Three-Dimensional Passive Circuit Technology For Ultra-Compact MMICs

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ABSTRACT

A novel passive circuit technology of a three-dimensional (3D) metal-insulator structure has been developed for ultra-compact MMICs. By combining vertical passive elements, such as a wall-like microwire for shielding or coupling and a pillar-like via connection, with multilayer passive circuits, highly dense and more functional MMICs can be implemented.

INTRODUCTION

Recent rapid improvement in mobile communication has increased the demand for highly dense and more functional MMICs. Building MMICs from multilayer passive circuits with polyimide insulators is useful [1-3], because, as shown in Fig. 1, two different passive circuits can be formed in the same area with the shield ground plane of the middle metal layer. Moreover, two or more different signal lines can be coupled through a window formed in the shield plane. On the other hand, vertical microwire technology [4-5] is another effective way to shrink the size of MMICs. As shown in Fig. 2, inductors and transmission lines can be miniaturized with a vertical wall-like microwire structure.

In this paper, a novel passive circuit technology that enables us to build even more compact and functional MMICs is proposed. In this technology, the multilayer and vertical passive structures are combined. This produces a completely three-dimensionalized structure that is useful in reducing chip size and improving MMIC performance.

A STRUCTURE

Many vertical passive elements can be utilized in the design of three-dimensional (3D) MMICs. Among them are a vertical shield wall, a miniature inductor, a miniature transmission line, a vertical coupler and a pillar-like via connection through the thick insulator layer. In addition, all these elements can be put together with a horizontal multi-metal-insulator-layer structure, as shown in Fig. 3. By employing the shielding and coupling effect in the 3D structure, a variety of passive functional circuits such as dividers, phase shifters, filters, mixers and so on can be formed to minimize the chip area and to greatly improve MMIC performance.

FABRICATION

A new fabrication technology was developed to build the 3D passive circuit structure. We call it Folded Metal Interconnection technology with a Thick insulator (FMIT). In FMIT, a U-shaped microwire[5] , as an essential vertical element, is buried in the thick insulator of the multi-metal-insulator-layer structure. The main flow of the fabrication process is shown in Fig. 4. The process has three key features. The first is the formation of a viahole or trench in the 10-um-thick polyimide insulator layer by RIE. The second is the formation of a metal sidewall along the surface of the formed viahole and trench. Low-current gold electroplating [6] is applied to grow 1-μm-thick metal sidewall. The third feature is the patterning of gold grown on the polyimide surface. Ion-milling is used to etch the gold with WSiN as a stopper. A U-shaped pillar-like via or wall-like metal is then formed along the surface of the viahole or trench. These U-shaped elements can be used to form

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the vertical structure in the thick polyimide insulator.

Fabricated 3D structure with the thickness of 10 μm is shown in Figs. 5(a) and 5(b). The polyimide insulator was almost completely removed by RIE to reveal the metal structure. The 10-μm-high pillar-like via and metal wall were successfully fabricated. These can be combined with, for example, a multilayer structure of five 1-μm-thick metal layers and four 2.5-μm-hick insulator layers. The farther detailed fabrication technology of three-dimansional structure will be submitted in the near future.

CIRCUIT APPLICATIONS

Figure 6 shows an example of a 3D passive element formed by this technology. The two micro-strip (MS) signal lines of the multilayer structure can be shielded effectively by employing the vertical metal wall buried in polyimide, as shown in Fig. 6(c). By using shield effect with vertical or horizontal wall in the 3D structure, Thin Film Microstrip (TFMS) line, which is a miniature transmission line, can offer a significantly reduced line width and provide strongly isolated crossovers.

Another 3D passive circuit as an example of usage of coupling effect by the vertical metal walls, a one-third or less miniaturized wideband balun, has also successfully operated [7]. The balun with 1.5 ±1 dB insertion loss over 10 to 30 GHz and 2 dB and 5 degrees of amplitude and phase balances over 5 to 35 GHz have been obtained with the intrinsic area of only 450 μm X 800 μm. By using coupling effect with vertical or horizontal metals, many other functional passive circuits like dividers, filters and mixers can be fabricated in a small area.

Vertical connection by pillar like vias can provide short signal delay and miniaturized connection even through very thick insulator. An inverted microstrip line(IMSL) with a thick insulator[8] has been formed by this same technology, which is useful not only for 3D MMICs but also for very high speed digital communication ICs.

Various kinds of passive elements can be realized in 3D structure to provide highly dense and more functional MMICs with high design flexibility.

CONCLUSIONS

The three-dimensional(3D) passive circuits were successfully fabricated. The technology enables to implement ultra-compact MMICs.

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REFERENCES

[1] M.W.Green et al., "Miniature Multilayer Spiral Inductors For GaAs MMICs," IEEE GaAs IC Symp., pp. 303-306, 1989.

[2] T. Tokumitsu et al., "Multilayer MMIC Using a 3 mm X 3-layer Dielectric Film Structure," 1990 IEEE MTT-S Digest, S-5, pp. 831-834, June 1990.

[3] I. Toyoda et al., "Multilayer MMIC Branch-Line Coupler and Broad-Side Coupler," IEEE 1992, MMWMC digest, pp. 79-82, June 1992.

[4] M. Hirano et al., "1/4 Miniaturized Passive Elements for GaAs MMIC s," IEEE GaAs IC Symp., pp. 34-40, 1991.

[5]]M. Hirano et al., "Folded U-Shaped Microwire Technology For GaAs IC Interconnections," IEEE GaAs IC Symp., pp. 177-180, 1992.

[6] M. Hirano et al., "Submicrometer Gold Interconnect Wiring by Sidewall Electroplating Technology," Jpn. J. Appl. Phys., Vol. 33 (1994), pp. L553-L555, Apr. 1994.

[7] I. Toyoda et al., "An Ultra-Wide band Miniature Balun for 3-Dimensional MMICs," APMC, 22-2, pp.511-514, Dec 1994.

[8] S. Yamaguchi et al., "An Inverted Microstrip Line IC Structure for Ultra-high-speed Applications," IEEE MTT-S, May 1995.

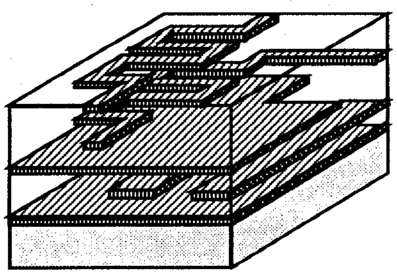

Fig. 1 Multilayer structure

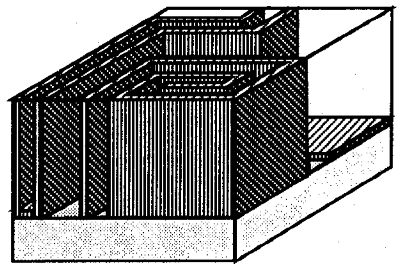

Fig. 2 Vertical structure

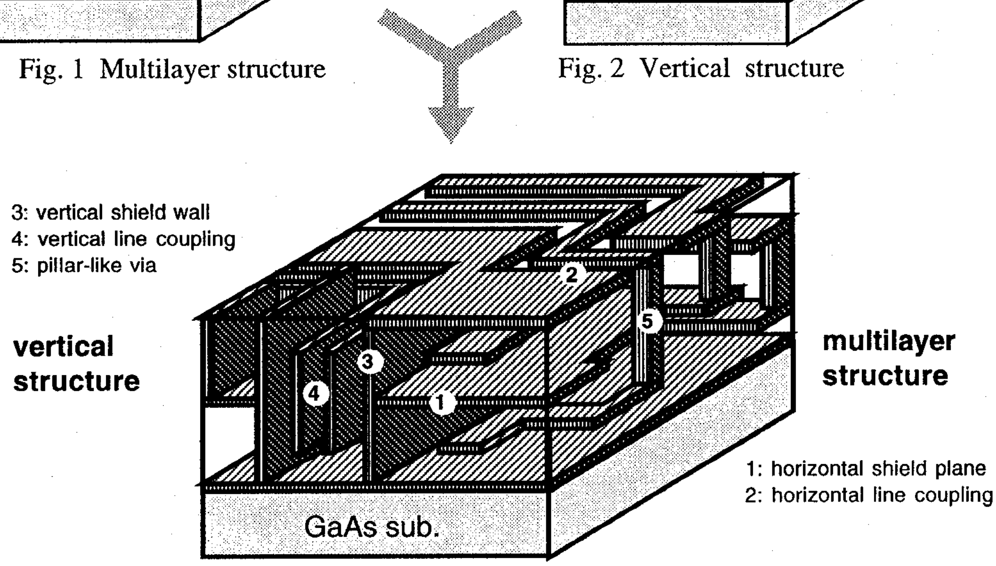

Fig. 3 Three dimensional MMIC

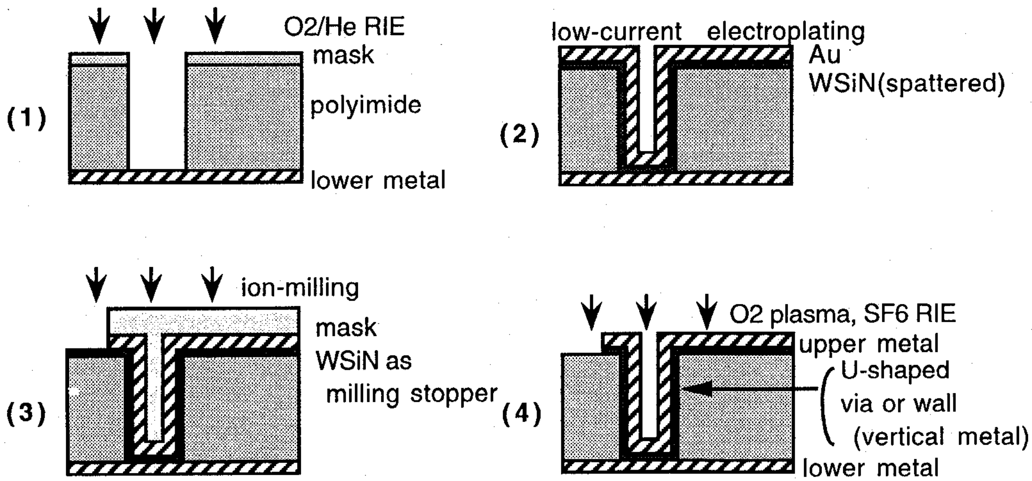

Fig. 4 Process Flow

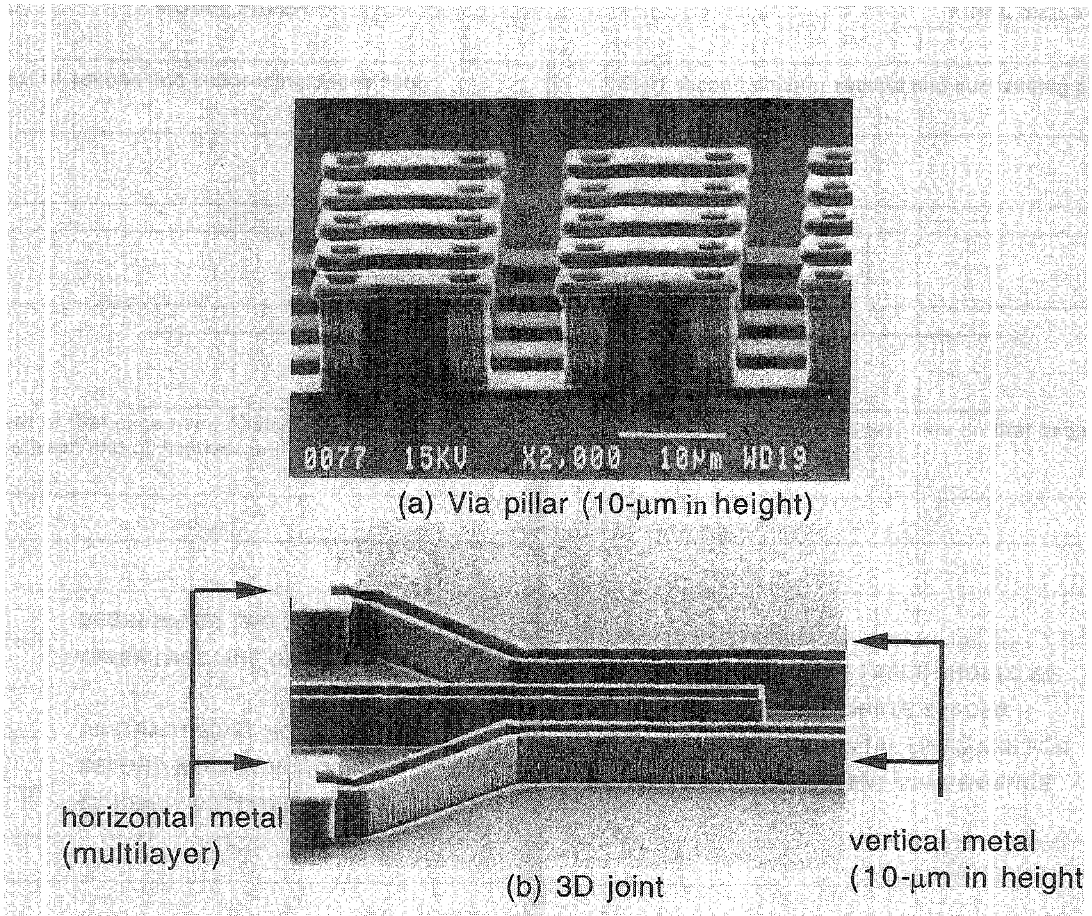

Fig. 5 Fabricated 3D structure
(The polyimide has been removed to reveal the metal structure.)

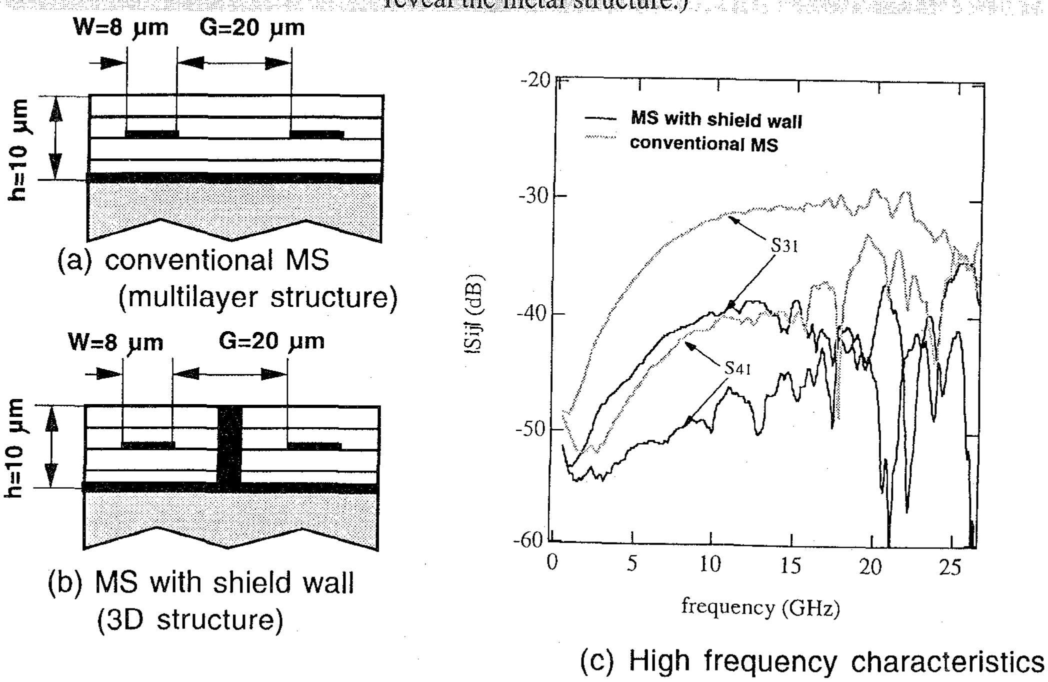

Fig. 6 Shield effect of vertical wall