On-Wafer Millimeter Wave Dipole Antenna with a Novel Horizontal Directed Structure

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1. Introduction

Recently, 60 GHz band is considerably interested in wireless personal area network (WPAN) applications because sufficient bandwidth up to 7 GHz is available for Gigabit wireless link [1]. The wideband applications of integrated millimeter wave circuits have created many challenges in front-end design. The 60 GHz front-end realized as an assembly of microwave monolithic integrated circuits (MMICs) in GaAs semiconductor technology [2]. In this paper, the authors proposed a novel structure for a 61 GHz on-wafer horizontal directed antenna with a higher transmission gain than previous designs. The horizontal directed design usually obtains a narrower 3-dB beamwidth of radiation pattern than that of conventional dipole antennas. The measured and simulated results were demonstrated in the paper. A simplified model for the chip antenna was also described.

2. Chip-Antenna Design

Figure 1 shows the top view, cross-sectional view, and photograph of fabricated horizontal directed on-wafer dipole antenna. It consists of CPS feed-line with two parallel radial open stubs, dipole element and horizontal directed. At millimeter wave frequencies, the circuits can be designed in differential configuration to less sensitivity to the common mode perturbation. The horizontal directed antenna offers a transition feed which is thus suitable for differentially integrated receivers and transmitters. The CPS feed-line with the radial open stubs not only feeds the antenna but also transforms the impedance of dipole element into 50 Ω. The optimized geometrical dimensions were obtained by the following design procedure: L = 900 μm, L_{dir} = 350 μm, L_{di} = 370 μm, H_{di} = 150 μm, H_1 = 160 μm, H_2 = 160 μm, W = 1000 μm, W_g = 90 μm, W_t = 120 μm, W_s = 60 μm, and W_{stub} = 190 μm. Since the quality of wireless links is critically dependent on the performance of antenna, transmission gain (T_{ant}) is calculated from the S-parameters in [3]. The power gain between a pair of antennas as expressed in Eq. (1). T_{ant} includes the transmitting gain (G_{tx}), receiving gain (G_{rx}), and the propagation loss. Where λ is the wavelength, α is the attenuation constant which is mainly attributed the conduction loss of substrate, and R is the antennas separation distance. T_{ant} is obtained by measuring two-port S-parameters of an antenna pair, and de-embedding the mismatch losses from $|S_{11}|$ and $|S_{22}|$ as illustrated in Eq. (1).

$$T_{ant} = \frac{|S_{21}|^2}{\left(1-|S_{11}|^2\right)\left(1-|S_{22}|^2\right)} = G_{tx}G_{rx}\left(\frac{\lambda}{4\pi R}\right)^2 e^{-2\alpha R} . \qquad (1)$$

Figure 2(a) shows the equivalent circuit model of on-wafer directed dipole antenna. The parasitic of probe pad is modeled as a series inductance L_{Pad} and a shunt capacitance C_{Pad} and the substrate is described as a resistance R_{sub} paralleled with a capacitance C_{sub}. The dipole antenna is characterized by a parallel resonator comprising the resonant elements of conductance G_{di}, inductance L_{di} and capacitance C_{di}. The parameter extracted procedure from S-parameters is described as follow. Since the input resistance is linked to the conductor loss of pad and substrate before the first resonance of antenna, these parameters are firstly extracted. The parasitics from pad can be obtained from an open pad measurement which result in L_{Pad} = 176 pH and C_{Pad} = 0.64 pF, respectively. These parasitics are then imposed on the equivalent model of dipole antenna for the resonant elements extraction. The resistance R_{di} in the equivalent circuit model represents the dipole radiation resistance and the dipole losses. R_{di} is achieved by computing the real part of antenna impedance. The value of radiation capacitance C_{di} is calculated from the slope of imaginary part whereas the radiation inductance L_{di} is easily obtained from the resonant frequency. The value of susceptance slope is 0.05 which is measured the derivate at ω_0 in Fig. 2(b). The obtained values of resonant elements are: R_{di} = 260 Ω, L_{di} = 43 pH, and C_{di} = 157 fF.

3. Measurements

Figure 2(b) shows the approximate results in horizontal directed dipole antenna. Figure 3 shows the measured return loss and transmission gain of the horizontal directed dipole antenna. The measured results indicate the excellent antenna quality and good impedance matching to 50 Ω at 61 GHz. Using a return loss criterion of VSWR < 1.5, the measured bandwidth for the antenna covers from 58 to 65 GHz. The simulated and measured radiation patterns of the on-wafer antenna in E-plane and H-plane at 61 GHz are shown in Fig. 4. The patterns are end-fire in shape with a front-to-back ratio greater than 12 dB and cross-polarization radiation less than -25 dB in the E-plane and less than -19 dB in H-plane. The obtained 3-dB beamwidth of H-plane is 120° which is much narrower than that of 360° in conventional dipole antenna. Table I illustrates experimental results of on-wafer antennas operating at millimeter wave frequencies [16-20]. This horizontal directed dipole antenna has a better performance in gain and bandwidth.

4. Conclusion

A horizontal directed of on-wafer dipole antenna for the end-fire operation has been designed and measured. The measured results of horizontal detected antenna show that the antenna achieves a minimum return loss of 30 dB at 61 GHz, which indicates the excellent antenna quality and good matching to 50 Ω termination. The antenna also radiates an end-fire beam with a large front-to-back ratio and a small cross-polarization level. The results indicate that the horizontal directed antenna can be utilized to improve the directivity. The obtained transmission gain of purposed horizontal detected dipole antenna is -37 dB which is the best result among the previous on-wafer antennas at V band.

Acknowledgements

The authors would like to thank to the support by the National Science Council under Contract NSC 96-2628-E-008-001-MY3 and service provided by Chip Implementation Center, Taiwan (R.O.C.).

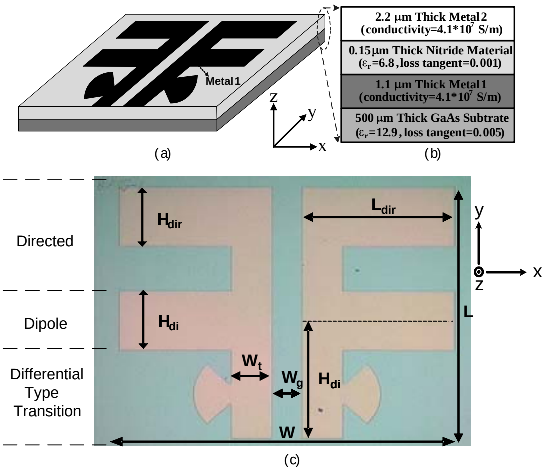

Fig. 1. Horizontal director of on-wafer dipole antenna. (a) Top view. (b) Cross-sectional view. (c) photograph of fabricated chip.

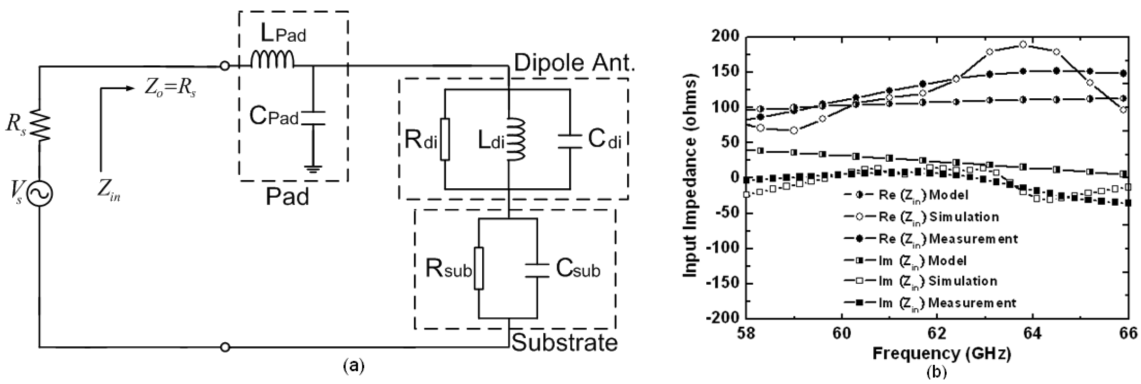

Fig. 2(a). Equivalent circuit model of directed on-wafer antenna. Fig. 2(b). The input impedance of horizontal directed on-wafer dipole antenna, which the susceptance slope at real part equal to zero is 0.05 at 61GHz.

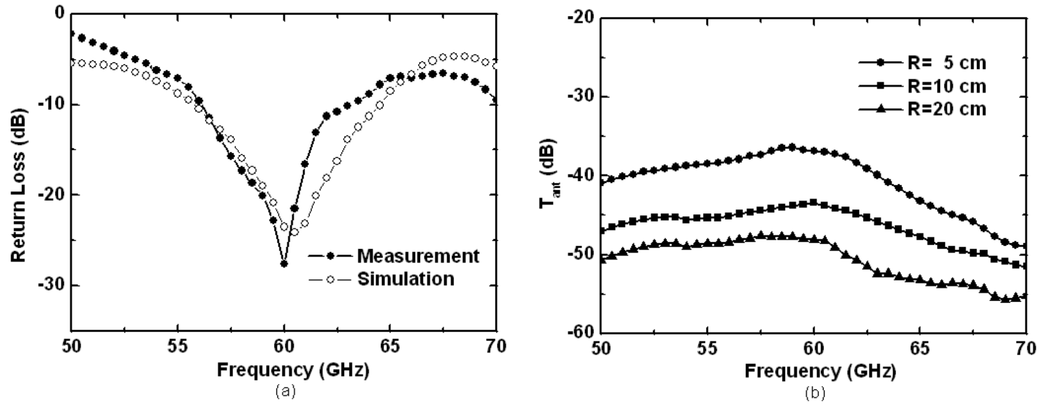

Fig. 3. Transmission gain versus frequency for horizontal directed on-wafer dipole antenna.

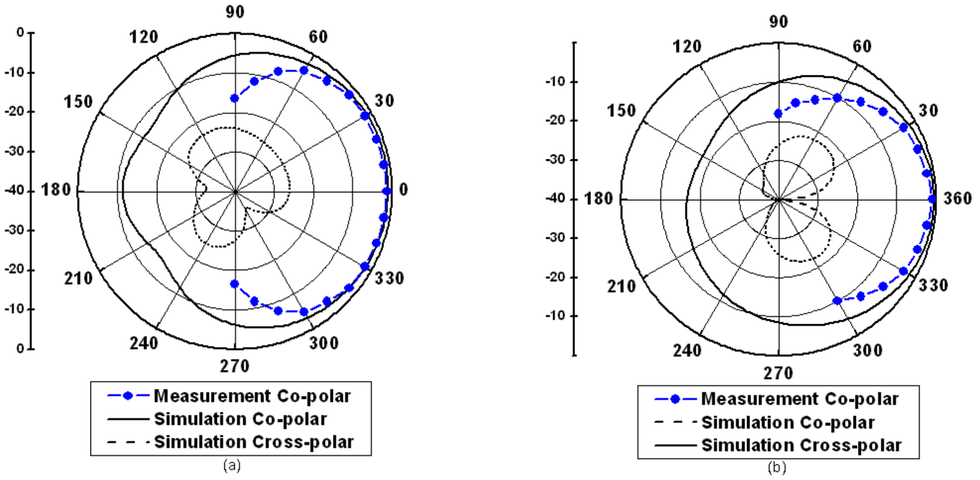

Fig. 4. Full wave simulated and measured radiation patterns of horizontal director of on-wafer dipole antenna. (a) E-plane pattern. (b) H-plane pattern.

Table I Comparisons with previous measurements of the millimeter-wave on-wafer antennas.

Reference	Time/ Journal	Process	Architecture	Frequency (GHz)	BW_{-10dB} (GHz)	Return Loss (dB)	Gain (dB)	Chip Area (mm×mm)
[4]	2006/ EL	GaAs	Waveguide Antenna	60	58.5-61.5	NA	NA	1.345×0.045
[5]	2003/ MTT	0.15-μm pHEMT	Folded Slot Antenna	60	59-65	NA	NA	1.25×1
[6]	2006/ MTT-S	0.15-μm pHEMT	Patch Antenna	58	NA	NA	NA	0.68×0.9
[7]	1998/ RFIC	0.15-μm pHEMT	Dual Band Patch Antenna	57, 59	57-57.7, 59-59.5	14, 11	1.5, 1	1.25×1
[8]	1997/ AP-S	0.15-μm pHEMT	Patch, Slot Antenna Array	60	60, 62-65	9.8, 13	7.6 (simulation)	10×10
This Work	Present	0.15-μm pHEMT	Horizontal Directed Dipole	61	58-65	28	-37 (transmission gain, dB; separation is 5 cm)	1×0.9

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