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MULTILAYER MMIC USING a 3μm×3-LAYER DIELECTRIC FILM STRUCTURE

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ABSTRACT

Newly developed, very small-size multilayer MMICs using miniature microstrip lines on a thin dielectric film are described. Other effective thin film transmission lines, line crossovers, and vertical connections are also discussed. 90-degree and 180-degree hybrids, multiport Wilkinson dividers, and distributed amplifiers are implemented in a very small area, less than $1mm^2$.

INTRODUCTION

Conventional microwave and millimeter-wave passive MMICs constructed with quarter-wavelength transmission lines occupy large areas on MMIC chips, because semi-insulating GaAs wafers, hundreds of μms thick, are used for the substrates of the transmission lines, which are usually microstrip lines. Although coplanar waveguides (CPWs) often used in uni-planar MMICs do not depend on wafer thickness, the degree of size reduction is limited due to the center conductor and grounds on the same surface of the substrate [1].

To overcome the problem of size reduction, and also to enhance circuit design flexibilities, we propose a 3μm×3-layer dielectric film structure, and use of the film for the substrate of microwave and millimeter-wave transmission lines. Very small hybrids, Wilkinson dividers, and distributed amplifiers using the valuable features of miniature, thin film transmission lines, are also demonstrated.

THIN FILM TRANSMISSION LINES

Configuration

Examples of thin film transmission lines are shown in Fig. 1. Each transmission line is formed on one side of a GaAs wafer, and offers a significantly reduced line width due to the thin, several-μm thick dielectric film, which is deposited or coated over the base metal on the GaAs wafer surface. The electric field is concentrated between the metal strip and the ground. Fig. 1 (a) is a thin film microstrip (TFMS) line [2], (b) inverted TFMS line, and (c) and (d) quasi-CPWs. The 50Ω line width of these lines is between 5μm and 20μm, and less than twice the film thickness. The width is similar to that of high impedance microstrip lines often used in the recent, generic-use compact MMICs, and also less than 1/10 that of 50Ω microstrip lines on a GaAs wafer.

Loss Characteristic

Thin film transmission lines, like conventional high-impedance microstrip lines, are not lossless, but rather lossy transmission lines, where the conductive loss is dominant. The surface resistivity R_s of the metal and the transmission loss *Loss* of the TFMS line, as a function of frequency *f*, are given by the following equations [2]:

$$R_s(f) = R_{s0} \times tK\sqrt{f} / (1 - e^{-tK\sqrt{f}}) \quad (1)$$

$$Loss \simeq 8.68 R_s(f)[1/Z_0 \cdot H/W][L/H] \quad (2)$$

where R_{s0} is the surface resistivity for dc current, t is the metal thickness, and Z_0, L, and W are line impedance, length, and strip width. H is the dielectic film thickness. K is a material constant giving the skin depth; $\delta = (K\sqrt{f})^{-1}$. Because $[1/Z_0 \cdot H/W]$ is nearly constant, larger H and smaller R_{s0} are required for lower loss. However, thickness H of around 10μm is effective for achieving both drastic chip-size reduction and reasonably low transmission loss. R_{s0} depends on the strip metal and its fabrication process.

Dielectric Material

Silicon oxynitride (SiON, $\varepsilon_r = 5.0$) and polyimide (SP-510, $\varepsilon_r = 3.3$) are used for the dielectric film. SiON is deposited in 3μm-thick layers, using a low-temperature plasma-CVD process. Polyimide is coated in 2.5μm-thick layers using a spin-coating method to

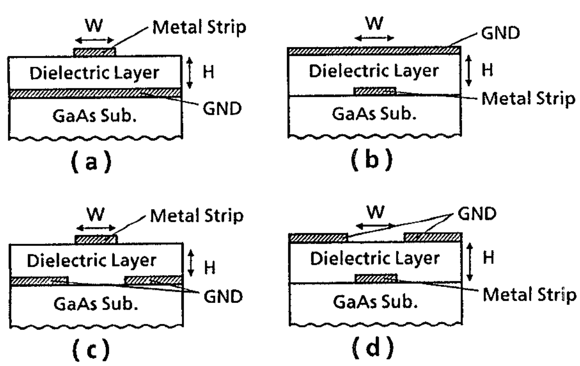

Fig. 1. Examples of miniature transmission lines fabricated using a thin dielectric film. (a) is thin film microstrip (TFMS) line, (b) inverted TFMS line, and (c) and (d) quasi-coplanar waveguides.

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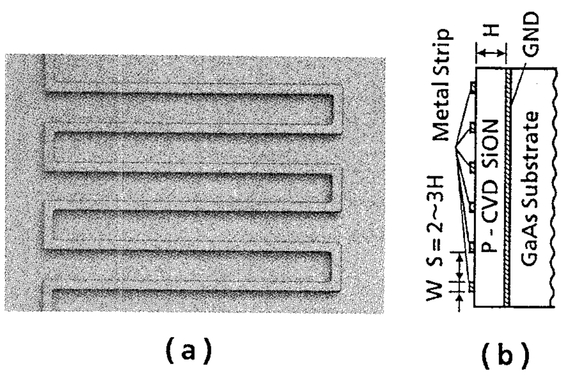

Fig. 2. A meander-like TFMS line. (a) Top view. (b) cross-sectional view.

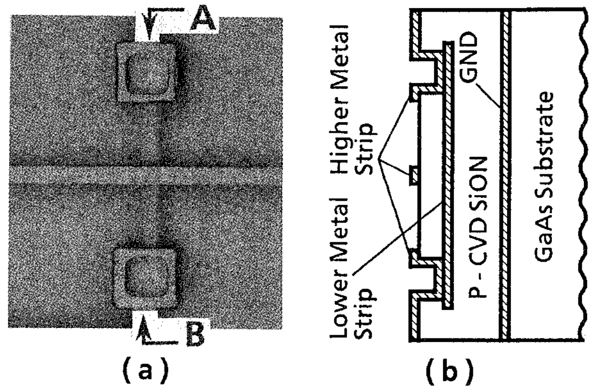

Fig. 3. A TFMS line crossover. (a) Top view. (b) cross-sectional view.

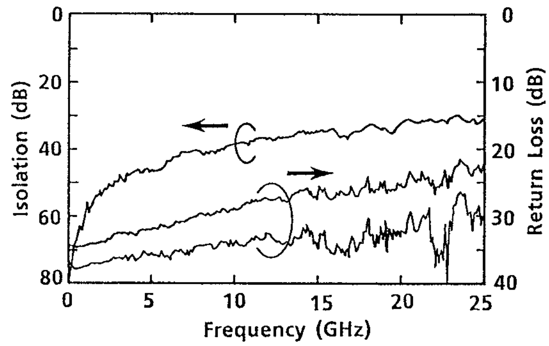

Fig. 4. Measured characteristics of a 50Ω TFMS line crossover.

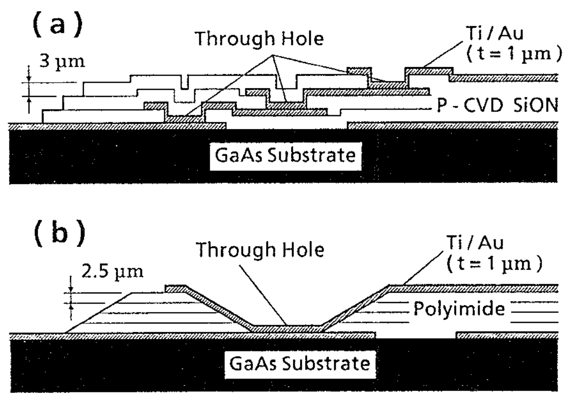

Fig. 5. Vertical connections through (a) SiON and (b) polyimede layers.

obtain layers well-controlled in thickness. These films have much lower film stress compared with other insulators such as SiO_2 and Si_3N_4 on GaAs substrates, and allow fabricating 10µm-thick dielectric films. Furthermore, polyimide flattens the surface of each layer.

VALUABLE FEATURES

The TFMS line, as well as the other thin film transmission lines in Fig. 1, offers the following features:
① a meander-like configuration with a spacing only 2 or 3 times that of the film thickness, which effectively miniaturizes quarter-wavelength transmission lines;
② a high isolation crossover composed of narrow-width lines on two different layers, which enhances layout flexibilities, maintains high frequency operation, and achieves chip size reduction;
③ a vertical connection between circuit elements on the dielectric layers and GaAs substrate, which eliminates lines and crossovers degrading high frequency operation and performance.

Fig. 2 shows a photograph of a meander-like TFMS line. The meander-like configuration widely used in the multilayer MMICs mentioned below, allows close agreement between measured and calculated performance due to negligibly small parasitics between lines and at corners. Figure 3 shows a photograph of a TFMS line crossover. The lower metal strip has pads on both sides and the upper metal strips are continuously fabricated. The metal strips in the direction A-B are connected via through holes on both sides of the lower metal strip. Fig. 4 shows the measured characteristics of a 50Ω TFMS line crossover. Isolation is better than 30dB and return loss is better than 20dB up to 25GHz. Fig. 5 shows vertical connections through dielectric layers. Sharp holes are formed through each SiON layer by using dry etching, and cone-shaped holes are formed through the polyimide film by using chemical etching.

MULTILAYER MMIC

Examples of multilayer MMICs using the advantages above are demonstrated in Figures 6-12. Although the examples are implemented using only TFMS line, these TFMS lines can be easily replaced with the other thin film transmission lines. Combinations of different lines also realize more efficient circuits.

Following MMICs are implemented by using SiON and polyimide, where a dc surface resistivity R_{s0} of 0.028Ω/□ was used in the performance predictions. Measured R_{s0} of the strip metal on the materials are 0.06Ω/□ and 0.03Ω/□, respectively.

90-degree hybrid

A 15GHz 90-degree hybrid (branch-line coupler)

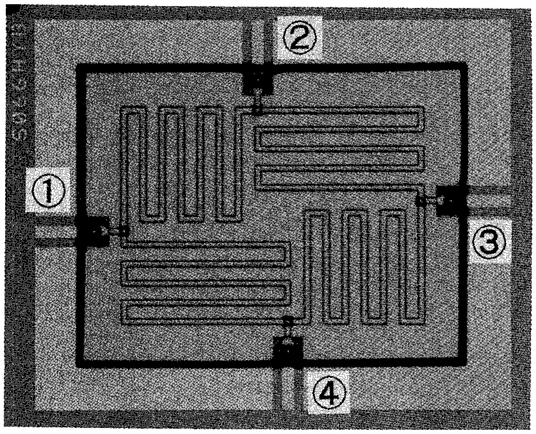

Fig. 6. Photograph of a 15GHz branchline coupler using TFMS lines on two different layers.

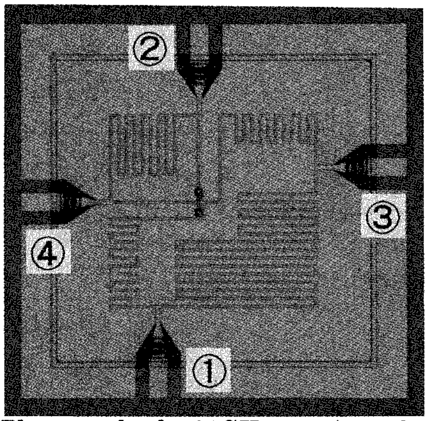

Fig. 8. Photograph of a 20GHz port-interchanged rat-race hybrid using a line crossover.

MMIC is shown in Fig. 6. The 35Ω TFMS lines between ports ①, ② and between ports ③, ④ are formed on a 5μm-thick polyimide layer coated over the ground on the surface of a GaAs wafer. The line width is 18μm. Another 2.5μm-thick polyimide layer is coated after the 35Ω metal strip is applied to the 5μm-thick polyimide layer. 50Ω TFMS lines between ports ①, ④ and between ports ②, ③ are formed on the top surface of the 7.5μm-thick film. The line width is 16μm. Each metal strip level is connected to the other metal strip level via through holes at the corresponding ports. The 35 and 50Ω TFMS lines on the different layers have almost the same line width and insertion loss. Therefore, the frequency characteristics are balanced.

The chip size is 1.3mm×1.6mm, while the intrinsic area after subtracting the input and output lines is only 0.7mm×1.0mm. Fig. 7 shows the measured and calculated performance. Both performances agree closely. This branchline coupler exhibits a coupling loss of 5.5dB±0.5dB, isolation better than 15dB (24dB at the center frequency), and return loss better than 10dB at frequencies between 12GHz and 16GHz.

180-degree hybrid

A 20GHz 180-degree hybrid (rat-race hybrid) using

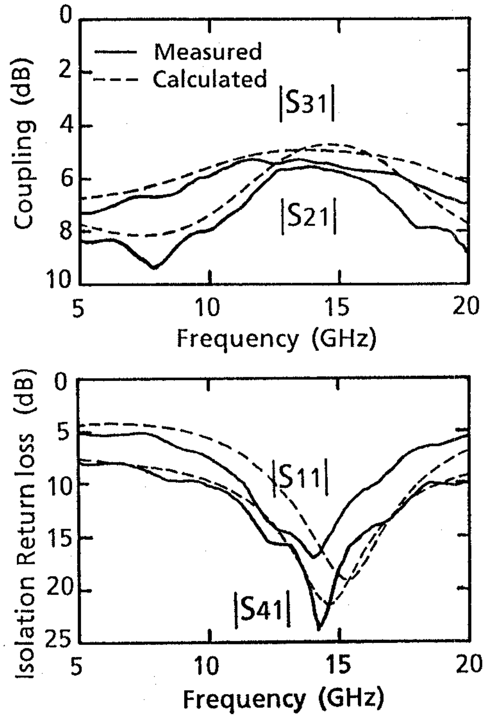

Fig. 7. Measured and calculated performance of the branchline coupler MMIC.

3μm×3-layer SiON film is shown in Fig. 8, where a TFMS line crossover is employed. The crossover in the rat-race hybrid MMIC allows the isolation ports ① and ④, which are diagonally allocated in the conventional rat-race hybrids, to be allocated on the other side of the hybrid from the input ports ② and ③. Each 70Ω strip width is 7μm. Measured isolation between the upper and lower strips is greater than 35dB up to 25GHz, due to stray capacitance as small as 0.001pF between the strips. The chip size is 1mm×1mm, and the intrinsic area is less than 0.7mm×0.7mm. This rat-race hybrid exhibits coupling loss of 6dB±1dB, isolation better than 20dB (30dB near the center frequency), and return loss better than 20dB between 17GHz and 23GHz [3].

Distributed Amplifier

The 6-stage distributed amplifier MMICs shown in Fig. 9 offer another application of the meander-like configuration and crossover of the TFMS lines. The MMICs are implemented using SiON film, and the chip size is 0.8mm×1.3mm. The two MMICs are designed using the same equivalent circuit scheme and parameters to achieve a 5dB gain across 0.5GHz and 18GHz. This sophisticated layout (b) is difficult in conventional planar MMICs. The layout flexibility allows enhancing circuit-packing density and heat radiation. In addition, TFMS lines fabricated over the RF bypath capacitors contribute to the chip size reduction. Fig. 10 shows the measured and calculated performance of both distributed amplifier MMICs.

Wilkinson Divider

A 12GHz 4-port Wilkinson divider MMIC with a chip size of 1.2mm×1.0mm is shown in Fig. 11. Four resistors and an H-shaped conductor connecting the resistors are clustered on the surface of a GaAs wafer. Input and output CPWs are, in this case, also formed on the same surface. A metal, which connects ground conductors of the CPWs via through holes, is applied on the first 3μm-thick SiON film. Four quarter-wavelength, TFMS line transformers are formed on a second 6μm-thick SiON film. Finally, the above resistors for output isolation and the TFMS transformers are connected vertually via through holes. A high isolation among the output ports, better than 30dB, is obtained at the center frequency, due to the absence of undesirable lines and crossovers for connecting the resistors and transformers; in other words, an electrically symmetrical configuration. Measured isolation characteristic is shown in Fig. 12 along with the power dividing characteristic.

CONCLUSION

Very small microwave and millimeter-wave MMICs using novel multilayer, thin film transmission lines have been demonstrated. The multilayer MMIC which we have proposed will prove valuable for multifunction MMICs due to advantages such as the variety and very small size of transmission lines, layout flexibilities, and vertical connections.

ACKNOWLEDGMENT

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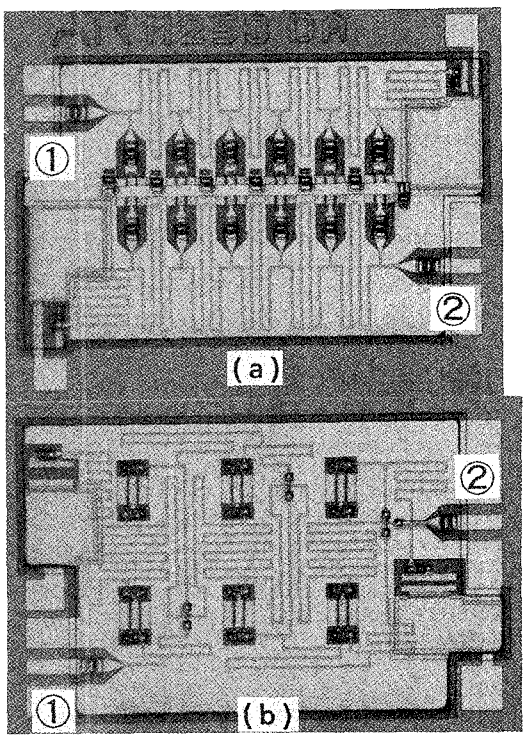

Fig. 9. Photographs of six-stage distributed amplifier MMICs with the same equivalent circuit scheme and parameters.

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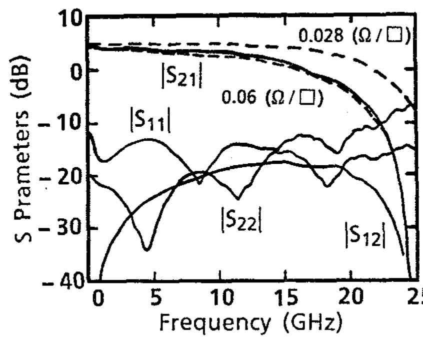

Fig. 10. Performance of the distributed amplifier MMICs. Solid: measured, dash: calculated.

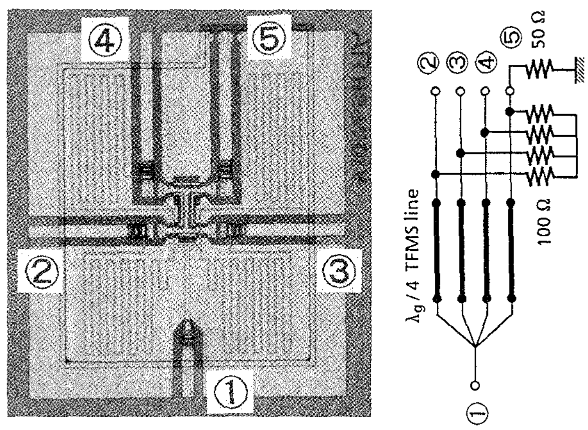

Fig. 11. Photograph of a 12-GHz, 4-port Wilkinson divider using vertical connections.

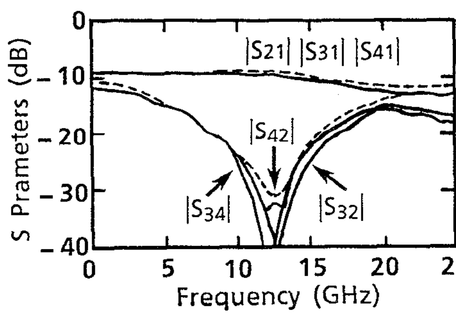

Fig. 12. Isolation and power dividing characteristics of the 4-port Wilkinson divider. Solid: measured, dash: calculated (R_{s0}=0.06Ω/□).