Influence of the SRO as Passivation Layer on the Microwave Attenuation Losses of the CPWs Fabricated on HR-Si

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***Abstract*—In this letter, silicon rich oxide (SRO) is used as the passivation layer of coplanar wave guides (CPWs) fabricated on high resistivity silicon (HR-Si). The microwave performance of the CPWs is evaluated computing the attenuation loss (α) of the device in the 0.045–50 GHz frequency range. It is shown that for frequencies lower than 5 GHz the losses of CPWs using SRO as a passivation layer are lower than those of CPWs using SiO_2. It is also shown that using a combination of thermal and CVD SiO_2, a reduction of the losses of CPWs is obtained.**

***Index Terms*—Attenuation loss, coplanar wave guides (CPW), matrix wave propagation, passivation layer transmission, silicon rich oxide (SRO).**

I. Introduction

CONSIDERABLE effort has been directed toward lowering the attenuation losses of coplanar wave guides (CPWs) fabricated on high resistivity silicon (HR-Si). Attenuation losses of CPWs have a negative impact in digital and analog circuits [1]. For example, in digital circuits they may produce logic glitches, and they can distort signals in analog circuits. It has been suggested that microwave losses of CPWs fabricated on HR-Si depend on the charges accumulated at the interface, the traps in the passivation layer, and the interface trapped charges [2], [3]. Recently, $Al/SiO_2/HR-Si$ and Al/Poly-Si/HR-Si structures have been devised in [4], [5] for eliminating the DC leakage current between the signal and ground conductors of CPWs and for minimizing the attenuation loss. In [6], a study of the dependence of the attenuation loss of a CPW on the bias, and on the thermally grown SiO_2 layer (deposited by Low Pressure Chemical Vapor Deposition, LPCVD), has demonstrated that the attenuation loss is not modified by the forward and reverse bias. On the other hand, there have not been any studies of the effect of SiO_2 grown in two steps (thermal oxidation plus Atmospheric Pressure Chemical Vapor Deposition, APCVD), nor the effect of silicon rich oxide (SRO) [7] deposited by LPCVD as the passivation layer of a HR-Si CPW, on the performance of such devices. Thus, in this paper we investigate the microwave performance of the CPW fabricated on HR-Si and using two different passivation layers: SiO_2 grown by thermal oxidation and APCVD, and silicon rich oxide SRO_{20} deposited by LPCVD.

Manuscript received February 25, 2003; revised July 18, 2003. This work was supported by a joint funding of CICESE-INAOE and CONACYT México. The review of this letter was arranged by Associate Editor Dr. Arvind Sharma.

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Digital Object Identifier 10.1109/LMWC.2003.819967

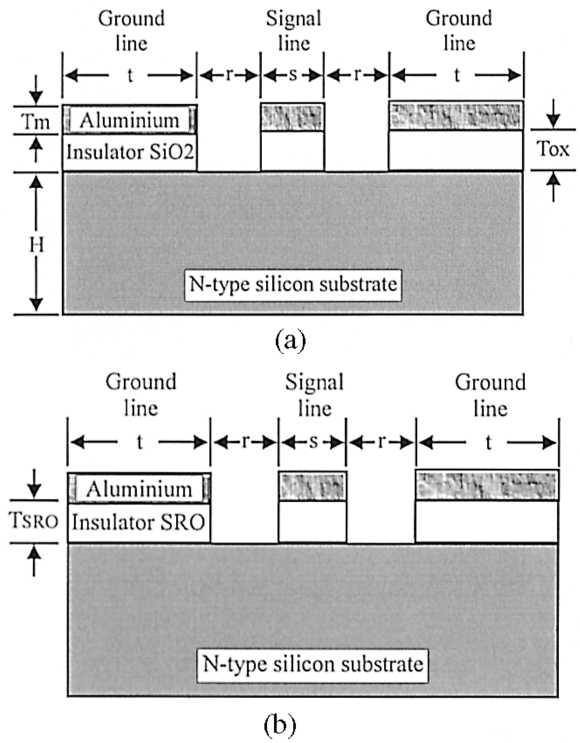

Fig. 1. The structure of the CPWs used in this study: (a) on patterned SiO_2 and (b) on patterned SRO_{20}.

II. CPW Fabrication

Fig. 1 shows the two structures used in this study. The CPWs were fabricated on 400 μm thick N-type Silicon with a resistivity higher than 2000 $\Omega - cm$. For the structure reported on Fig. 1(a), the silicon dioxide was grown in two steps. In the first step, a 600 Å SiO_2 layer was grown in Cl atmosphere at 950 °C. Then at 1100 °C in wet oxidation, the thickness was augmented to 20 000 Å, as in our standard CMOS process. Subsequently, to increase the thickness to at least 25 000 angstroms, an Atmospheric Pressure (APCVD) Silox deposition was carried out.

As for the structure reported in Fig. 1(b), the Silicon Rich Oxide (SRO) was low pressure chemical vapor deposited on the silicon substrates, and the ratio of reactive gases was $Ro = 20$.

TABLE I
RESULTS OF MEASUREMENT OF THE DIMENSIONS OF THE PLANES

Structure	t (μm)	s (μm)	r (μm)	Dielectric
CPW1	320 (360)	67 (100)	81 (50)	SiO_2
CPW2	345 (360)	88 (100)	60 (50)	SRO_{20}

A hot wall LP CVD system was used, and the reactive gases were N_2O and SiH_4. The deposition temperature was 700 °C, and the pressure was varied from 1.9 to 2.4 torr. The thickness and refractive index of the films were measured in a Gaertner model L117 ellipsometer with a 6328 Å helium neon laser and a 70 ° angle of incidence. The SiO_2 thickness measured was 2.69 μm, and for SRO_{20} the thickness was 0.55 μm. The films were then patterned to form the ground (t) and the signal (s) planes with various notch lengths (r). After patterning, the dimensions of the planes were measured using an optical microscope and a reticle with a filament. Results of measurement are shown in Table I (the values between parentheses correspond to the dimensions of the mask used). The overall length of the CPWs were 1 and 4 mm. Aluminum was used as a conductive layer on the planes. An aluminum layer was evaporated using an electron gun and patterned. The thickness was more than 1 μm.

III. MEASUREMENTS

To evaluate the microwave performance of the CPWs, an automatic network analyzer HP8510C system, a cascade probe station and coplanar probes were utilized. Prior to S parameter measurements, an off-wafer Through-Reflect-Match calibration was performed in the 0.045–50 GHz frequency range to establish the reference plane at the probe tips.

The measured S parameters of the CPWs are converted to transmission matrix to determine the line impedance and the wave propagation constant of the line using a new procedure reported in [8], [9]. The transmission matrix T_L of a line of length l featuring the unknown characteristic impedance Z_L can be expressed in terms of the propagation constant γ and reflection coefficient Γ in the form

$$\mathbf{T_L} = \frac{1}{(1-\Gamma^2)e^{-\gamma l}} \begin{pmatrix} e^{-2\gamma l} - \Gamma^2 & \Gamma(1-e^{-2\gamma l}) \\ -\Gamma(1-e^{-2\gamma l}) & 1-\Gamma^2 e^{-2\gamma l} \end{pmatrix} \quad (1)$$

where

$$\Gamma = \frac{Z_L - Z_o}{Z_L + Z_o} \quad (2)$$

and Z_0 is the reference impedance.

The method for computing γ and Γ of lines of unknown impedance is based on the fact that (1) may be expressed as [8], [9]

$$\mathbf{T_L} = \mathbf{T_\Gamma T_{50L} T_\Gamma^{-1}} \quad (3)$$

where

$$\mathbf{T_\Gamma} = \begin{pmatrix} 1 & \Gamma \\ \Gamma & 1 \end{pmatrix} \quad (4)$$

and

$$\mathbf{T_{50L}} = \begin{pmatrix} e^{-\gamma l} & 0 \\ 0 & e^{\gamma l} \end{pmatrix} = \begin{pmatrix} \frac{1}{\lambda} & 0 \\ 0 & \lambda \end{pmatrix}. \quad (5)$$

Solving (3) for $\boldsymbol{T_{50L}}$ one has

$$\mathbf{T_{50L}} = \mathbf{T_\Gamma^{-1} T_L T_\Gamma}. \quad (6)$$

On the other hand, the transmission matrix $\boldsymbol{T}$ resulting from the measurement of the uniform line L can be written as

$$\mathbf{T} = \mathbf{T_L} = \begin{pmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{pmatrix}. \quad (7)$$

It should be noted that (7) has to be equal to (1), which implies that the line has to be uniform and the network analyzer must be calibrated at the end of the probe tips. Under this assumption, combining (4), (5), and (7), (6) becomes (8), shown at the bottom of the page.

Comparing each term of the matrices on both sides of (8), λ may be expressed in the form

$$\lambda = \frac{t_{22} + \Gamma t_{21} - \Gamma(\Gamma t_{11} + t_{12})}{1-\Gamma^2} \quad (9)$$

and Γ will be given by the solution to the quadratic equation

$$\left[\frac{1}{\Gamma}\right]^2 t_{21} + \left[\frac{1}{\Gamma}\right](t_{22} - t_{11}) - t_{12} = 0. \quad (10)$$

Once the Γ value is determined at each measurement frequency, the value of the impedance is calculated as follows:

$$Z_L = \left(\frac{1+\Gamma}{1-\Gamma}\right) Z_o. \quad (11)$$

On the other hand, using expression (9) along with the Γ value computed using (10), the wave propagation constant is determined using the following expression:

$$\gamma = \frac{1}{L} \ln \lambda. \quad (12)$$

The wave propagation constant γ is directly related to the attenuation coefficient α and phase constant β ($\gamma = \alpha + j\beta$, $\beta = 2\pi f \sqrt{\varepsilon_{eff}}/c$; where f is the frequency and c is the speed of light). Following this procedure, the attenuation coefficient α per centimeter length and the effective dielectric constant ε_{eff} have been determined and their variations versus frequency are shown in Fig. 2 and Fig. 3.

Fig. 2 shows the attenuation coefficient α per centimeter length of the CPW investigated. It should be noted that at frequencies lower than 5 GHz, the CPW2 made with SRO_{20} exhibits lower attenuation than the CPW1 made with SiO_2. On

$$\begin{pmatrix} \frac{1}{\lambda} & 0 \\ 0 & \lambda \end{pmatrix} = \frac{1}{1-\Gamma^2} \begin{pmatrix} t_{11} + \Gamma t_{12} - \Gamma(t_{21} + \Gamma t_{22}) & \Gamma t_{11} + t_{12} - \Gamma(\Gamma t_{21} + t_{22}) \\ -\Gamma(t_{11} + \Gamma t_{12}) + t_{21} + \Gamma t_{22} & -\Gamma(\Gamma t_{11} + t_{12}) + \Gamma t_{21} + t_{22} \end{pmatrix} \quad (8)$$

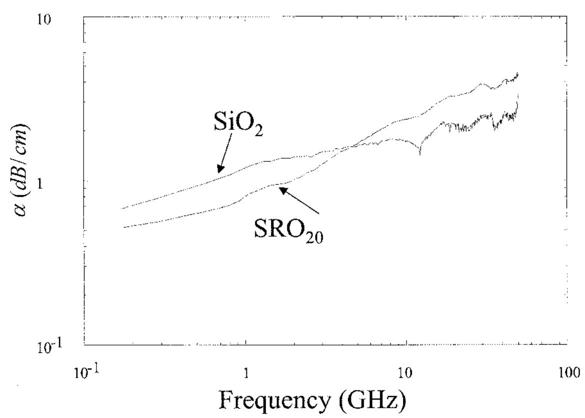

Fig. 2. Attenuation per physical length versus frequency computed with the new technique.

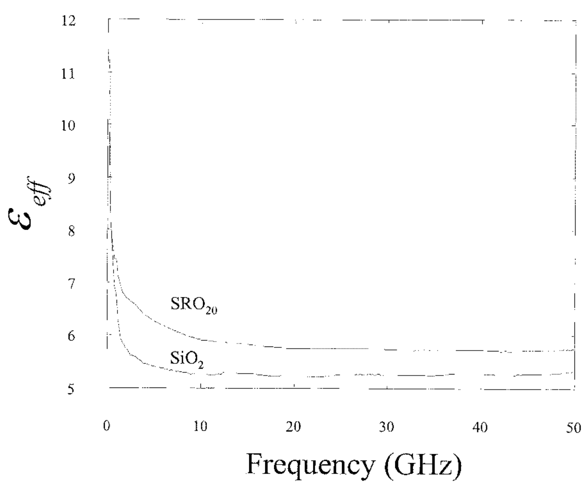

Fig. 3. Effective dielectric constant versus frequency for the CPW lines computed with the new technique.

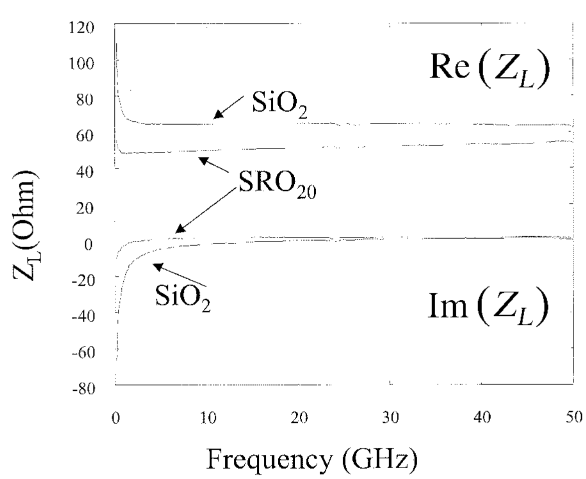

Fig. 4. Real and imaginary parts versus frequency computed with the new technique.

the other hand, the α measured in the CPW1 indicates that the SiO_2, obtained as described here, has a positive impact, since the losses are kept under 3 dB/cm and are better or at least comparable to lines made with SiO_2 deposited by CVD [6]. The difference on ε_{eff} observed in Fig. 3, is due to the different impedance value, computed using (10) and (11). Indeed, the impedance value measured for CPW2 (70 Ω) is larger than the impedance value of CPW1 (50 Ω) as shown in Fig. 4.

IV. Conclusions

The microwave performance of CPWs using SRO_{20} as the passivation layer has been evaluated for the first time. It is observed that the SRO_{20} passivation layer has a positive impact in the line losses, and this can be attributed to the charge trapping properties of SRO. In fact, if the trapped charge in the SRO is negative, the surface becomes depleted instead of accumulated as will be expected normally for an N-type silicon substrate.

Acknowledgment

The authors would like to thank J. de Jesús Ibarra Villaseñor and B. Ramírez Durán for device measurements.

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