Folded U-Shaped Microwire Technology for Ultra-Compact 3D MMICs

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ABSTRACT

A novel microwire technology has been developed to fabricate 3-dimensional structures for use in ultra-compact GaAs MMICs. By folding metal into a U-shaped wall and burying it in a relatively thick polyimide insulator, vertical microwires can be made with both greatly reduced process complexity and process compatibility with multi-level interconnects. The proposed microwires are suitable for miniature transmission lines, miniature inductors, shielding walls, and multi-function passive elements like baluns and couplers.

INTRODUCTION

The rapid growth in mobile communication has increased demand for both low-cost and high-performance RF receivers/transmitters. One promising solution is to combine the necessary functional building blocks of RF architecture in single-chip MMICs and offer a better performance as compared with a multi-chip approach. We have developed a novel microwire technology for application to high-density and multi-function GaAs MMICs. It involves folding metal into a U-shaped wall and burying it in a relatively thick polyimide insulator [1]. The resulting U-shaped microwires are very useful in shrinking the size of GaAs MMICs. Additionally, the U-shaped vertical microwires are process compatible to a multi-level-interconnect structure by means of a polyimide insulator [2-4], which is another useful approach to making GaAs MMICs more compact. By combining with multi-level-interconnect technology, various passive circuits can be formed in an extremely small area.

In this paper, we report the fabrication process of the vertical U-shaped microwires and describe several applications for passive circuits, i.e., transmission lines, inductors, baluns, couplers, and shielding walls between signal lines.

FABRICATION

In order to build a completely 3-dimensional passive circuit structure, a novel fabrication technology was developed. The key process is the fabrication of the vertical U-shaped microwire, which is similar to micro-machining. The main flow of the fabrication process is shown in Fig. 1.

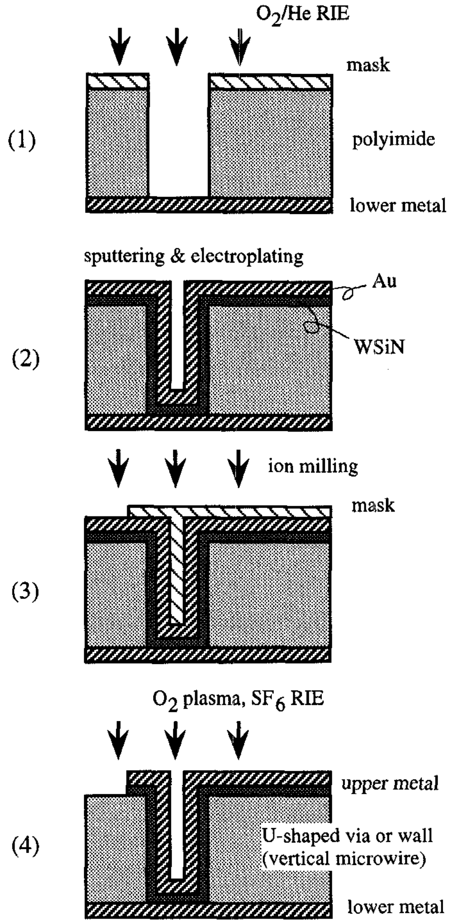

Figure 1. Process flow of vertical U-shaped microwire

First, deep trench patterns are formed in a 10-μm-thick polyimide insulator layer. O_2/He RIE is used to prevent the side-etching of polyimide. The ratio of O_2 to He is 2 to 1 and gas pressure is as low as 30 mtorr. RF power density is 0.2 W/cm^2. The lower metal beneath the 10-μm-thick polyimide acts as an etching stopper. The sputtering effect of He ions effectively eliminate the residue produced on the bottom surface of the deep trench patterns. Second, a 1-μm-thick metal sidewall is formed along the surface of the deep trenches by low-current gold electroplating. Prior to the electroplating, WSiN/Au is coated by sputtering deposition.

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Using a current density as low as 0.2 mA/cm^2 for plating results in splendid conformability and uniformity of the plated metal. The larger grain size and the fewer defects are obtained. Finally, the gold grown on the polyimide surface is patterned by ion milling with a photoresist mask. The sputter deposited WSiN layer beneath the gold is very useful as a milling stopper. It is removed by SF_6 RIE after ion milling.

For example, we usually fabricate 6 levels of interconnects stacked on GaAs substrate, where each gold metal and polyimide insulator layer are respectively 1-µm and 2.5-µm thick. Active devices and MIM capacitors are formed simultaneously on GaAs substrate by using first and second levels of interconnect. In these multi-level-interconnect structures, the vertical U-shaped microwires 10-µm thick can be formed if the 2nd level of the interconnect is used for a lower metal and the 6th level is for folded U-shaped metal. Therefore, this U-shaped microwire technology, which is process compatible with multi-level interconnects by means of the polyimide insulator, offers designers a wide range of circuit design options and flexibility.

APPLICATIONS

Some examples of 3-dimensional passive elements and circuits that can be devised by means of this vertical U-shaped microwire technology are given below.

1. Miniature transmission lines and couplers

Vertical U-shaped microwires are used for coplanar transmission lines, as shown in Fig. 2(a). The width, height and gap of the fabricated microwires are 4, 10 and 16 µm, respectively. The metal thickness of U-shaped microwires is 1.3 µm. Although I-shaped microwires (Fig. 2(b)) have more metal volume, they are less reliable or are not process compatible with multi-level interconnects. Because voids remain inside the I-shaped microwires, if they are fabricated according to the flow in Fig. 1. Figure 2(c) shows characteristics of fabricated coplanar transmission lines. The performance is almost the same as that of I-shaped microwires even though the cross-sectional area is one-third less.

Thin-film-microstrip lines can also be designed using the U-shaped microwires. These U-shaped signal lines occupy only one-quarter of the area occupied by a conventional 2-µm-thick microwire (Table 1).

Table 1. Size of transmission lines by vertical U-shaped microwires

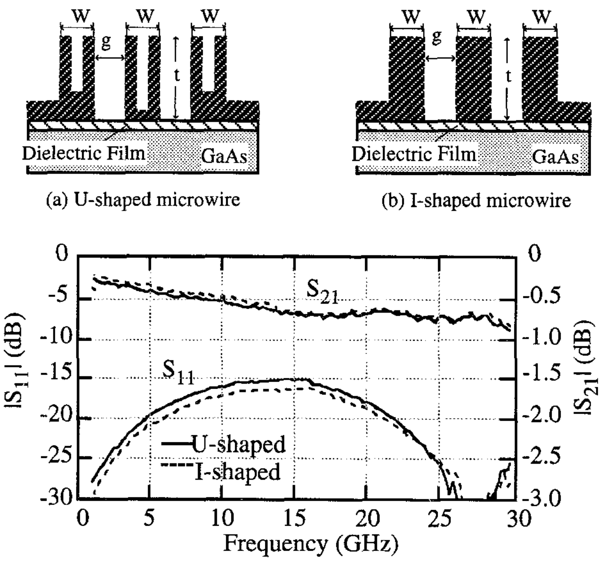
Coplanar transmission line

	U-shaped	conventional
size	w=4µm g=11µm	w=20µm g=17µm
loss	0.16 dB/mm	0.15 dB/mm

Thin film microstrip transmission line

	U-shaped	conventional
size	w=4µm g=10µm	w=17µm g=1µm
loss	0.24 dB/mm	0.23 dB/mm

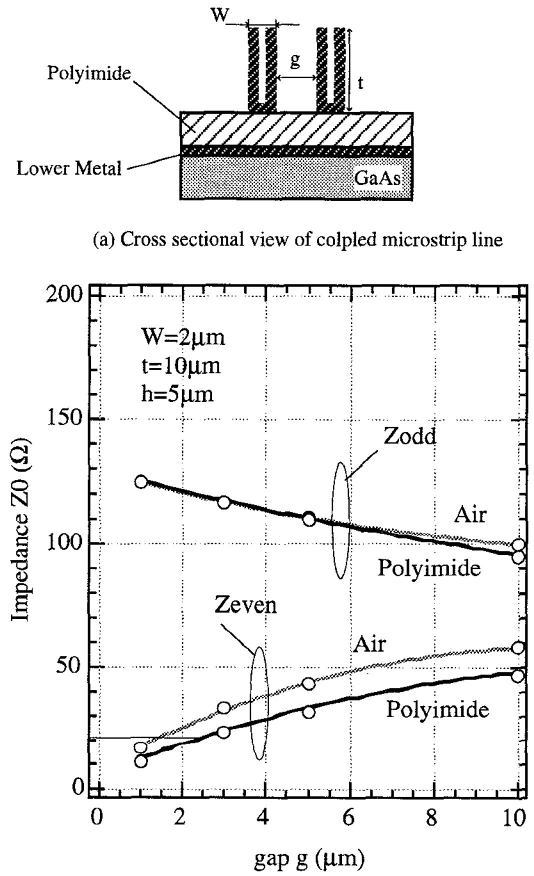
@characteristic impedence 50Ω
frequency 10GHz



(a) U-shaped microwire (b) I-shaped microwire

(c) Frequency dependence of |S11| and |S21|

Figure 2. Characteristics of coplanar transmission lines



(a) Cross sectional view of colpled microstrip line

(b) Even and odd mode characteristic impedance of coupled microstrip line

Figure 3. Design of miniature broadside coupler using vertical U-shape microwires

A miniature broadside coupler can be designed by using the coupled U-shaped microwires as shown in Fig. 3(a). The even and odd characteristic impedance of the coupled microstrip line are calculated using the finite element method. When the width, height and gap of the microwire are 2, 10, and 2.5 μm on 5-μm-thick insulator, the even and odd mode characteristic impedance is 121 and 21 Ω as shown in Fig. 3 (b), when the coupled microstrip lines are buried in the polyimide insulator.

2. Miniature inductors and filters

The U-shaped microwire technology can also be applied to fabricate spiral and meandering inductors [5]. Both the width and gap of the microwires are 4 μm and the height is 10 μm. As compared with conventional 2-μm-high microwires with both a width and gap of 10 μm, inductors made from U-shaped microwires are only half the size, as shown in Fig. 4(a)-(b), and the parasitic resistance is only three-quarters as high. These inductors were also fabricated with I-shaped microwires and their characteristics are the same as U-shaped ones.

A miniaturized low-pass filter was made with the U-shaped microwire inductors. It consists of two spiral inductors of 5 nH and three MIM capacitors. Its intrinsic area is 780 μm square, which is one-fifth the size of a conventional one. Figure 5 shows the characteristics of fabricated low-pass filter in comparison with the simulated result with Q = 5. The insertion loss is under 3 dB and the attenuation is 15 dB for a 300-MHz offset.

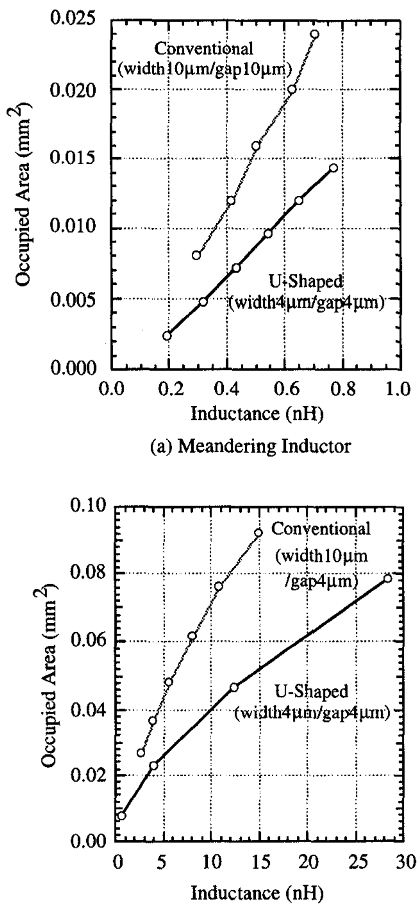


Figure 4. Occupied areas of meandering and spiral inductors using vertical U-shaped microwires

3. Shielding walls

Figure 6(a) shows a U-shaped vertical wall used as a shielding between two microstrip transmission lines in a multi-level-interconnect structure [6]. The width and gap of the two microstrip lines are 8 and 20 μm, respectively. The polyimide thickness between the microstrip line and ground is 5 μm. If 10-μm-high vertical wall is buried in the thick polyimide insulator for shielding, the isolation characteristics are improved by about 10 dB as shown in Fig. 6(b). Employing such a U-shaped vertical wall between thin film microstrip lines significantly reduces the area needed to provide strong isolation against crossover.

4. Miniature balun

A miniature wideband 3-dimensional balun was also fabricated [7]. Figure 7(a) shows the circuit diagram of the GaAs MMIC balun. Three narrow U-shaped microwires with the quarter wavelength, 1.55 mm, at the center frequency of 2 0 GHz are formed with the width and height of 6 and 10 μm, respectively. The conductor gap is 14 μm because the unbalanced and balanced characteristic impedance is designed to be 100 Ω. The insertion loss is 1.5 ± 1 dB at frequencies from 10 to 30 GHz, and the return loss is better than 10 dB at frequencies from 13 to 28 GHz. The amplitude and phase balances are 2 dB and 5 degrees, respectively, at frequencies from 10 to 30 GHz, and the return loss is better than 10 dB at frequencies from 13 to 28 GHz. The amplitude and phase

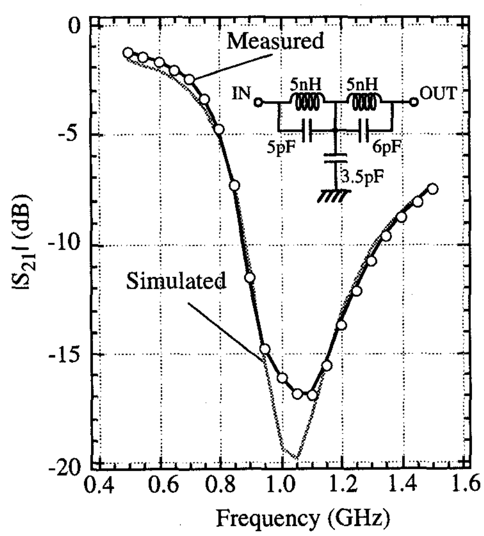


Figure 5. Measured characteristics of low-pass filter with miniatured inductors by means of vertival U-shaped microwires

balances are 2 dB and 5 degrees, respectively, at frequencies from 5 to 35 GHz as shown in Fig. 7(b). The intrinsic area is only 450 μm X 800 μm. Figure 7(c) is an SEM image of the fabricated U-shaped microwires and the transition point to thin film microstrip lines.

CONCLUSION

A novel microwire technology that is process compatible with multi-level interconnects by means of a polyimide insulator has been developed. Because this 3-dimensional technology can achieve a variety of highly miniaturized and multi-function passive circuits, it enables us to implement ultra-compact GaAs MMICs. With this technology, circuit designers can take advantage of smaller chip areas and greater design flexibility to get higher-performance GaAs MMICs.

ACKNOWLEDGEMENT

The authors would like to thank Drs. Kazuo Hirata, Masayoshi Aikawa, Kimiyoshi Yamasaki for fruitful suggestions, their support and constant encouragement. They would especially like to acknowledge Kenjiro Nishikawa for his circuit design and simulation and Shinji Aoyama and Suehiro Sugitani for circuit fabrication. Thanks are also due to their colleagues at NTT LSI Laboratories and NTT Wireless Systems Laboratories for their helpful assistance.

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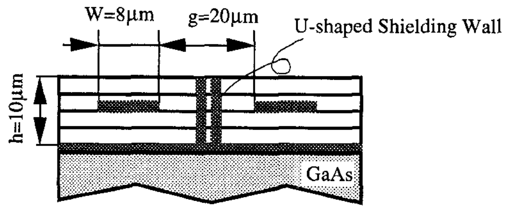
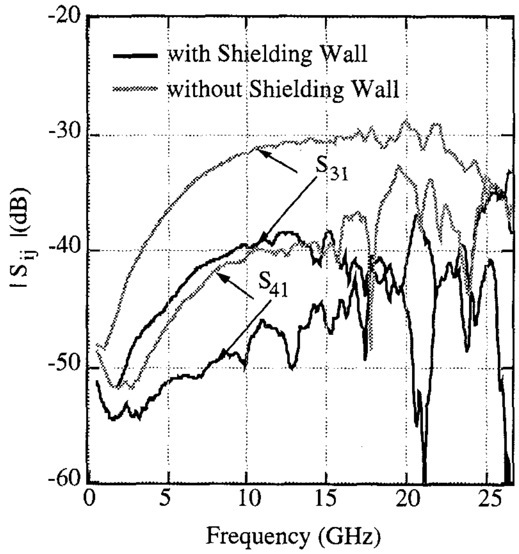
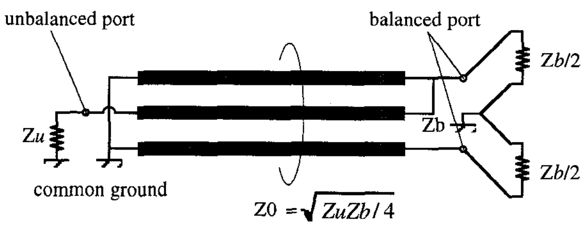


(a) Thin-film microstrip lines with shielding wall in multi-level-interconnect structure

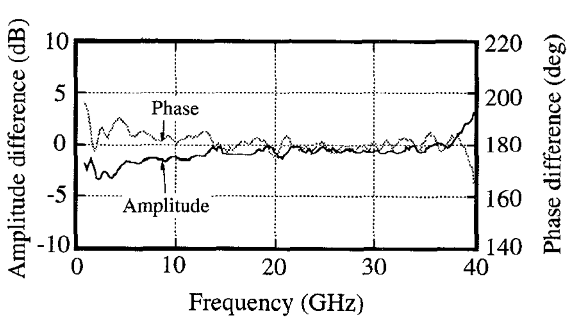


(b) Isolation characteristics with and without shielding wall

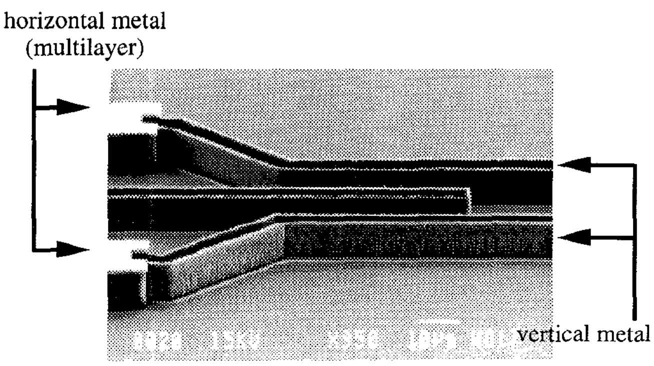
Figure 6. Shielding effect by vertical U-shaped metal wall in multi-level-interconnect structure



(a) Circuit diagram



(b) Amplitude and phase balance of fabricated MMIC balun



(c) SEM image (10-μm height). Polyimide was removed in order to see the microwire structure.

Figure 7. Miniature wideband 3-dimensional balun