Ultrawideband Characteristics of Fractal Dipole Antennas Integrated on Si for ULSI Wireless Interconnects

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***Abstract*—Ultrawideband characteristics of Sierpinski carpet fractal antennas fabricated on silicon substrates with the resistivities of 2290, 79.6, and 10 Ω·cm were investigated. The return losses lower than −10 dB and high transmission gains of approximately −14 dB were obtained for the antennas with 10-mm distance on the Si substrate with the resistivity of 2290 Ω·cm in the frequency range from 18 to 26.5 GHz. Gaussian monocycle pulses with 70 ps pulsewidth were transmitted in the Si substrates successfully and the corresponding voltage gains were −23, −26, and −39 dB for the Si resistivities of 2290, 79.6, and 10 Ω·cm, respectively.**

***Index Terms*—Fractal, Gaussian monocycle pulse, Sierpinski carpet dipole antenna, ultrawideband, wireless interconnect.**

I. Introduction

FUTURE ultralarge scale integrated systems (ULSIs) are expected to process high-frequency (>10 GHz) and high-speed (<100 ps) signals between the chips as well as in the chip. However, conventional metal interconnects have physical limits for transmitting and receiving ultrahigh frequency signals with keeping the signal integrity due to the parasitic capacitances. A wireless interconnect using integrated antennas on a semiconductor substrate is one of the potential solutions for clock and data transmissions [1]–[4]. In such cases, the necessary transmission distance is within a few centimeters.

Recently, ultrawideband (UWB) communication has been received more attention for short distance signal transmission. We have reported Si integrated antennas for use in UWB communication in a ULSI chip and between chips [5]. However, the requirements for UWB antennas are low return losses and constant gains in the ultrawide frequency range. Therefore, it is necessary to develop UWB antenna in Si ULSI. In this letter, the transmission characteristics of fractal dipole antennas are investigated for use in ULSI.

II. Experimental

P-type Si wafers with resistivities of 10, 76.9, and 2290 Ω·cm were used as substrates. The thickness of the substrate was 260 μm. The surface of Si was oxidized by $H_2 - O_2$ at 1050 °C to form 0.3 μm thick field SiO_2. The 1-μm-thick aluminum was deposited on the SiO_2 layer by direct current magnetron sputtering. Antenna patterns were formed by electron beam lithography followed by chemical etching. Fig. 1(a) and (b) shows schematic configurations of a Sierpinski carpet dipole antenna [6], [7] and a time domain measurement setup for Gaussian monocycle pulses, respectively. The antenna configuration was $W/L = 1.0/1.9$ mm, the gap of the dipole for the excitation port was 70 μm and measurement pads were in the antenna as shown in Fig. 1(a). Distances between transmitter and receiver antennas were ranging from 5.0 to 30.0 mm on the Si substrate which was placed on a 2.6-mm-thick wooden low-*k* substrate whose relative dielectric constant was 2.15 at 1 GHz. The time domain transient characteristics of Gaussian monocycle pulses were measured by use of serial bit error rate tester, impulse forming networks and sampling oscilloscope as shown in Fig. 1(b). The pulsewidth and the amplitude of the Gaussian

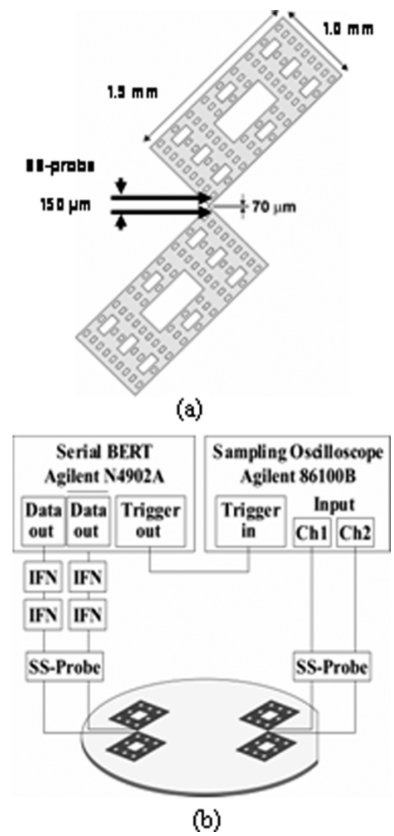

Fig. 1. (a) Schematic configuration of a Sierpinski carpet dipole antenna ($W/L = 1.0/1.9$ mm). (b) Time domain measurement setup for Gaussian monocycle pulses.

Manuscript received July 6, 2005; revised July 19, 2005. The review of this letter was arranged by Editor K. De Meyer.

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Digital Object Identifier 10.1109/LED.2005.856012

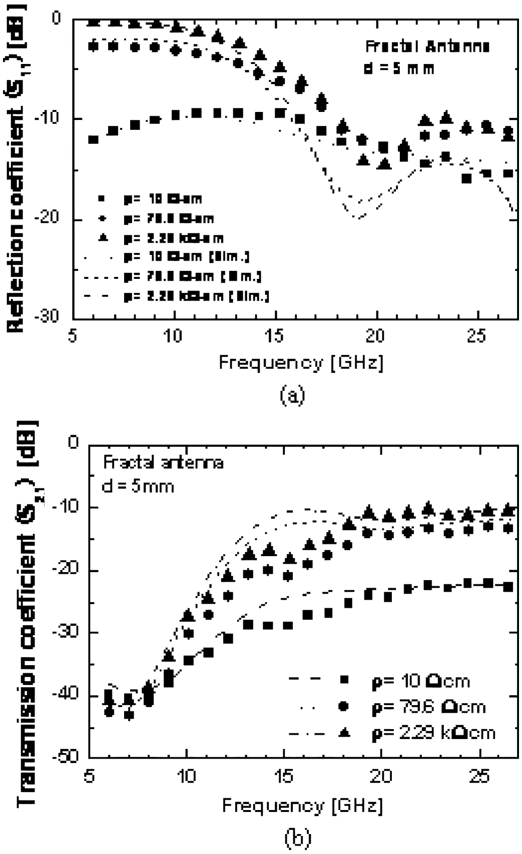

Fig. 2. Measured and simulated transmission characteristics as a function of frequency for Sierpinski carpet dipole antennas fabricated on the Si substrates with the resistivities of 10, 76.9, and 2290 $\Omega \cdot$ cm. (a) Return losses (S_{11}). (b) Transmission coefficients (S_{21}).

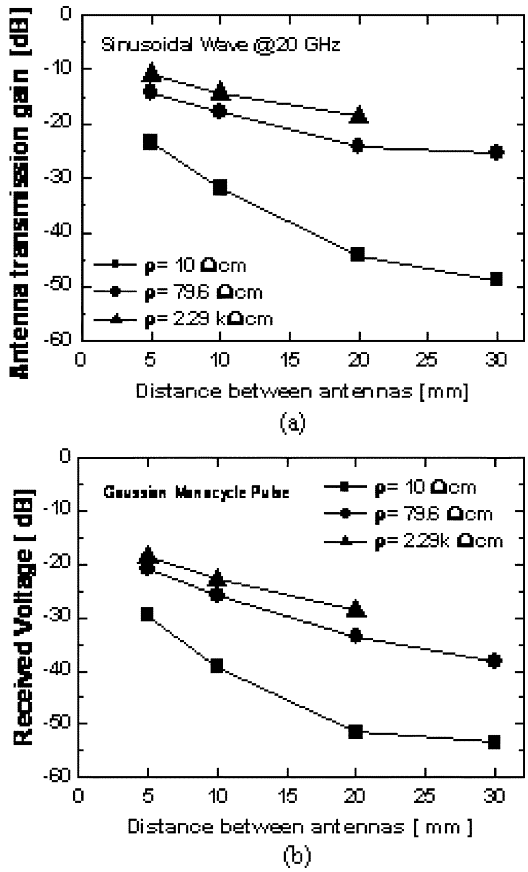

Fig. 3. Transmission characteristics as a function of distance for Sierpinski carpet dipole antennas fabricated on the Si substrates with the resistivities of 10, 76.9, and 2290 $\Omega \cdot$ cm. (a) Transmission gains of sinusoidal waves. (b) Voltage gains of Gaussian monocycle pulses.

monocycle pulse were 70 ps and 150 mV, respectively. The center frequency and bandwidth were approximately 15 and 20 GHz, respectively. A frequency domain measurement set-up for the dipole antennas consisted of a vector network analyzer, 180° hybrid couplers, signal-signal-probes and a microwave probe station [4]. Through-reflection-line/match calibration was carried out for a signal-signal probe and a vector network analyzer. An impedance standard substrate was used for SS-probe calibration.

III. Results and Discussion

Fig. 2(a) and (b) shows measured reflection coefficients (S_{11}) and transmission coefficients (S_{21}), respectively. Theoretical calculations of Maxwell's equation were carried out by Ansoft HFSS with respect to Si substrate resistivities. Measurement data were consistent with the simulation data. The return losses of the Sierpinski carpet dipole antennas on the Si substrates with the resistivities of 10, 76.9, and 2290 $\Omega \cdot$ cm were less than -10 dB in the frequency range of 18–26.5 GHz as shown in Fig. 2(a) so that the voltage standing wave ratio was less than 2. The 10 Ωcm Si substrate shows much lower return loss in the frequency range from 6 to 26.5 GHz. The resonant frequency at approximately 19 GHz, which correspond to the diagonal length of the fractal antenna, was observed more apparently for the antennas on the Si substrates with 76.9 and 2290 Ωcm. The input impedances of the Sierpinski carpet dipole antenna on the higher resistivity Si substrates were calculated from the measured S_{11}. The real part of the antenna impedance was much lower than the characteristic impedance of the coaxial cable and the imaginary parts became capacitive so that the antenna impedance was not matched below 15 GHz. The transmission coefficients were approximately -12, -14, and -24 dB for the Si resistivities of 2290, 76.9, and 10 $\Omega \cdot$ cm, respectively. On the other hand, S_{21} below 18 GHz decreased with decreasing frequency.

As shown in Fig. 3(a), the transmission gains of sinusoidal waves at 20 GHz decreased with increasing the distance and the attenuation rates for the distances less than 20 mm were approximately -1, -0.5, and -0.4 dB/mm for the Si substrates with the resistivities of 10, 76.9, and 2290 $\Omega \cdot$ cm, respectively. The voltage gains of the Gaussian monocycle pulses with the distance of 10 mm were -39, -26, and -23 dB for the Si substrates with the resistivities of 10, 76.9, and 2290 $\Omega \cdot$cm, respectively. The attenuation rates of the received Gaussian monocycle pulse were approximately -1.45, -0.68, and -0.66 dB/mm for the Si substrates with the resistivities of 10, 76.9, and 2290 $\Omega \cdot$ cm, respectively, as shown in Fig. 3(b).

IV. Conclusion

Sierpinski carpet dipole antenna was investigated and the return loss lower than -10 dB was achieved in the frequency range from 18 to 26.5 GHz. The Gaussian monocycle pulse having

70-ps pulse width as a UWB signal was transmitted between antennas with 10-mm distance on the Si substrate. The voltage gains of the received Gaussian monocycle pulses were improved from -32 to -23 dB by increasing the Si substrates resistivities from 10 to 2290 $\Omega \cdot$ cm.

ACKNOWLEDGMENT

The authors would like to thank Prof. P. S. Hall, University of Birmingham, U.K. for his useful discussion.

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