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P12-1

Effect of High Resistivity Si Substrate on Antenna Transmission Gain for On-Chip Wireless Interconnects

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1. Introduction

According to the scaling rule for ultra-large-scale integrated circuits (ULSI), conventional metal interconnects will have a limitation in global clock frequency of ULSI for high speed operation due to parasitic RC delay. In order to eliminate the influence of parasitic RC-delay, the transmission line technology must be introduced.[1,2] In this work, a novel antenna technology by use of electromagnetic wave propagation was developed for a global interconnect in silicon ULSI.[3,4] An integrated antenna on a semi-infinite semiconductor substrate with a dielectric constant of ε radiates $\varepsilon^{3/2}$ times more power into the substrate than into free space.[5] The silicon substrate has a conductive loss, resulting in degradation of the transmission gain of the antennas.[6,7] In this paper, high transmission gain dipole antenna was achieved on high resistivity Si substrates.

2. Fabrications and Measurement

Figures 1, 2 and 3 show layout pattern of integrated antennas on a Si, a plane view of transmitting and receiving antennas on a Si substrate and schematic cross-sectional diagram of dipole antennas, respectively. Antenna test structures were fabricated on 260 μm thick Si wafer with a resistivity of 10Ω-cm or 2.29kΩ-cm with 0.5 μm field oxide. Figure 4 shows the schematic diagram of proton implantation. Figure 5 shows the profile of the proton ion implantation at $1\text{x}10^{12}/\text{cm}^{-2}$ of proton dose. Proton implantation was then performed in 6 steps in order to provide a uniform proton profile throughout the entire depth of the Si substrate. 1 μm field oxide was grown before sputtering the Al for antenna formation. Figure 6 shows the setup for S-parameter measurement. It consists of HP8510C vector network analyzer, 180° hybrid couplers (6.0-26.5GHz), probe station and Signal-Signal probes. Wafers were measured on wood (2.6 mm thick) on the metal chuck of the probe station. The relative dielectric constant of wood was measured as 2.15 at 1 GHz.

3. Results and Discussion

Figures 7 and 8 show the measured reflection coefficient (S_{11}) and transmission coefficient (S_{21}) of dipole antennas, respectively, on standard Si and proton implanted Si substrates as a function of frequency. The reflection coefficient for proton implanted Si is approximately -0.1~-2 dB, while that for standard Si is -5~-10 dB. The transmission coefficient increases more than +10 dB at 20 GHz by proton implantation compared with standard Si. The power transmitted to receiving antenna is calculated from the scattering parameters using antenna transmission gain (G_a) as derived form *Frii's* transmission formula.[1] Figure 9 shows the antenna transmission gain versus proton dose. The antenna transmission gain for proton implanted Si is approximately –20 dB, while that for standard Si is –30 dB.The antenna was fabricated on a high resistivity Si substrate, and the fundamental antenna characteristics were compared with the standard Si substrate. Figure 10 shows transmission coefficient versus antenna length (L) when antenna distance is 10 mm. The transmission coefficient increases with antenna length. Figure 11 shows transmission coefficient versus antenna distance when antenna length is 3.0 mm. On the standard Si substrate the transmission coefficient decreases with antenna distance. On the other hand, on the high resistivity Si substrate and proton implanted Si substrate the transmission coefficient did not decrease but fixed at -15~-20 dB with increasing antenna distance. Figure 12 shows transmission coefficient versus frequency with Si resistivity as a parameter. Both measured and simulated data show similar trend, however, the measured transmission coefficient is about 5 dB less than the simulated value at high frequency. This is due to the impedance mismatch between the antenna and the measuring instruments. It turns out that the 50Ω-cm of resistivity Si substrate has the same effect as the proton implanted Si substrate.

4. Conclusion

We have demonstrated the highest transmission gain of the integrated dipole antenna on Si by use of high resistivity Si substrates. The high resistivity Si substrate showed equivalent transmission gain to proton implanted Si substrate.

Acknowledgements

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References

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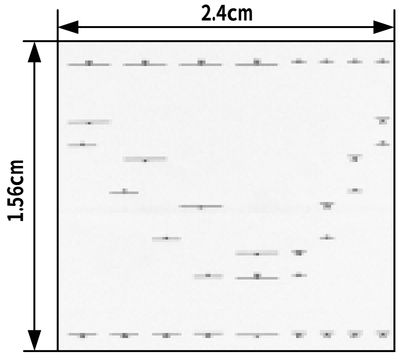

Fig.1. Layout pattern of integrated antennas on a silicon chip.

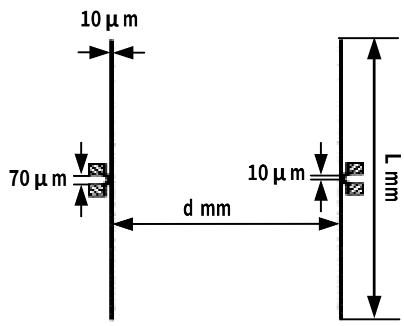

Fig.2. A plan-view of transmitting and receiving antennas on a Si substrate.

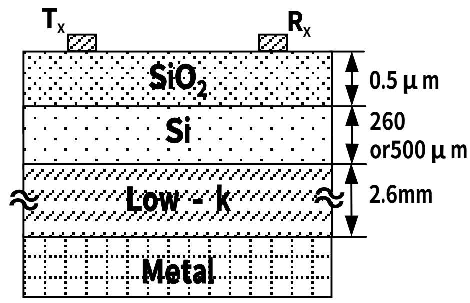

Fig.3. Schematic cross-sectional diagram of dipole transmitter-receiver antennas. T_X = Transmitter, R_X = Receiver.

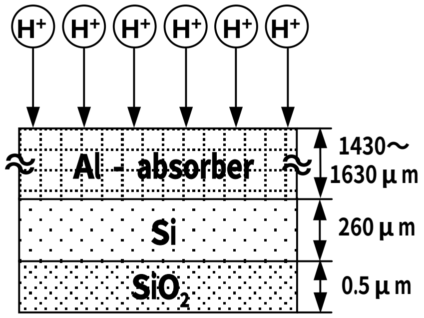

Fig.4. Schematic diagram of proton implantation.

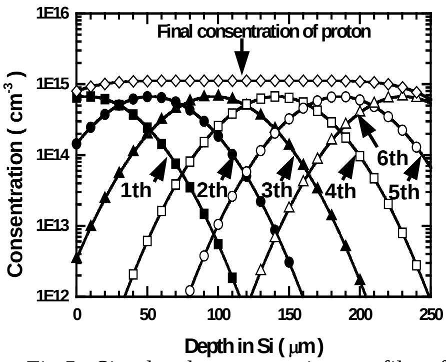

Fig.5. Simulated concentration profile of proton in Si. Implantation was done in 6 steps with a fixed energy of 17.4 MeV and a fixed dose of 10^{15} cm^{-2}.

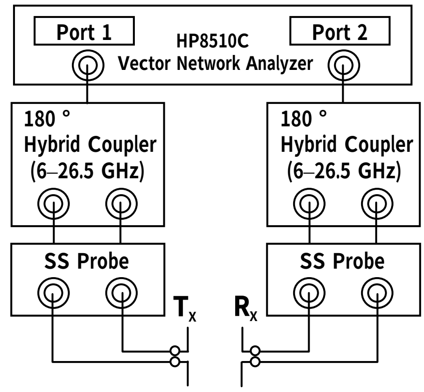

Fig.6. Experimental set-up for on chip antenna characterization.

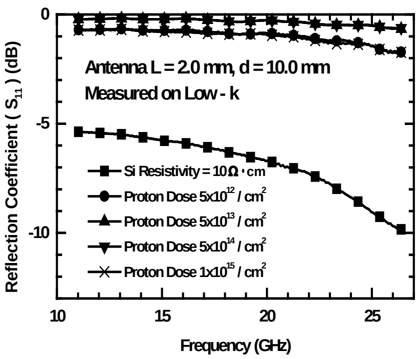

Fig.7 Reflection coefficient (S_{11}) versus frequency. (Effect of proton dose) (Antenna L=2.0mm, d=10.0mm)

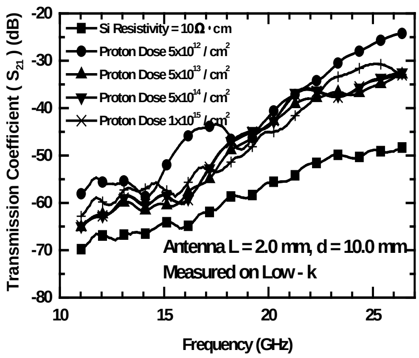

Fig.8 Transmission coefficient (S_{21}) versus frequency. (Effect of proton dose) (Antenna L=2.0mm, d=10.0mm)

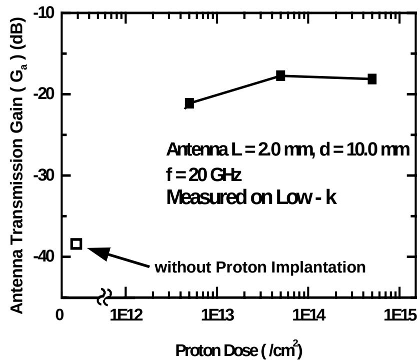

Fig.9 Antenna transmission gain (G_a) versus proton dose. (Antenna L=2.0mm, d=10.0mm)

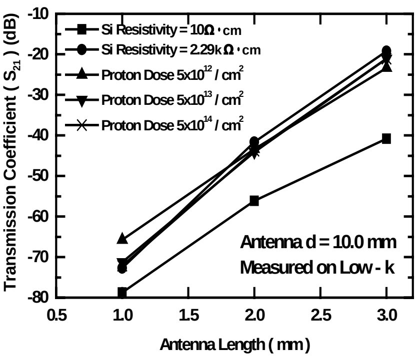

Fig.10 Transmission coefficient versus Antenna length. (Effect of proton dose) (Antenna d=10.0mm)

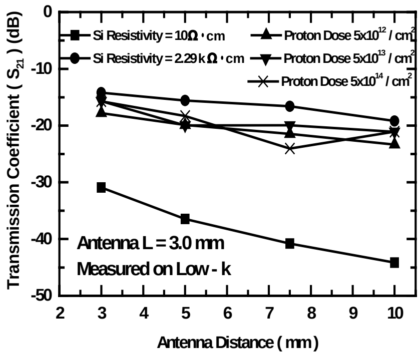

Fig.11 Transmission coefficient versus Antenna Distance. (Effect of proton dose) (Antenna L=3.0mm)

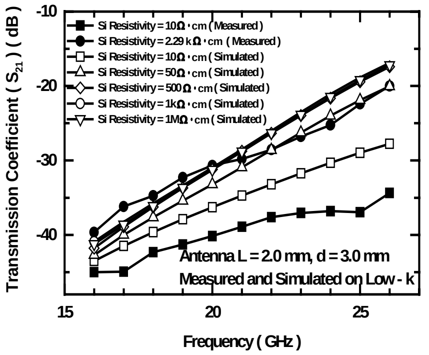

Fig.12 Transmission coefficient versus frequency with Si resistivity as a parameter. Measured and simulated data are compared. (Antenna L=2.0mm, d=3.0mm)