A Novel 3-dB Coupler for MMIC Using Air-Gap Stacked Microstrip Lines

Gi-Hyon Ryu, Dae-Hyun Kim, Jae-Hak Lee, and Kwang-Seok Seo

***Abstract*—A simple broadside-coupled line structure for MMIC is proposed which uses air-gap stacked microstrip lines and does not require any dielectric process. The analysis and optimization of the coupled line structure were performed by using an electromagnetic simulator. The fabricated 3-dB coupler shows broad-band characteristics (23–45 GHz) with the coupling loss of 3.33 ± 0.46 dB and the transmission loss of 3.73 ± 0.43 dB.**

***Index Terms*—Air-gap stacked microstrip line, broadside-coupled line, coupler, MMIC.**

I. INTRODUCTION

QUADRATURE directional couplers are extensively used in microwave integrated circuits (MIC's). They are used in phase shifters, balanced amplifiers, mixers, baluns, and other microwave circuits. Many of these applications require 3-dB couplers which are traditionally realized by using parallel-coupled multiconductor microstrip transmission lines, such as the Lange coupler [1]. However, on thin GaAs substrates used for monolithic microwave integrated circuits (MMIC's) (thickness of 75–125 μm, ε_r = 12.9), tightly coupled thick metal structures are difficult to realize because the spacing between the conductors is very narrow (approximately 4 μm for a 75-μm-thick GaAs substrate). Some techniques such as broadside-coupled lines [2], [3] and semireentrant sections [4] have been proposed as alternative structures to obtain tight coupling with reasonable manufacturing tolerances. These coupled line structures require an extra dielectric layer, such as polyimide. An embedded microstrip coupler with MMIC-compatible 0.2-μm-thick SiN film has been also proposed [5]. However, the offset between the two conductors, which controls the coupling factor, is very sensitive to misalignment problem.

In this letter, a novel coupled line structure is presented which uses air-gap stacked microstrip (AGSM) lines. The proposed structure does not need any dielectric layer and is insensitive to misalignment between two conductors. Based on the electromagnetic simulation, the optimum 3-dB coupled line structure has been designed and fabricated using a standard air-bridge process.

II. DESIGN AND FABRICATION

The structure of the proposed AGSM coupler is shown in Fig. 1. It consists of two broadside-coupled conductors on the 75-μm-thick GaAs substrate with backside ground. The design parameters of the AGSM coupler are the widths of lower and upper conductors (W1 and W2, respectively) and the overlap width between the two conductors. To obtain 3-dB coupling, two conductors are fully overlapped to enhance the coupling through the air-gap. Thus, the proposed structure has a misalign-insensitive coupling factor, which is controlled by the overlap width between the two conductors. The 2.5-μm gap between the two conductors is determined by the thickness of the photoresist in the standard air-bridge metal process. The analysis of the AGSM coupler is difficult because the lines are asymmetrically broadside-coupled. Approximate solution for this structure can be obtained by using an electromagnetic simulator. In this work, HP-Momentum was used to analyze the structure for the design of a 3-dB coupler. The widths (W1, W2) were taken from the simulation results with the condition of matching and isolation better than 15 dB and the transmission loss better than 5 dB. The determined widths of lower and upper conductor are 20 and 40 μm, respectively.

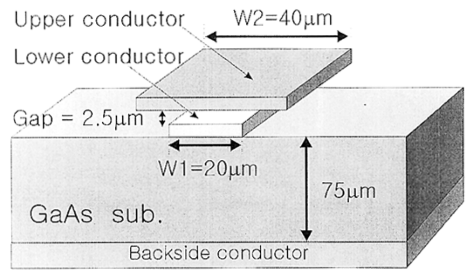

Fig. 1. Cross section of air-gap stacked microstrip coupler structure.

Fig. 2 shows the microphotograph of the entire AGSM coupler, which has 900-μm length on a 75-μm GaAs substrate. To measure the transmission loss of the 4-ports coupler with the 2-ports measurement system, port 3 (coupling port) and port 4 (isolation port) were terminated by on-chip 50-Ω resistors as shown in Fig. 2. The input and two output ports (direct and coupling ports) are conveniently placed on the opposite sides. Thus, this AGSM coupler can be easily applicable to balanced MMIC circuits. The fabrication of the test structure for AGSM coupler started with the deposition of a thin (about 800 Å NiCr film onto the GaAs substrate). The sheet resistance of the NiCr film was 20 Ω/sq. Next, a lower conductor metal (0.5-μm-thick Au) was deposited on the NiCr film. Then, the thick upper conductor metal (3-μm-thick Au) was formed above the lower conductor by using an air-bridge process technique. The 2.5-μm height of the air-bridge can be accurately controlled by the coating speed of the air-bridge photoresist. Finally, backside lapping, via-hole etching and backside thick (about 3 μm) metal plating processes

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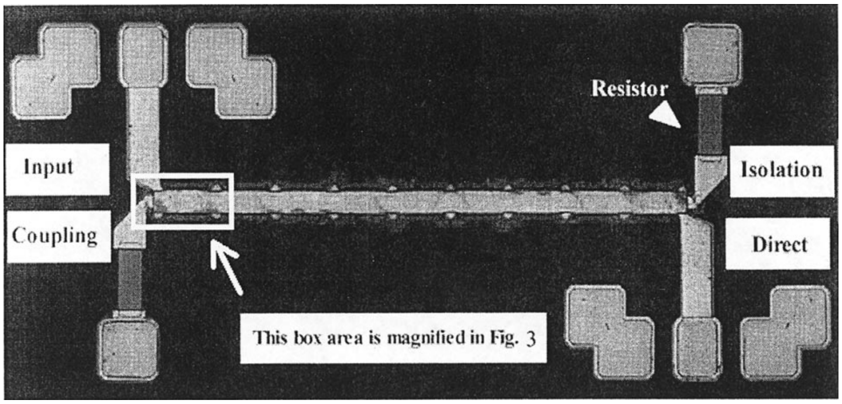

Fig. 2. Microphotograph of the entire AGSM coupler.

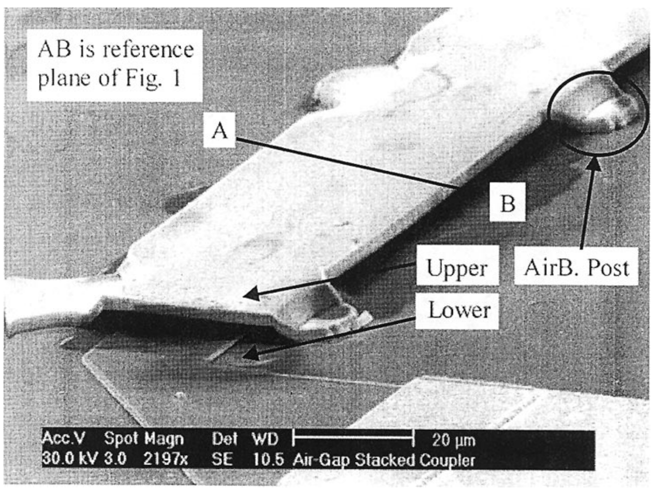

Fig. 3. SEM photograph of the fabricated AGSM coupler.

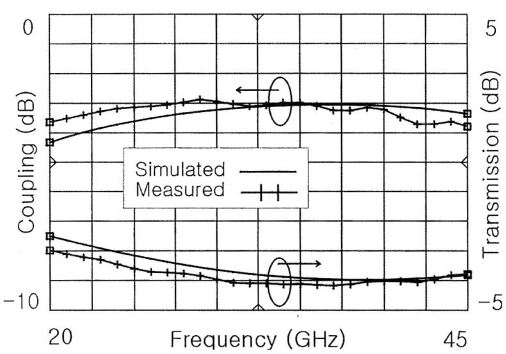

Fig. 4. Measured and simulated coupling and transmission characteristics of the AGSM coupler.

were followed. SEM photograph of the fabricated AGSM coupler is shown in Fig. 3. As we can see in Fig. 3, the upper conductor is firmly floated above the lower conductor through air-bridge posts which are 100 μm apart from each other.

III. Measurements and Discussion

The AGSM coupler was tested by using Cascade Microtech on-wafer probing station and HP8510C Network Analyzer. The input signal was entered to the upper conductor to minimize the

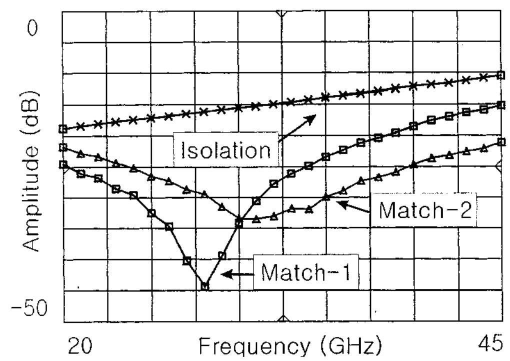

Fig. 5. Measured matching and isolation characteristics of the AGSM coupler.

transmission loss, which was dominantly affected by the conductor loss. Therefore, the transmission loss is relatively lower value of 3.73 ± 0.43 dB and the coupling loss is 3.33 ± 0.46 dB in the wide frequency band (23–45 GHz) as shown in Fig. 4. The results of the electromagnetic simulation are also shown in Fig. 4. As expected from the electromagnetic simulation, the 3-dB coupling and transmission performances are achieved. At all ports, the AGSM coupler shows the return loss greater than 15 dB and the isolation greater than 10 dB, as shown in Fig. 5. The phase difference between the output ports is 85 ± 3 degrees over the 23–45-GHz band.

IV. Conclusion

This letter proposed a novel MMIC 3-dB coupler that uses AGSM lines. The fabrication of the structure does not need any extra process step for the standard MMIC process flow. Moreover, the structure is insensitive to the misalignment. The AGSM coupler has been successfully fabricated, exhibiting good electrical performances. This proposed coupler can be conveniently applied for the balanced monolithic circuits.

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