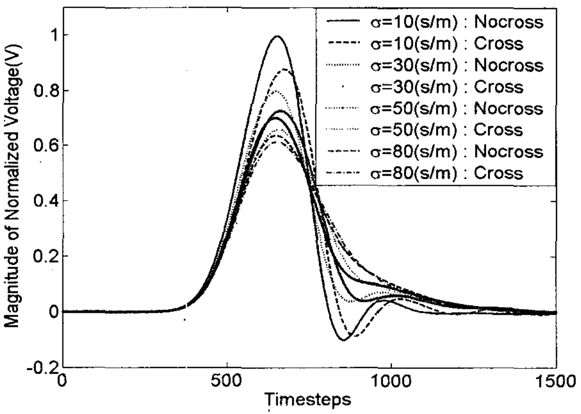

그림 2. 크로스바를 가진 단일 MIS 선로의 전압크기

Fig. 2. Magnitude of normalized monitored voltages for the FDTD simulation of a single MIS line with the embedded cross-bar substrate shielding structure.

Figs. 4 and 5 show the frequency-dependent effective dielectric constants and characteristic impedances for various types of resistivity for no cross bar cases as well as cross bar cases, respectively. It can be seen that the effective dielectric constant and characteristic impedance are changed only slightly by the presence of the cross bar structure. From the results of the characteristic impedance and propagation constant we can also easily calculate the total line parameters over equations (6) and (7) such as the overall capacitance C and inductance L shown in Figs. 6 to 7. And the results show us the rapid increase in capacitances for a slightly decrease of inductance at high frequency along the semiconductor resistivity.

Finally, Fig. 8 shows the capacitance calculated from equation (9) on silicon layer. It is observed that

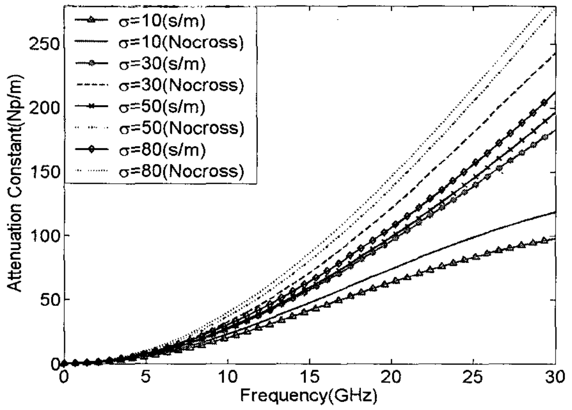

그림 3. 크로스바를 가진 단일 선로의 손실 상수

Fig. 3. Attenuation constant for a single MIS line with the embedded cross-bar substrate shielding structure.

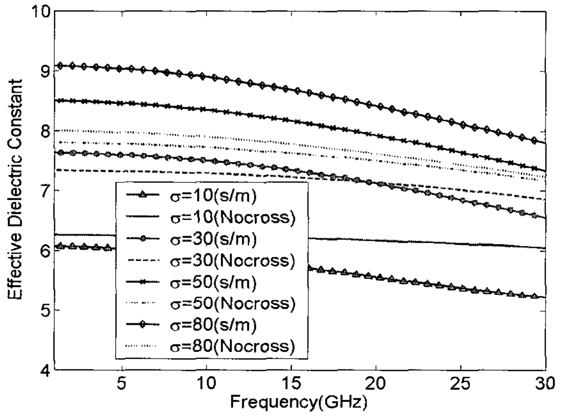

그림 4. 크로스바를 가진 단일 MIS 선로의 유효 유전율

Fig. 4. Effective dielectric constant for a single MIS line with the embedded cross-bar substrate shielding structure.

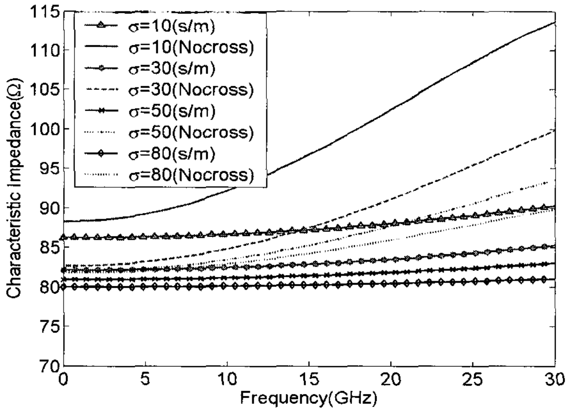

그림 5. 크로스바를 가진 단일 선로의 특성 임피던스

Fig. 5. Characteristic impedances for a single MIS line with the embedded cross-bar substrate shielding structure.

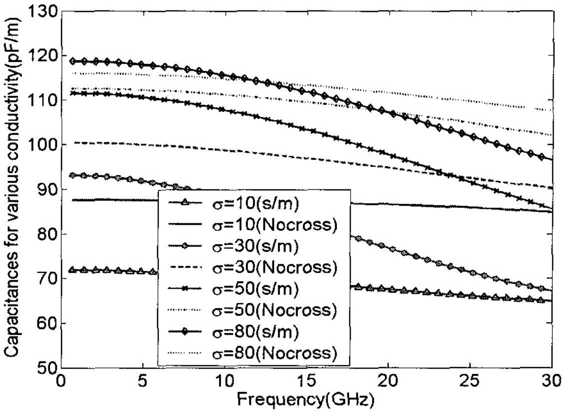

그림 6. 크로스바를 가진 단일 선로의 전체 커패시턴스

Fig. 6. Total capacitances for a single MIS line with the embedded cross-bar substrate shielding structure.

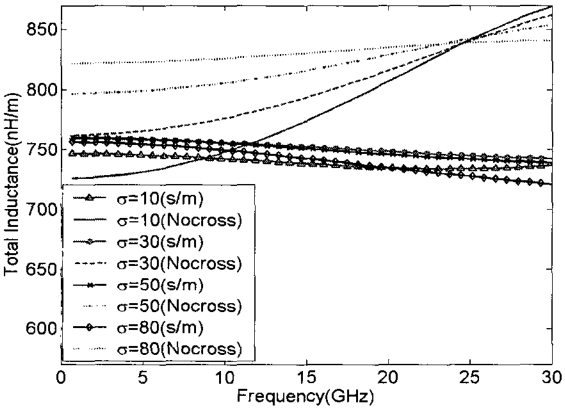

그림 7. 크로스바를 가진 단일 선로의 전체 인덕턴스

Fig. 7. Total inductances for a single MIS line with the embedded cross-bar substrate shielding structure.

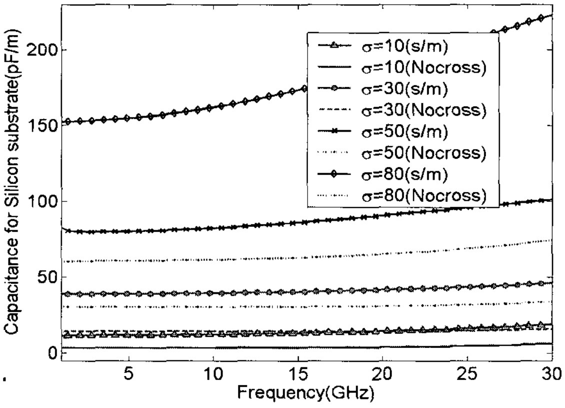

그림 8. 크로스바를 가진 단일 선로의 실리콘 층에서의 커패시턴스

Fig. 8. Capacitances for silicon for a single MIS line with the embedded cross bar substrate shielding structure.

the silicon layer conductance $C_{si}(\omega)$ is increased with the higher semiconductor resistivity.

IV. CONCLUDING REMARKS

In this paper, the Finite Difference Time Domain (FDTD) method has been applied to compute the propagation constants and characteristic impedances of Si-based multi-layer single microstrip line MIS structures. The results show that the transmission line characteristics are strongly influenced by the lossy nature of the silicon substrate. In order to reduce the lossy substrate effects with various types of resistivity on the transmission line characteristics, a shielding structure consisting of grounded cross bar conductor lines has been examined.

The extracted, distributed transmission line parameters and corresponding equivalent circuit parameters as well as line voltages and currents have been examined as a function of frequency. It was found that the attenuation characteristics of the multi-layered MIS transmission lines with cross bars can be improved without significant change in the characteristic impedance and effective dielectric constant. As mentioned above, we can see that attenuation characteristics are reduced along the crossbars and semiconductor resistivity.

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