Dispersion and Attenuation Characteristics of Suspended Microstrip Line on Multilayer Lossy Silicon Substrate at 60 GHz

Manish Prasad, Arun Singh Gaur, Vivek Kr. Sharma and Nagendra P. Pathak

Abstract— **In this paper, transmission line parameters such as characteristic impedance Z_0, effective dielectric constant ε_{eff}, attenuation constant α of Suspended Microstrip line on multilayer low resistivity silicon substrate are investigated. Effect of variation in the thickness of Si_3N_4, polyimide and metal layer are studied using HFSS. Due to suspended nature, significant reduction in transmission loss is observed in the simulation.**

Index Terms— **Dispersion, Multilayer Suspended Microstrip Line, CMOS grade Silicon, Discontinuities, Equivalent Circuits, CMOS millimeter wave integrated circuits.**

I. Introduction

Due to the increased interest in system on chip which includes RF circuits, IF circuits, antennas, it is necessary to develop low cost wireless modules on low loss silicon substrates. Performance of RF circuits on CMOS grade Si at 60 GHz are very poor due to very high loss coming from the Si substrate [1-2]. To overcome this problem, TFMS and CPW lines were proposed [3-5]. Since, suspended strip line and suspended microstrip lines are low loss transmission lines used to develop millimeter wave integrated circuits; suspended substrate line on multilayer lossy silicon substrate is considered in present work to investigate its suitability for the CMOS based integrated circuits at 60 GHz. The physical structure of suspended microstrip line is shown in Fig. 1. It consists of a lossy silicon substrate (ρ=10 Ω-cm) and thin layers of silicon nitride (ε_r=7.5, tanδ=0.0005) and polyimide (ε_r=4.3, tanδ=0.004). Part of lossy silicon substrate is removed to make structure suspended in air and to reduce the overall losses occurred in 60GHz frequency range. Perfect Electric wall boundary condition is applied to lateral boundaries and absorbing boundary condition is used at the top wall to simulate the multilayer suspended microstrip line in commercially available full wave FEM simulator HFSS [6]. The physical parameters used in the simulation are: side wall separation, a= 2000 μm (selected for single mode operation), height of the lossy *Si* wafer =300 μm, thickness of remaining silicon wafer after micromachining t_1=10 μm, thickness of silicon nitride layer t_2= 10 μm, thickness of polyimide layer, t_3 =20 μm and thickness of metallization t=2μm.

Authors are with the Department of Electronics & Computer Engineering Indian Institute of Technology Roorkee-247667-INDIA (email: nagppfec@iitr.ernet.in)

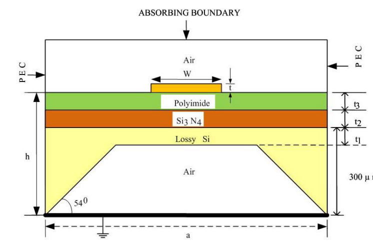

Fig. 1 Geometry of Suspended Microstrip Line on Multilayer Lossy Silicon Substrate

II. Dispersion and Attenuation Characteristics

Because of the inhomogeneous nature of the suspended micro strip structure, frequency dependence of the characteristic impedance and effective dielectric permittivity becomes important. Variation in characteristic impedance Z_0 and effective dielectric constant ε_{eff} with normalized conductor width W is shown in Fig. 2.

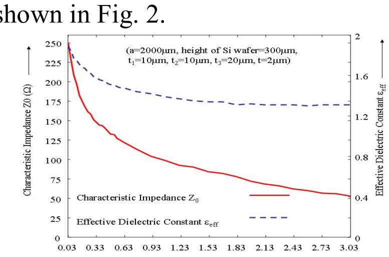

Fig. 2 Variation in Z_0 and ε_{eff} with W/h

From the figure, it is evident that highest impedance that can be realized in this geometry is 250Ω. At lower side of the impedance curve, we find that width of conductor is wide enough to help in easy fabrication. For the line width of 900 μm characteristic impedance is 50 Ω. The value of effective dielectric constant is low, ε_{eff}<2, which results in a higher propagation velocity required in high speed digital circuits.

978-1-4244-2120-6/08/$25.00©IEEE.

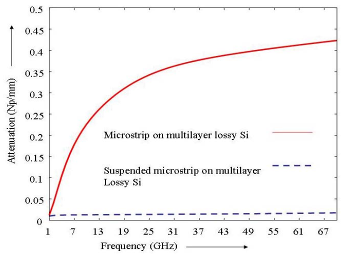

Fig. 3 Comparison of Attenuation in Microstrip Line and Suspended Microstrip Line on Multilayer Lossy Si

The overall attenuation in this transmission line structure can be separated into two parts: attenuation due to conductor loss at millimeter wave frequencies and attenuation due to dielectric loss in polyimide, silicon nitride and low resistivity silicon substrate. The variation in attenuation constant α (Np/m) is shown in Fig. 3. It is clear from the figure, that attenuation characteristics of suspended micro strip on multilayer lossy silicon are much better than micro strip line on lossy silicon substrate.

A. Variation in Thickness of Si_3N_4 and Polyimide layer

Effect of variation in thickness of Si_3N_4 and polyimide layer on over all attenuation characteristics of this transmission structure is studied. The thickness of silicon nitride layer t_2 is varied to obtain minimum attenuation. In the simulation, other structural parameters are fixed: t_1=10 µm, t_3=20 μm, t= 2µm and W=900 µm. Simulated attenuation constant (α) ranges from 9 Np/m to 20 Np/m in the frequency range of 1 GHz – 70 GHz as shown in Fig. 4. From the simulated results, the required thickness of Si_3N_4 layer for minimum attenuation is t_2 =10 μm. Similarly, the thickness of polyimide layer (t_3) is varied keeping the thickness of the Si_3N_4 layer t_2 =10 μm fixed. In this case other parameters of suspended micro strip line are: t_1=10 µm, t= 2µm and W=900 µm. From the simulation, the required thickness of polyimide layer for minimum attenuation is t_3 =2 μm. The variation in attenuation with thickness of polyimide layer is shown in Fig. 5.

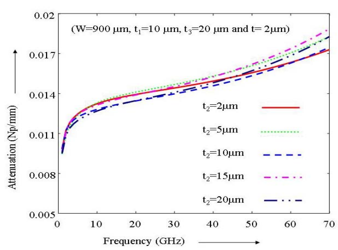

Fig. 4 Effect of Variations in Si_3N_4 Thickness on Attenuation

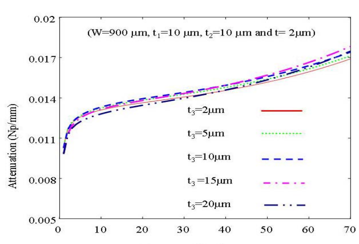

Fig. 5 Effect of Variation in Polyimide Thickness on Attenuation

B. Variation in Thickness of Strip Conductor

The thickness of strip conductor is varied while keeping thicknesses of the dielectric layers constant to select the conductor thickness, *t*, for which the attenuation constant (α) is minimum. The physical parameters used in the simulation are: W=900 μm, t_1=10 μm, t_2=10 μm and t_3=2 μm. The variation in attenuation with strip conductor thickness is shown in Fig. 6. From the simulated results, the required thickness of the conductor for minimum attenuation is t= 2 μm.

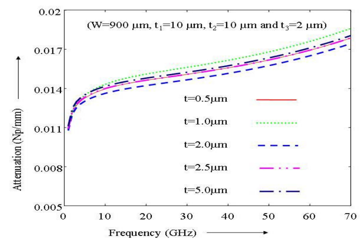

Fig. 6 Effect of Variation in Strip Conductor Thickness on Attenuation

III. CONCLUSION

Transmission line parameters of low loss multilayer suspended micro strip line on low resistivity silicon substrate have been investigated. Full wave simulation results shows that due to suspended nature of this transmission line, loss occurred due to lossy silicon substrates can be significantly reduced at 60 GHz frequency. Effect of variation in the thickness of silicon nitride and polyimide layers on the attenuation is also studied and optimum thickness for minimum attenuation has been obtained numerically.

REFERENCES

[1] C. H. Doan, S. Emami, A. M. Niknejad and R. W. Brodersen, "Millimeter-Wave CMOS Design", IEEE Journal of Solid State Circuits, Vol. 40, No. 1, pp. 144-155, January 2005

[2] G. E. Ponchak and A. N. Downey, “Characterization of Thin Film Microstrip Lines on Polyimide”, *IEEE Transactions on Components, Packaging and Manufacturing Technology-Part B*, Vol. 21, No. 2, pp. 171-176, May 1998.

[3] G. E. Ponchak,, E. Dalton, M. M. Tentzeris, and J. Papapolymerou, “Coupling Between Microstrip Lines With Finite Width Ground Plane Embedded in Thin-Film Circuits”, *IEEE Transactions on Advanced Packaging*, Vol. 28, No. 2, pp. 320-327, May 2005.

[4] G. E. Ponchak, A. Margomenos and L. P. B. Katehi, “Low Loss CPW on Low Resistivity Si Substrates with a Micromachined Polyimide Interface Layer for RFIC Interconnects”, *IEEE Transactions on Microwave Theory and Techniques,* Vol. 49, No. 5, pp. 866-870, May 2001.

[5] L. Zhang and J. Song, “Effects of the Thin Film Metal Ground Embedded in On-Chip Microstrip Lines”, *IEEE Microwave and Wireless Components Letters*, Vol. 17, No. 6, pp. 439- 441, June 2007.

[6] Ansoft HFSS 10, User’s Guide.

978-1-4244-2120-6/08/$25.00©IEEE.