Extended Abstracts of the 2012 International Conference on Solid State Devices and Materials, Kyoto, 2012, pp160-161

60 GHz Wireless Interconnection Using Electromagnetic Coupling of Open-Ring Resonators

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1. Introduction

We have proposed electromagnetic coupling of open-ring resonators (ECOR) for wireless signal transmission between insulating substrates and experimental results at 15 GHz [1] and simulation results at 60GHz have been presented. [2] Here, we present the successful experimental results at 60GHz range.

60GHz range is expected to be used short range wide-band wireless communication. However, since the handling power for the miniaturized MOS transistors decreases, the combination of other devices such as AlGaN/GaN HFETs is required. As device speed increases, conventional mechanical interconnection is not suited due to signal degradation and high assembly cost.

Resonator coupling is a short distance but high efficiency signal transmission technology. Different from the conventional antenna technology, point to point efficiency can be almost unity so that it is used for wireless power transmission [3]. As the frequency increases, the size of the resonator shrank. At 60GHz, the resonator diameter becomes as small as bonding pad on IC chips. Since the resonators can be made by only single metallization process, ECOR will be useful for heterogeneous integration of microelectronics components.

2. Interconnect Structure

Open-ring resonator is a $\lambda/2$ resonator with circular shape to prevent radiation loss. When two resonators are placed closely, they couple electromagnetically and exchange energy wirelessly. Then, the resonant frequency splits and a band pass filter (BPF) is formed. The resonance occurs only within the distance less than the wavelength. For 60GHz, it is 5mm in the air and 1.5mm in silicon or sapphire. Therefore, the ring diameter $d=\lambda/2\pi$, will be 230 μm on silicon or sapphire.

We performed electromagnetic simulation using HFSS. Through 200μm thick sapphire substrate, 3dB band was formed from 58.1GHz to 66.4 GHz (bandwidth of 8.3GHz) with the minimum losses of 1.35 dB (73.3% transmission) for perfect electrical conductor (PEC) and 1.85 dB (65.3%) for gold wiring.

Impedance matching to the signal feeder line is obtained by selecting the optimum port angle θ. The transmission band is 5 GHz at the thickness of 200 μm and the band exists up to 400 μm.

3. Experiments

Based on the HFSS simulation, mask patterns are designed. The ring outer diameter is 335 μm and the inner diameter is 145 μm. 50Ω coplanar lines are connected to the rings for signal input and output.

The ring and lines are made on c-plane sapphire substrate with the thickness of 200 μm. Conventional photo lithography technology and electrolytic plating of gold are used to make the sample chips. The gold plated sample chips are cut, overlapped, aligned, and bonded with electron wax for the measurement. The measurement was carried out using Agilent E8361A and N5260A.

The maximum transmission is obtained with the port angle of 80° and 55° as -2.3dB (58.9%). From simulation, the losses are estimated as 0.5dB by the conductor metal and 1.35 dB by radiation, maybe, by parallel plate mode propagating between the two metal planes. For 80° port angle sample, bandwidth defined by -3dB frequencies from the maximum S21 is obtained as 7.4GHz (68.1~75.5GHz). The band is shifted about 10 GHz higher than simulated frequencies. The reason is not clear, but tuning will not be difficult for practical applications.

4. Conclusion

ECOR demonstrated 58.9% transmission efficiency and 7.4GHz bandwidth at 60GHz range for the wireless transmission through 200μm sapphire substrate.

ECOR has already been confirmed to works on high resistivity Si substrate (> 1 kΩcm) [5], and its alignment tolerance is so wide as around a half the ring diameter [6]. In addition, ECOR is easy to fabricate on any kind of material. It will contribute to low cost assembly and heterogeneous integration of millimeter wave devices.

Acknowledgement

Authors would like to thank Dr. Ikuo Awai of Ryutech Corp. for valuable discussion and Dr. Gregg Jessen of AFRL for his encouragement on this work. This work is supported by Asian Office of Aerospace Research & Development (AOARD, Grant FA2386-11-1-4084).

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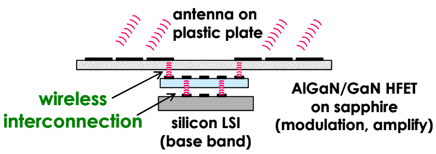

Fig.1. Schematic model of millimeter wave system using ECOR (Electromagnetic coupling of open-ring resonator).

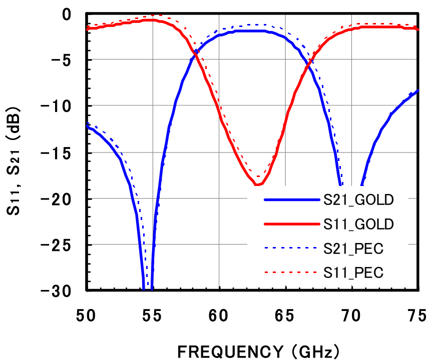

Fig.2 Simulated transmission characteristics through 200 μm sapphire substrate. θ=55°. S21 is transmission and S11 is reflection. PEC stands for perfect electric conductor.

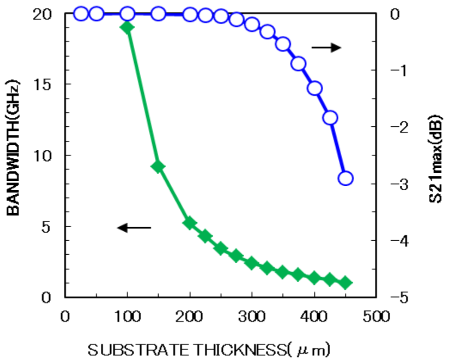

Fig.3 Simulated S21 peak value and the bandwidth as functions of sapphire substrate thickness.

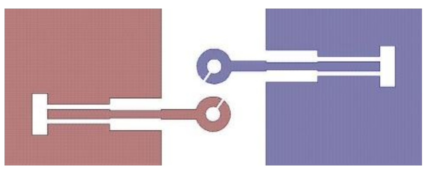

Fig.4 Open-ring resonator patterns for s-parameter measurement. Patterns for the two layers are shown. In the actual measurement, the rings are aligned to overlap. The ring outer diameter is 335μm.

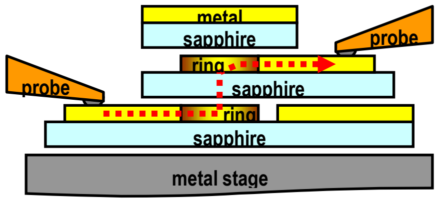

Fig.5 Schematic diagram of the measurement set up.

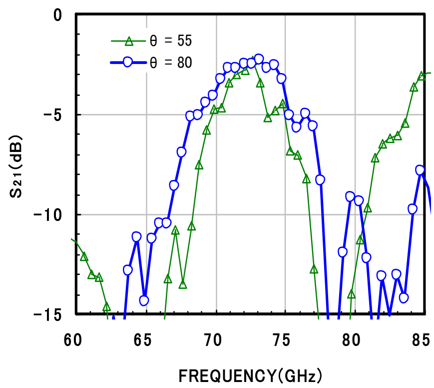

Fig.6 Measured S21 for the rings with port angles of 55° and 80°.

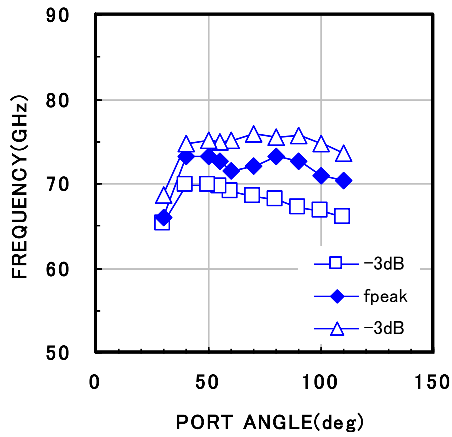

Fig.7 Measured S21 peak and the frequencies -3dB from the peak S21 value.

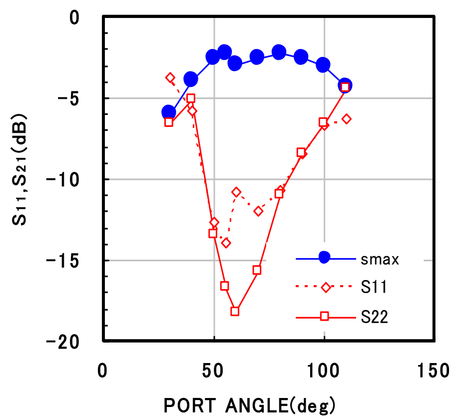

Fig.8 Measured S21 peak value and the S11 values at the same frequency.