Multilayer MMIC Branch-Line Hybrid Using Thin Dielectric Layers

Seiichi Banba, *Member IEEE,* Takao Hasegawa, *Member IEEE,* and Hiroyo Ogawa, *Member IEEE*

Abstract—**A miniature MMIC branch-line hybrid circuit utilizing a multilayer structure composed of thin-film transmission lines is proposed. The branch-line hybrid circuit is designed for a center frequency of 20 GHz and fabricated in a 0.49 mm × 0.53 mm area. A coupling loss of 5.5 dB ± 0.5 dB over a 3 GHz bandwidth is achieved.**

I. Introduction

THE branch-line hybrid, which is constructed with four quarter-wavelength transmission lines, is employed as a 3 dB-directional coupler in microwave integrated circuits (MIC's). However, its use in monolithic microwave integrated circuits (MMIC's) is limited due to its large size.

Recently, the performance of thin-film transmission lines, which utilize narrow width microstrip conductors on thin (several-μm thick) dielectric materials fabricated over ground metal on GaAs wafer surface, was reported [1]–[5]. Thin-film transmission lines allow for high-density circuit integration because of reduced linewidths and their ability to be used in multilayer configurations. Therefore, cross-over structures and meander-like configurations are easily fabricated. In addition, thin-film transmission lines can be integrated within coplanar circuits, and are normally called multilayer MMIC's [3].

In this letter, the multilayer MMIC branch-line hybrid is proposed. The branch-line hybrid is constructed as a multilayer structure that consists of microstrip and inverted microstrip thin-film transmission lines. These transmission lines are isolated by ground plane metal that is formed on the center layer of the dielectric materials. Therefore, the coupling effect between two transmission lines is eliminated. Proposed branch-line hybrid circuit can be applied to high density integration of MMIC's.

II. Multilayer Structure

Fig. 1 shows a cross-sectional view of the multilayer structure of microstrip lines and inverted microstrip lines with polyimide film ($\epsilon_r = 3.3$) as the dielectric material. The process for polyimide film preparation and subsequent chemical etching was described in [6]. This process can generate cone-shaped via-holes, which can connect the microstrip conductor on the upper surface with the input/output transmission lines or a ground metal on the GaAs substrate.

Manuscript received July 19, 1991.

The authors are with ATR Optical and Radio Communications Research Laboratories, Sanpeidani, Inuidani, Seika-cho, Soraku-gun, Kyoto 619-02, Japan.

IEEE Log Number 9103575.

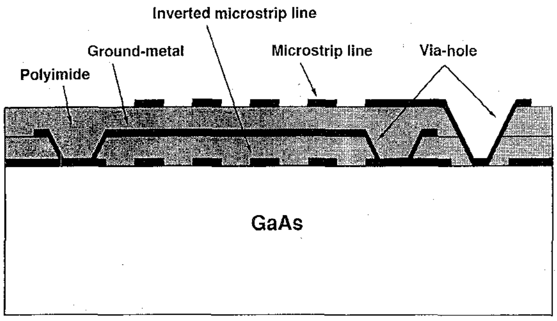


Fig. 1. Cross-sectional view of multilayer trnsmission line structure.

The multilayer structure consists of two polyimide layers and a three-level metallization on GaAs wafer surface. The polyimide layer and metal thicknesses are 5.0 μm and 1.0 μm, respectively. A uniformity in polyimide film thickness of better than 1% is obtained up to thicknesses of 10 μm. The measured film stress of polyimide is a constant value of -2.4×10^8 dyn/cm^2, and is one-tenth as large as Si_3N_4 and SiO_2 films. Furthermore, the surface of polyimide films, which are formed by spin-coating, is flattened due to viscosity. These properties show that polyimide films are a suitable dielectric material for the multilayer MMIC fabrication.

III. Thin-Film Transmission Line

Branch-line hybrids are designed using 35 Ω and 50 Ω transmission lines. In this case, the structures of 35 Ω and 50 Ω transmission line are constructed with the inverted microstrip line and microstrip line, respectively. The characteristics of the inverted microstrip and microstrip lines are determined from calculations by the finite-element method and their performance is tested using on-wafer probes and microwave vector network analyzer. Table I summarizes the experimental results (at 20 GHz) and the corresponding guided wavelengths of these transmission lines. Thin-film transmission lines have much more conduction losses than conventional structures, because of the reduced conductor cross section [1]. Although these transmission lines have different characteristic impedances and guided wavelengths (λg), the transmission lines show almost same loss per quarter-wavelength.

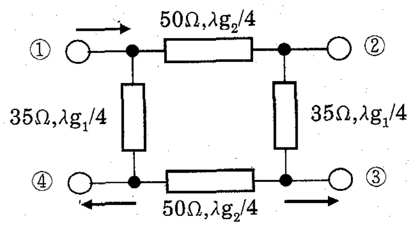
IV. Branch-Line Hybrid Design

Fig. 2(a) and (b) show the circuit diagram and microphotograph of a 20 GHz-band branch-line hybrid. The 35 Ω inverted microstrip lines between ports 2 and 3, and between ports 4 and 1 are formed on the GaAs wafer surface with the 5-μm thick polyimide film and 1-μm thick ground plane metal overlay. Next, 50 Ω microstrip lines between ports 1

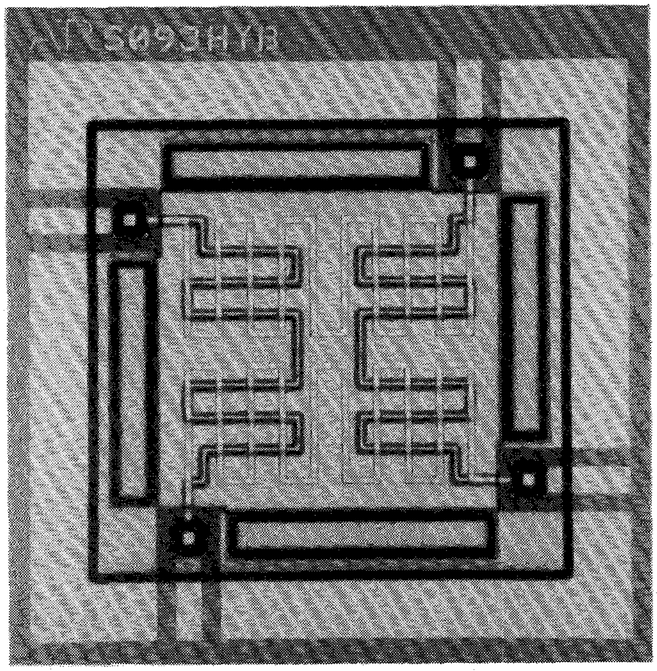
TABLE I
EXPERIMENTAL RESULTS AND LINE LENGTHS OF THE MICROSTRIP LINE AND THE INVERTED MICROSTRIP LINE

	Microstrip Line	Inverted Microstrip Line
Impedance (Ω)	50	50
Linewidth (μm)	11	11
Linelength of quarter-wavelength λg(μm)	2330	1540
Line loss (dB/mm)	0.65	0.93
Line loss per quarter-wavelength λg(dB)	1.30	1.39

Polyimide film thickness = 5 μm, frequency = 20 GHz.



(a)



(b)

Fig. 2. Circuit diagram and microphotograph of a *K*-band branch-line hybrid. (a) Circuit diagram. (b) Microphotograph.

and 2 and also between ports 3 and 4 are formed on a 5-μm thick polyimide film over the ground plane metal.

Each transmission line has a meander-like configuration. The microstrip lines are connected to the inverted microstrip lines through via-holes and each transmission line is connected to the coplanar waveguide (CPW) input/output ports. The ground plane metal is also connected to the ground conductors of the CPW input/output ports through via-holes. The lengths of 35 Ω and 50 Ω transmission lines are 1.54 mm and 2.33 mm, respectively. Both transmission lines have almost the same insertion loss and line widths, therefore the frequency characteristics are effectively balanced.

Fig. 3 shows the measured characteristics of the fabricated branch-line hybrid. This hybrid shows coupling losses for

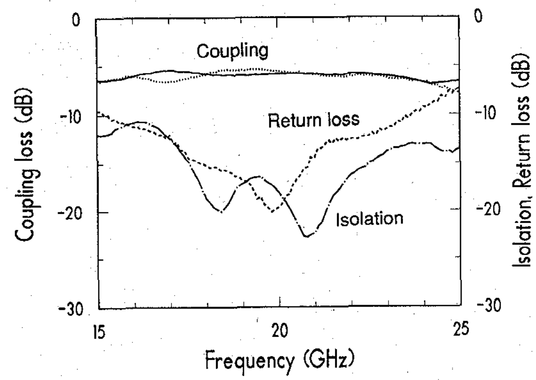


Fig. 3. Measured characteristics of a *K*-band branch-line hybrid. Coupling losses (|S31|, |S41|), isolation (|S31|) and return loss (|S11|).

|S31| and |S41| of 5.5 dB ± 0.5 dB, and isolation, |S 21|, better than 15 dB. Return loss, |S11|, is better than 15 dB in the frequency range from 18 GHz to 21 GHz. The branch-line hybrid exhibits approximately 2.5 dB of excess coupling loss. This loss is primarily due to the lossy thin-film transmission lines whose characteristics are shown in Table I. However, the chip area is very small, e.g., 0.95 mm × 0.91 mm, while the intrinsic circuit area is only 0.53 mm × 0.49 mm. The performance is similar to previous circuits reported in references [3]–[4], while the circuit area is reduced by one-half.

V. CONCLUSION

The very small-sized branch-line hybrid circuit using a multilayer structure has been demonstrated. The multilayer structure can be effectively used for microwave distributed-element such as rat-race hybrid and Wilkinson power divider. The 20 GHz-band branch-line hybrid has been designed within a very small area, less than 0.3 mm^2 while good performance has been maintained. This simple and useful hybrid circuit can be applied to high density integration of MMIC's such as balanced amplifiers and mixers.

ACKNOWLEDGMENT

The authors would like to thank Dr. K. Habara, Dr. Y. Furuhama, and Dr. M. Akaike for their continuous support and encouragement.

REFERENCES

[1] T. Hiraoka, T. Tokumitu, and M. Aikawa, "Very small wide-band MMIC magic-*T*'s using microstrip lines on a thin dielectric film." *IEEE Trans. Microwave Theory Tech.*, vol. MTT-10, pp. 1569–1575, Oct. 1989.

[2] H. Nakamoto, T. Tokumitu, and M. Aikawa, "A monolithic, port-interchanged rat-race hybrid using a thin film microstrip line crossover," in *19th European Microwave Conf.*, Sept. 1989, pp. 311–316.

[3] T. Tokumitu, T. Hiraoka, H. Nakamoto, and T. Takenaka, "Multilayer MMIC using a 3 μm × 3-layer dielectric film structure," *IEEE Int. Microwave Symp. Dig.*, May 1990, pp. 831–834.

[4] H. Nakamoto, T. Hiraoka, and T. Tokumitu, "Very small multilayer MMIC hybrid using polyimide films," *3rd Asia-Pacific Microwave Conf.*, Sept. 1990, pp. 1113–1116.

[5] H. Ogawa, T. Hasegawa, S. Banba, and H. Nakamoto, "MMIC transmission lines for multi-layered MMIC's," *IEEE Int. Microwave Symp. Dig.*, June 1991, pp. 1067–1070.

[6] Y. Harada, F. Matsumoto, and T. Nakakado, "A novel polyimide film preparation and its preferential-like chemical etching techniques for GaAs device," *J. Electrochem. Soc.*, vol. 130, no. 1, pp. 129–134, Jan. 1983.