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Wireless Inter-Chip Signal Transmission by Electromagnetic Coupling of Open-Ring Resonators

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1. Introduction

Interconnections between chips and boards are serious bottle necks in high speed systems due to the inductance of bonding wires. Instead of metal wires, several methods have been developed or investigated, such as flip-chip bonding, optical device integration and electro-magnetic coupling with antenna or coupled inductors. Especially, non-contact wireless interconnections are required from reliability and cost points of view. Figure 1 is an example of future low-cost microwave transmitter. Here, baseband microwave signals are generated on silicon VLSI, then they are amplified by AlGaN/GaN HFET MMIC on sapphire [1], and, finally, the signals are emitted by antennas on plastic plates. In such applications, wireless interconnection with wide bandwidth and low loss will be the key technologies.

2. EM Simulation of Interconnection on Sapphire

We developed a structure which exchanges high frequency signals between planar circuits through insulating substrates such as sapphire. Sapphire is a good substrate for microwave components due to its high dielectric constant and low dielectric loss. Also, CMOS VLSI can be made directly on it, which is known as SOS (silicon on sapphire) technology. In addition, high performance AlGaN/GaN HFET microwave amplifiers can be made on it, as well.

The interconnection uses electromagnetic coupling of $\lambda/2$ resonators on each substrates where the resonators are open-ring type and they are placed anti-symmetric direction which minimizes the undesirable signal radiation [2]. Figure 2 shows the structure used for electromagnetic simulation. One open-ring is placed on the lower sapphire substrate and the other one is on the second substrate. On top of the second substrate, another sapphire plate is placed to maintain the structure symmetry. The top and the bottom surfaces of the structure are covered with metal. To each ring, 50 Ω coplanar waveguide is connected for signal feed. The connection position on the ring is selected so as to obtain matching.

Figure 3 shows the transmission characteristics simulated with Ansoft HFSS. The ring diameter, the line width and the gap width for the ring are 960 μm, 100 μm and 60 μm, respectively. These sizes are designed for 15GHz signal transmission. The ring material is assumed to be 1μm thick gold with the conductivity of 4.1×10^7 S/m. The three substrate thicknesses are 200 μm, respectively, with the dielectric constant of 10 ε_0. The maximum transmission rate S21 is -1.02dB(79.19%) and 3dB-frequency is ranging from 12.7GHz to 19.5GHz, giving the bandwidth of 6.8GHz.

3. Experiments

We fabricated the structures on 200 μm *c*-plane sapphire substrates (Fig. 4). First, thin Ti/Au layer is deposited and photoresist patterns are made on it. Then, gold electroplating was applied for the ring and wiring. After removing the photoresist, Ti/Au is etched by sputtering. The thickness of the gold was 1.0~1.4 μm. For the transmission characteristics measurement, sapphire chips with ring patterns are stacked as shown in Fig. 5. To accurately stack the chips, we modified a mask aligner and stick the substrates with electron wax. The alignment accuracy was less than 40 μm. According to numerical simulations, the structure is insensitive to such misalignment and the value is enough for transmission experiments.

Figure 6 shows the transmission characteristics measured with Agilent E8364B network analyzer. S_{21} at the central frequency, 19.0GHz, is -1.54dB (70.1%) and 3dB bandwidth is 4.8 GHz, corresponding to fractional bandwidth of 25%. This indicates 4.8 Gbps digital signal can be transferred with this wireless interconnection.

As the thickness of the middle sapphire substrate is increased, the bandwidth is decreased as shown in Fig. 7, but more than 50% power transmission is kept even through 400 μm thick substrate. In this experiment, port position on the ring was shifted to obtain good matching. The angle between the coplanar line and the ring-gap is designed as 98°, 114° and 128°, respectively, each for 200 μm, 300 μm and 400 μm thick substrates.

4. Conclusion

Wireless interconnection between IC chips are realized with electromagnetic coupling of two open-ring resonators. For substrate thickness of 200 μm, more than 70% power can be transmitted and bandwidth of 4.8GHz or fractional bandwidth of 25% is obtained. Major transmission loss comes from the conductor loss and undesired radiation around the ring structure. High efficiency signal transmission from conducting silicon substrates is a problem yet to be solved, but this technology can be used for wide variety of high speed systems.

References

[1] Y.Ohno and M.Kuzuhara,"Application of GaN-Based Heterojunction FETs for Advanced Wireless Communication,"IEEE Transiactions on Electron Devices,48p.517-523

[2] Awai and A.K.Saha"Open Ring Resonators Applicable to Wide-band BPF,"Proceedings of Asia-Pacific Microwave Conference,WE3B-5(2006)

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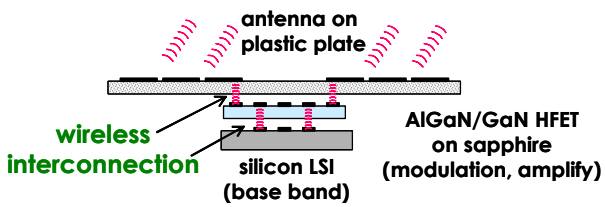

Fig. 1. Schematic model of microwave system using the wireless interconnections.

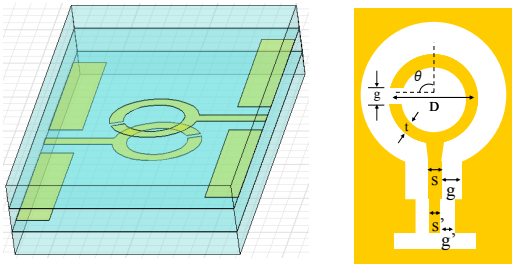

Fig. 2. Interconnection structure for electromagnetic simulation.

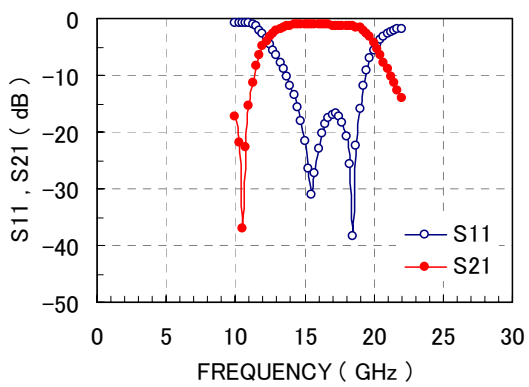

Fig. 3. Simulated transmission characteristics. The substrates are 200 μm thick and the rings are designed for 15GHz range signals.

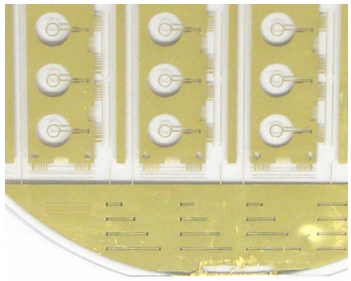

Fig. 4. Photograph of ring patterns for measurement made on 2"ϕ sapphire substrate. Ring diameter is 960 μm.

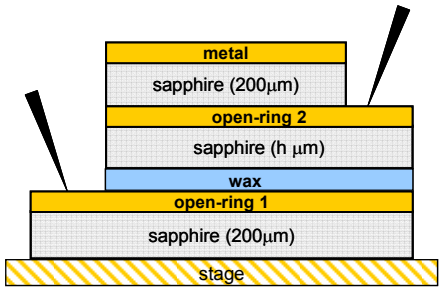

Fig. 5. Structure for transmission measurements with network analyzer.

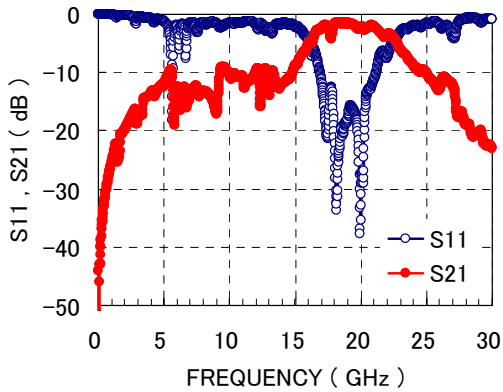

Fig. 6. Measured transmission characteristics with 200 μm thick substrate.

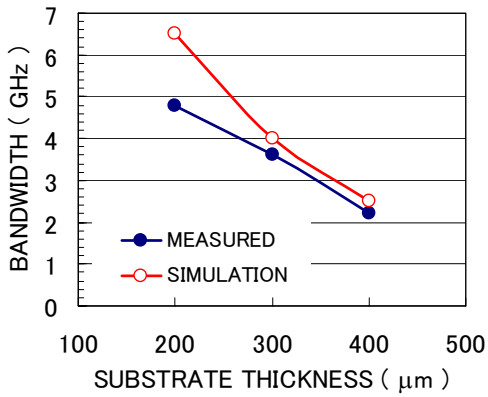

Fig. 7. Measured and simulated bandwidth for different substrate thickness for transmission.