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Efficient Design of Integrated Antenna on Si for On-chip Wireless Interconnect

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1. Introduction

The speed limitations of conventional interconnect metal lines have led to the concept of wireless interconnections on Si using integrated antenna [1]-[3]. Microwave clock distribution using integrated antennas can reduce the chip area used in interconnection while reducing the clock skew and dispersion, thus allowing higher clock frequency for a given chip size. All the reported work of wireless interconnect using integrated antennas have focused on dipole and monopole antennas with the field excitation along the plane of antenna (horizontal excitation) [1]-[3]. This is so far the most convenient way of providing excitation to the antenna in integrated circuit fabricated with planar IC technology. In this paper we have reported that the forward transmission co-efficient drastically reduces in a multi layer metal interconnect scheme when a plate of second metal layer is placed above the antenna at an usual inter-layer metal distance, an indication that effective field excitation can not take place in such cases. We have also shown that the negative effect of upper metal layer of a multi layer metal process can be avoided by exciting the antenna vertically through the Si substrate. In this case the excited field mode propagates through the silicon substrate without suffering any reduction in the power transmission capability of the antenna due to the existence of upper metal layers. The simulations have been performed using ANSOFT High Frequency Structure Simulator (HFSS) program employing 3-D finite element method.

2. Results and Discussion

Figure 1 shows the cross-sectional diagram of dipole antenna excited horizontally through the plane of the antenna. 1 mm thick Si layer was used as substrate. Simulation was performed with the Si resistivity varied from 10 to 1000 ohm-cm. Simulation was done with and without a second metal layer above the antenna. The antenna was formed with the first metal layer and the second metal layer was placed at a distance of 4 μm above the first metal. The inter-layer metal space is filled up with insulating oxide layer. A metallic microwave ground was placed at the bottom of the Si substrate. Figure 2 shows the forward transmission co-efficient (S_{21}) versus frequency of the dipole antenna excited horizontally. The length of the dipole antenna was 2mm and the transmitter and the receiver were separated at a distance of 3 mm. As shown in the graph, when there is no second metal layer on top of the antenna, the antenna transmission gain increases with frequency and reaches at about –20 dB at 25 GHz. However, when two layer metal process is used and a plate of second metal layer is placed above the antenna, the transmission co-efficient decreases drastically at all frequency. At 25 GHz the transmission co-efficient reduces to about –90 dB. This data shows that when a metal layer existed in such a close proximity and the dipole antenna is excited horizontally, effective excitation of electromagnetic wave can not take place and transmitted power reduces drastically.

Figure 3 shows the cross-sectional diagram of a monopole antenna on the same Si substrate as before. The monopole antenna is excited vertically through the Si substrate. The length and separation distance of the monopole transmitter and receiver are same as that of the dipole antenna i.e. antenna length 2 mm and separation distance 3mm. As shown in Fig. 4, the transmission co-efficient at high frequency with a second metal layer is almost same as that without a second metal layer. It shows that when the antenna is excited vertically through the Si substrate, most of the power is transmitted through the Si layer and the negative effect of upper metal layers of a multilevel metal process is eliminated. Again in this case the gain at lower frequency is almost same to that at higher frequency which may cause due to reflection.

Subsequently we have investigated the effect of Si resistivity on antenna transmission gain. As seen from Fig. 5 and 6, with no metal layer above the antenna the transmission gain increases with increase of resistivity for both the dipole excited horizontally and the monopole excited vertically.

3. Conclusion

The effect of any top or bottom metal layer of a multi layer metal process on the transmission characteristics of integrated antenna have been investigated. If we approximate the interconnect metal layers by a solid metal plate, the simulation shows that almost no power is propagated when the dipole antenna is excited horizontally parallel to the plane of Si. This is due to the reason that no field mode can be produced by such excitation due to the presence of a metal plate in such close proximity. On the other hand if we excite the antenna vertically through the Si substrate, field mode is excited which propagate through the Si Substrate and any metal layers on top of the antenna can not degrade the field propagation. Therefore for integrated antenna system in multi level metal process the best way to transmit power is to design the antenna on first metal layer and to excite it vertically through the Si substrate.

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References

[1] B.A. Floyd et. al., IEEE Journal of Solid-State Circuits, Vol. 37, 2002, p. 543

[2] A.B.M. H. Rashid , S. Watanabe and T. Kikkawa , IEEE Electron Devices Lett. Vol. 23, No. 12, December 2002 pp. 731

[3]A.B.M. H. Rashid S. Watanabe and T. Kikkawa, Jpn. J. Appl. Phys. 43B (2004) 2283

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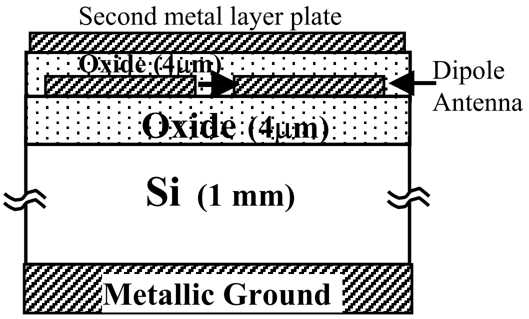

Fig- 1 Cross-sectional diagram of dipole antenna excited horizontally. A second metal layer is placed above the antenna on a SiO_2 layer of thickness 4 μm above the antenna. Simulation was done with and with out the second metal layer. Si resistivity was varied from 10 – 1000 ohm-cm.

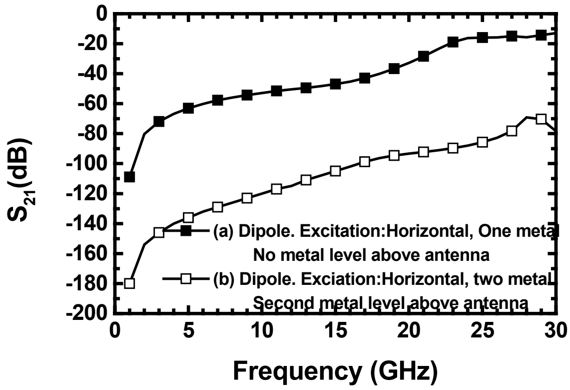

Fig- 2 The s-parameter forward transmission co-efficient (S_{21}) versus frequency for dipole antenna excited horizontally. When a second metal layer is present above the antenna the gain drastically reduces. Si resistivity = 1000 ohm-cm.

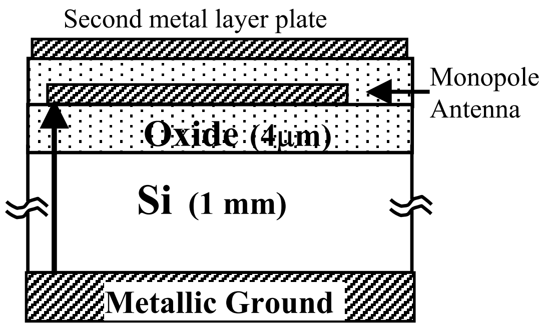

Fig- 3 Cross-sectional diagram of a monopole antenna excited vertically through the Si layer. A second metal layer is placed above the antenna on a SiO_2 layer of thickness 4 μm above the antenna. Simulation was done with and with out the metal layer. Si resistivity was varied from 10 – 1000 ohm-cm.

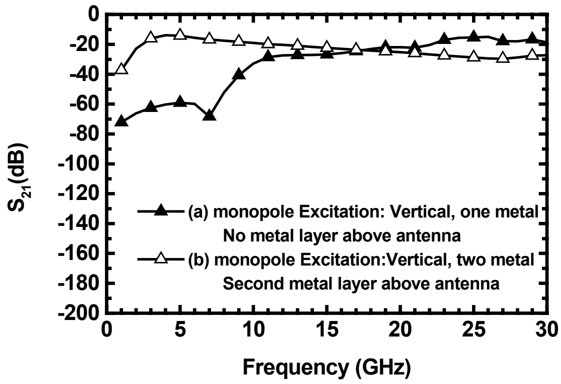

Fig- 4 The s-parameter forward transmission co-efficient (S_{21}) versus frequency for monopole antenna excited vertically through the Si substrate. When a second metal layer is present above the antenna the gain remains almost identical at high frequency and increases at low frequency compared to the case when no metal layer is present above the antenna. Si resistivity=1000 ohm-cm.

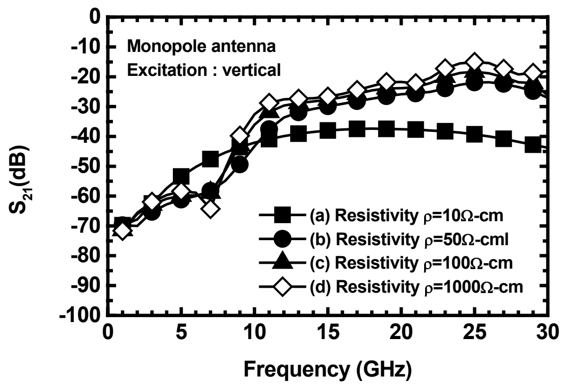

Fig- 5 The effect of Si resistivity on antenna transmission co-efficient for monopole antenna excited vertically with no metal layer above it. The transmission co-efficient increases with Si resistivity. At 25 GHz the gain increases by about 20 dB.

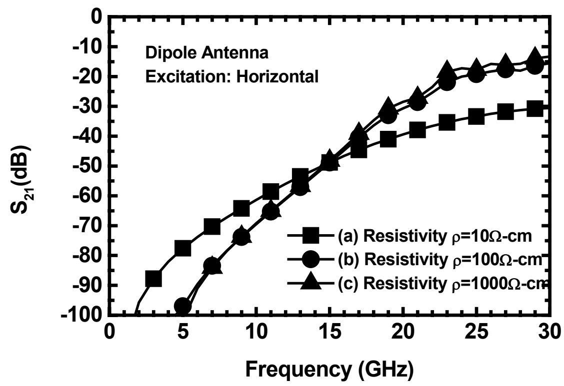

Fig- 6 The transmission co-efficient increases with Si resistivity at high frequency for dipole antenna excited horizontally with no metal layer above the antenna. At low frequency the transmission co-efficient decreases.