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Transmission Characteristics of Silicon On-chip Integrated Antennas as Millimeter-Wave Wireless Interconnects

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1. Introduction

Operation frequency of ultra-large scale integrated circuits (ULSI) increases as silicon (Si) technologies have improved. However the operation frequency is limited due to global interconnect delay becoming large. To overcome this limitation, 3D-integration system has been proposed as shown in Fig. 1 [1]. Wireless interconnection with integrated antennas has been studied [2-4]. This wireless interconnect system consists of integrated receivers (R_x) and transmitters (T_x) with on-chip antennas, which utilize electromagnetic (EM) wave transmission. Receivers and transmitters communicate in a single chip or among multiple chips without the effect of delay time from both parasitic capacitance and resistance.

One of the issues for wireless interconnects using Si integrated antennas is that antenna sizes are large compared with recent chip size of complementary metal oxide semiconductor (CMOS) circuits. Antenna length is reduced with increasing operation frequency of antennas. CMOS cutoff frequency has increased and CMOS technology for millimeter wave signal transmission has been developed [5]. Therefore, in this paper antenna characteristics were investigated in the frequency band up to 40 GHz for intra- and inter-chip communication.

2. Experiment

Fig. 2 shows a sample structure and measurement setup of Si integrated linear dipole antennas. The integrated antennas made by 10 μm-wide aluminum are patterned on SiO_2 layer, which is fabricated on a 260 μm-thick Si substrate with 10 Ω·cm resistivity (ρ). Thicknesses of aluminum and SiO_2 layer are 1 μm and 0.3 μm, respectively. Fig.3 shows a schematic layout of a linear dipole antenna fabricated on a Si substrate. As shown in Figs.2, 4 and 5, transmission characteristics were investigated for intra-chip, inter-chip with air gap and through stacked Si chips signal transmissions, respectively. The antenna length (L) and distance between antennas (d) were changed for above signal transmission structures. For stacked-chip structure, the horizontal distance of 3 mm between antennas was fixed and the vertical distance was changed from 0 mm to 2.34 mm by inserting Si chips with thickness of 260 μm and resistivity of 10 Ω·cm.

Scattering parameter (S-parameter) measurement set-up in the frequency domain is shown in Fig. 2, which is composed of a vector network analyzer E8361A, a S-parameter test set N4420B, Ground-Signal-Ground-Signal-Ground (GSGSG) probes and a microwave probe station. The measurement sample was placed on a 2.6 mm-thick low-k substrate whose dielectric constant was 2.08 at 1 GHz.

3. Results and Discussion

Fig.6 shows measured reflection coefficient (S_{11}) of linear dipole antennas as a function of frequency. Antenna length was changed from 1.6 mm to 6 mm. Fig.7 shows simulated and measured results of resonant frequency as a function of antenna length. The measured results were consistent with the simulated results. As shown in fig.7, resonant frequency was in inversely proportional to antenna length. Antenna length was reduced to 1.6 mm at the resonant frequency of 38.4 GHz.

Figs. 8, 9 and 10 show measured transmission coefficient (S_{21}) of 1.6 mm-long antennas for intra-chip, inter-chip and stacked-chip signal transmission, respectively. The distance between antennas was changed from 3 mm to 20 mm for intra- and inter-chip structures and from 3 mm to 3.8 mm for stacked-chip structure. S_{21} decreased with increasing the distance. Fig. 11 shows effects of transmission structure on S_{21}. The attenuation rates of S_{21} were -1.8 dB/mm for intra-chip structure, -0.7 dB/mm for inter-chip structure and -15.3 dB/mm for stacked-chip structure. For intra-chip structure EM wave is transmitted as surface wave on Si substrate. On the other hand, for inter-chip structure EM wave is transmitted as a direct wave in the air. For stacked-chip structure EM wave is transmitted in Si substrate. Attenuation rate of the air was much smaller than that of Si substrate because of conductive loss of Si substrate. Fig. 12 shows S_{21} at 16 GHz (L = 4 mm) and 38 GHz (L = 1.6 mm) for intra- and inter-chip structure. The attenuation rates of S_{21} for inter-chip were -0.7 dB/mm and -0.6 dB/mm at 38 GHz and 16 GHz , respectively.

4. Conclusion

Antenna length was shortened from 4.0 mm to 1.6 mm at by changing the resonant frequency from 16 GHz to 38.4 GHz. The attenuation rates of S_{21} were -1.8 dB/mm for intra-chip structure, -0.7 dB/mm for an inter-chip structure and -15.3 dB/mm for a stacked-chip structure, respectively. Si integrated antennas were extendable for use in millimeter-wave.

Acknowledgment

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References

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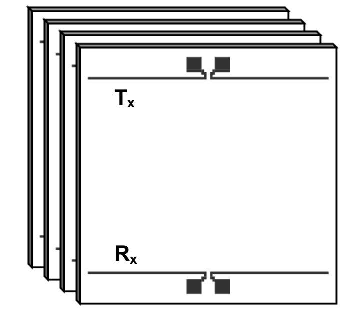

T_x : Transmitting antenna, R_x : Receiving antenna

Fig.1 A conceptual diagram of wireless interconnects of 3D-integration system.

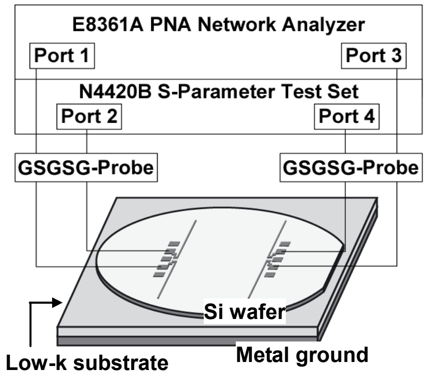

Fig.2 A sample structure for intra-chip signal transmission and measurement setup of Si integrated antennas.

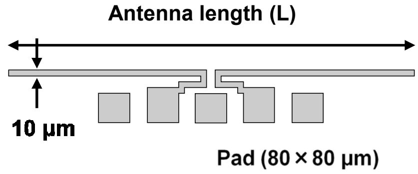

Fig.3 A schematic layout of a linear dipole antenna.

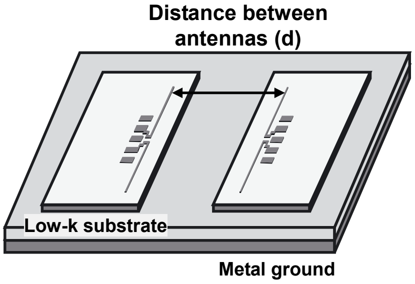

Fig.4 A sample structure of Si integrated antennas for inter-chip signal transmission with air gap.

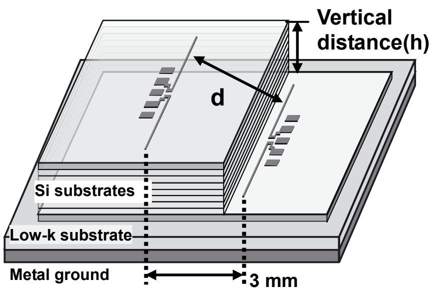

Fig.5 A sample structure of Si integrated antennas for stacked-chip signal transmission.

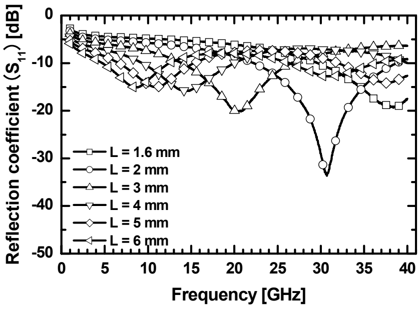

Fig.6 Dependence of antenna length on reflection coefficient (S_{11}) as a function of frequency.

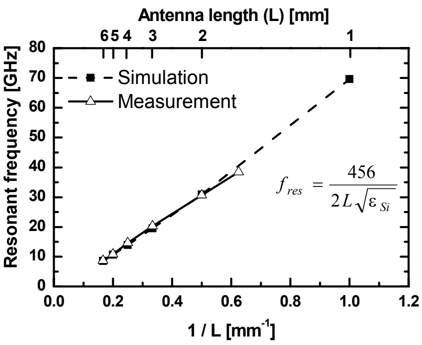

Fig.7 Resonant frequency versus antenna length.

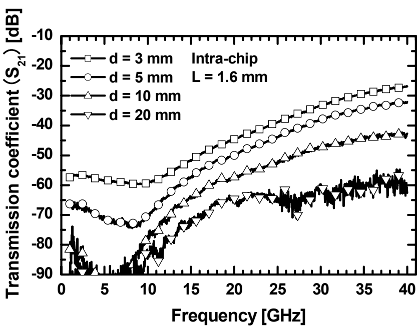

Fig.8 Dependence of distance between antennas on transmission coefficient (S_{21}) for intra-chip transmission (L=1.6mm).

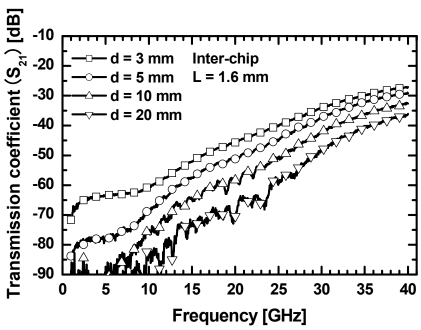

Fig.9 Dependence of distance between antennas on transmission coefficient (S_{21}) for inter-chip transmission (L=1.6mm).

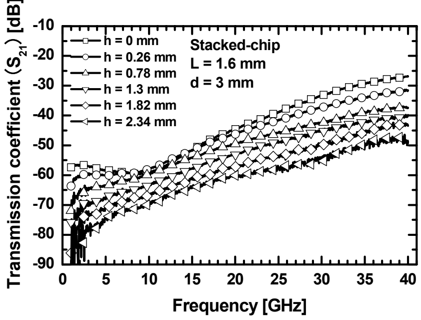

Fig.10 Dependence of distance between antennas on transmission coefficient (S_{21}) for stacked-chip transmission (L=1.6mm).

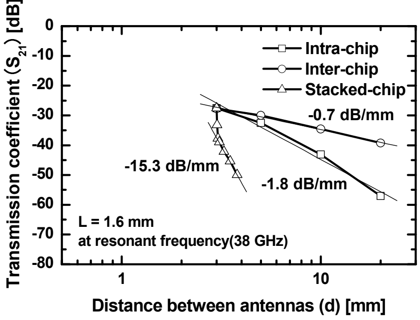

Fig.11 The effect of transmission structure on transmission coefficient (S_{21}).

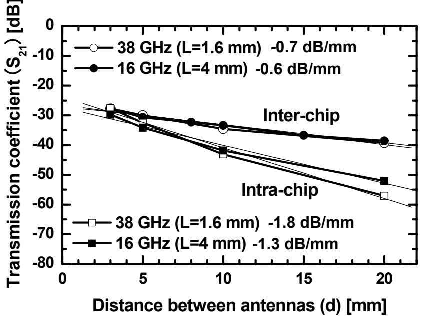

Fig.12 The effect of distance between antennas on transmission coefficient (S_{21}) at 16 GHz (L=4mm) and 38 GHz (L=1.6mm) for intra- and inter-chip transmission.