A Design of New Miniaturized MMIC Low pass Filter

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Abstract— **In this paper, a new miniaturized MMICs low pass filter with reduce size design is being discussed. The multilayers configured with gallium arsenide (GaAs) as a substrate while the polyimide layer as dielectric. The filter consists of buried coplanar layer and a polyimide overlay and has overall area of 160 x 120 μm^2. An electromagnetic simulator *Sonnet Lite* is used to characterize and predict the filter response. The results of this simulation show that the filter well operates without spurious in the passband or stopband. The results also revealed that these miniaturized structure are appropriate for low cost and low loss which are smaller than that of conventional equivalents. By using the same structure three different cut-off frequencies has been obtained with three different sizes of transmission line. The simulation results show all the values of insertion and return losses.**

Index Terms— **gallium arsenide, MMICs, multilayer, buried coplanar waveguide and transmission line.**

I. Introduction

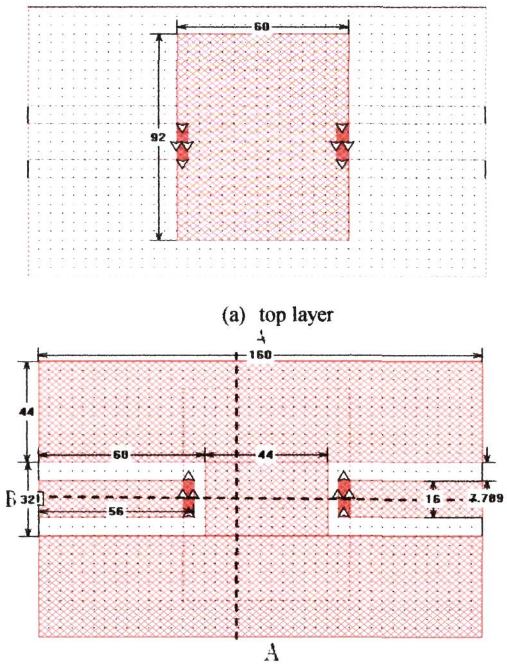
Newly developed and powerful integrated circuits are widely expansion to the wireless industry in microwave communication system. The filter is an essential component, which is usually used in both receivers and transmitters. Thus, the quality of filters is extremely important. In addition to miniaturize them, they have to be faster and consume less power. They are well suited to use in applications such as filtering, impedance matching, signal processing and other functions required for communication technology. Multilayer MMIC filter technology employing multilevel dielectrics and metals which found increasing an application in compact and high performance circuits and is one of the most popular filters in communication systems due to its advantages of ease in manufacture, ease of synthesis method, low cost, and high practicality [1]-[2].

There are two important goals exist in this paper. The first is size reduction but critical obstacle in effort to reduce the module size is the design of passive component. The reduction was described in terms of slow wave structure, which exhibit higher permittivity, ε_r, reducing spurious content in the passband is the second objectives in owing to phase effects between the inductors and capacitors.

This research had proposing a new technique to overcome these problems which use a combination of multilayer polyimide overlay structure with buried coplanar waveguide (CPW) technology. Meanwhile, this overlay structure offer low loss at high frequencies and reduction of size in which a combination of the solution to the problems of large chip area and spurious content. The multilayer filter in this paper has been designed to operate with a cut-off frequency of 3 GHz with an overall circuit size of 160 × 120 μm^2 and 20 dB of stopband insertion loss and 25 dB passband of return loss respectively. The thicknesses of the gold and polyimide layersare 5 μm each which designed on 200 μm semi-insulating *GaAs* substrates thick.

II. Structure and Circuit Layout

Fig. 1 shows two layouts of multilayer filter created by *xgeom* in *Sonnet Lite* for electromagnetic field simulations. From Fig. 1 (a), the middle metal layer is shown by the dotted line, while the shadowed area represents the top metal layer. The size of the top metal layer area is 60 μm × 92 μm. Two rectangular via holes crossing polyimide thin film was used as contact between the middle and top layers while the depth of via holes are the same as polyimide thickness. Number 1 and 2 at the end of both sides in Fig. 1b) represented the input and output ports respectively for de-embedding purpose. With the limited amount of computer memory and the consideration of a balance between simulation speed and accuracy, the minimum cell size in the simulation is reduced to be 4.0 × 4.0 μm^2. The circuit simulated is assumed to be in a metal box containing air having a height of 1000 μm such as free space with impedance of 377Ω. The height is chosen to prevent the simulated signal from touching the box. At the same time the box also acts as a ground plane contact [1].

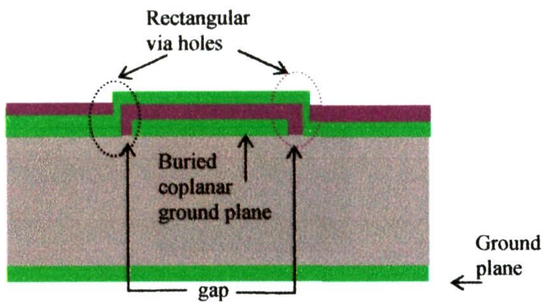


(b) Middle layer

Fig, 1: Layout of multilayer filter created by *xgeom* in *Sonnet Lite*

This structure is intended to obtain higher values of capacitance because ideal design suffers from a large value of capacitance since capacitance is proportional to the conductor area and dielectric constant of the substrate but inversely proportional to the substrate thickness. Fig. 1 (b) shows buried coplanar stripline at Ports 1 and 2 in the middle metal layer of the structure. A space equivalent to one cell was used as separation between via hole and buried coplanar ground plane at the middle metal layer. The selection of dielectric constant ε_r of substrate material is required to give a large value of capacitance. The contact between the substrate and metal or the other substrates also needs to be considered. There will be problems if the substrate chosen is not suitable when the circuit is attempting to be fabricated. The cross sectional area at AA is shown by Fig. 2 (a) which is built of five main layers which consist of three gold, GaAs substrate and polyimide thin film. The bottom metallization under GaAs substrate is set as ground plane. The thickness of GaAs employed in this design is set to be 200 μm. The polyimide and metal layers are all 5 μm thick. The top surface layer shown in the figure is a flat metal layer.

(a)



(b)

Fig.2: Cross section of multilayer structure (a) At AA (b) At BB

Fig. 2 (b) shows the cross sectional area at BB. It clearly shows that the middle and the top metal layers are connected by two via holes each of them had the depth of 5 μm and of the same width as the smaller transmission line that connects Port 1 to Port 2 in the middle metal layer. This rectangle via connections use 90° bends at both ends either in the middle or top conductor. This is second design used in MMIC where buried coplanar with polyimide thin film as a gap cover between the top and the metal layers. The figure shows there is a pair of 3 μm gaps between via hole in the buried coplanar plane that separated gold, transmission line connected to port 1 and 2 in the middle metal layer.

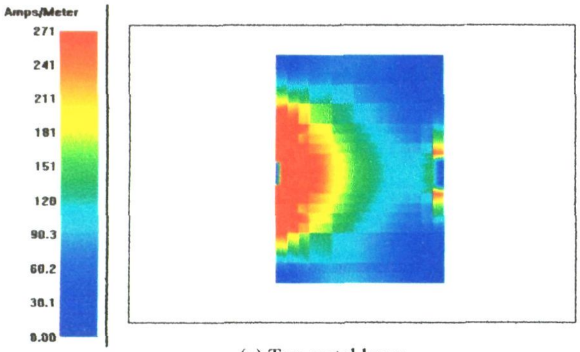
Coplanar waveguide (CPW) technology has gain in the design of microwave and millimeter wave circuit due to integration capability with the active device and simple process steps to avoid substrate thinning and via hole .[3] This design was used a buried CPW between GaAs substrate and polyimide thin film having finite conductor thickness. This, however, requires additional thin film process and thus result in non-negligible dielectric loses at high frequencies. This paper present compact filter realized with air-gap overlay structures. The wall of the boundary box have the two outside conductors are grounded there. There is capacitance effect between the top face of the conductor, where the electric field lines are partially contained in the dielectric and air. Beside, other effect of capacitances is caused by the parallel plate between the conductors due to finite metal thickness and dielectric fields on the bottom face of the conductors.[1] As a 'slow wave' structure allows the signal to propagate in the buried CPW with a wavelength much smaller than wavelength in free space [12-13].

The parasitic resistance in the circuit increased with frequency due to skin effect and current crowding [11]. This is the main reason why MMIC filters show evidence of poor insertion loss characteristics at high frequencies. The combination of several materials in the new multilayer structure produce miniature circuit while containing the same equivalent inductances and capacitances [15].This occurred by the buried coplanar, via holes n the transmission line. Using this new structure, the stopband filter shows no spurious throughout the range of the simulated frequency. This is caused by the buried coplanar, via holes and the transmission line.

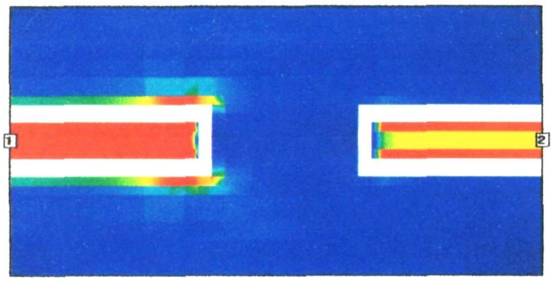
The overall circuit size area is 160 x 120 μm², smaller than coplanar multilayer filter proposed by Warns *et al* [3] where they used metallization layers separate by polyimide layer on GaAs or silicon. Even though their filter operated at higher frequency about 0-40 GHz but the chip area was about 1.35mm^2 and 1.5mm² respectively [1] which was larger compared to this new design. The size of MMIC components should be in compact size when operate at higher frequency according to the relationship of the transmission line and frequency, which was explained before. Via holes used in the new structure represent inductor and capacitor in the circuit simultaneously. The value of inductance is due their filter operated at higher frequency about 0 to 40 GHz but the chip area was about 160 x 120 μm^2 respectively [1] which were larger compared to this new design. The size of MMIC components should be in compact size when operate at higher frequency according to the relationship of the transmission line and frequency, which was explained before.

III. RESULT AND DISCCUSSION

Fig. 3 shows the simulated current density for top and middle metal layers in the passband. This software can present current density, which shows the physical flow of a signal in a device. The colour in Fig. 3 (a) shows the value of current density A/m - red indicates high current density (~ 271 A/m^2) while blue/green implies the opposite (~ 0 A/m^2).



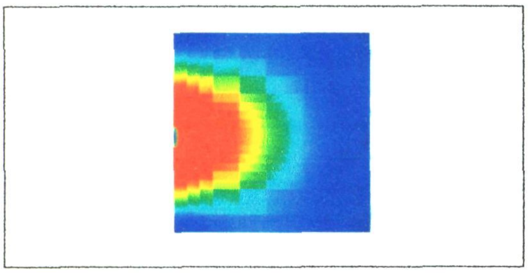
(a) Top metal layer



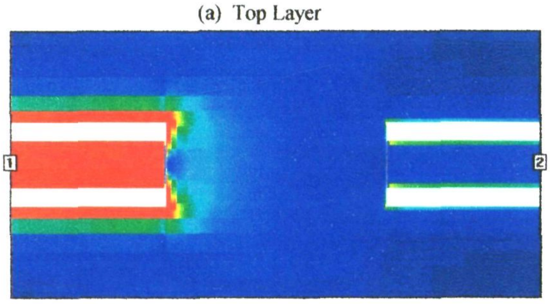
(b) Middle metal layer

Fig. 3: Current density flow in the top and middle layers of the filter at the passband.

From the figure, the large amount of current flow from the input to the output in the passband as predictable. Both diagrams in (a) and (b) show the signal that pass through the device smoothly in the passband. Conversely, at the stopband that shown in fig. 4, Port 1 produced high current density, while low current density is present at the Port 2 that implies blocks of signal.



(a) Top Layer



(b) Middle Layer

Fig. 4: Current density in the top and middle metal layers of the filter in the stopband.

The surface of top gold metal layer shows the current is only located at the middle of the circuit. There is only small amount of currents flow through the metal.

Fig.5 shows insertion and return losses of a new structure having no ripple in the passband and stopband. The response is obtained since Butterworth filters have no ripple. This result shows that the filter features having a Butterworth response even though it was designed using MMICs approach. The fig 5 also shows that the insertion loss of the filter is about 20 dB in the passband and 25 dB in the stopband. The cut-off frequency of this graph about 3 GHz and this filter response was extended to 40 GHz without any spurious compared to [2]-[3]. At the same time the graph justifies the use of multilayer, via hole, polyimide thin film and buried coplanar waveguide to reduce the problems of size and spurious.

To prove this design, it has used the same structure but different size of transmission line. For fig 6 and 7 show that different frequencies cut-off was obtained .For reduction transmission line the cut-off frequency increased about 5 GHz while the cut-off frequency value of enlarge size of transmission line is decreased about 2 GHz from the ideal design. The filter responses maintained the same characteristic of lumped Butterworth filters with out ripple in the passband and stopband.

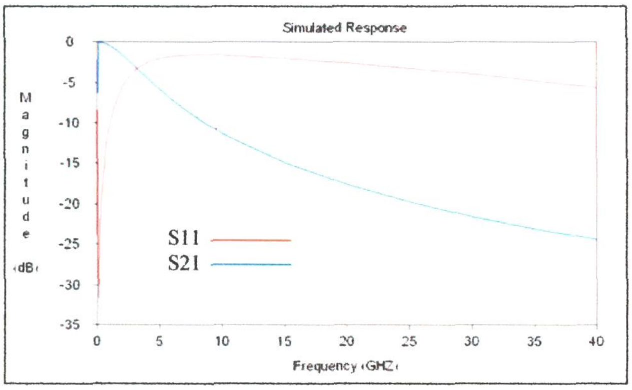


Fig. 5: Simulation graph from ideal transmission line

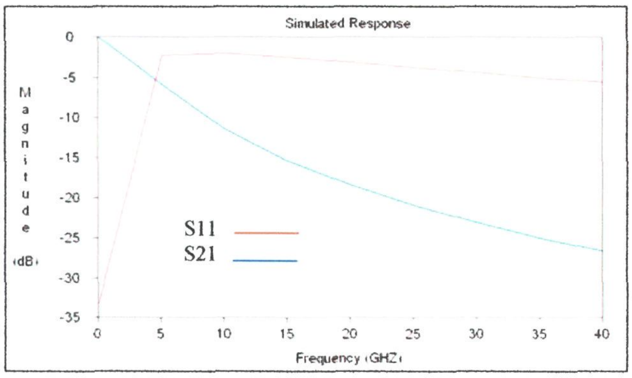


Fig. 6: Simulation graph from reduction transmission line

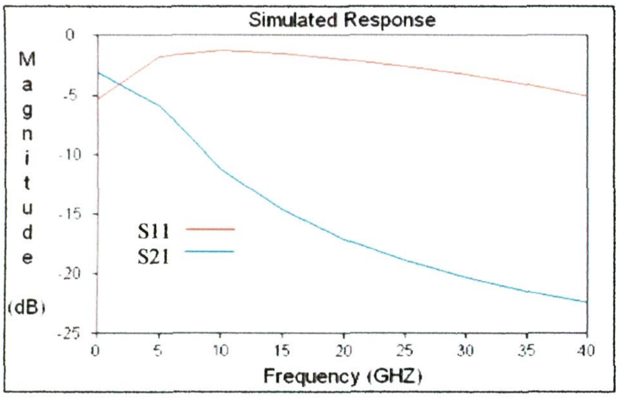


Fig.7: Simulation graph from increase transmission line

IV. CONCLUSION

The result demonstrates that these structures are well suite only for one structure of polyimide and gallium arsenide layers and buried coplanar layer. Good response has been obtained from a new multilayer filter suitable for MMIC. The combinations of via holes, polyimide and several metal layers contributed to an improved, clean response with respectable insertion loss values. The result also revealed that these miniaturized structure are appropriate for low-cost, which are smaller than that of convectional equivalents while maintaining the same performance and thus making efficient use of MMIC chip area.

V. FUTURE AND DEVELOPMENT

Further research in this project will expand by designing the newly miniature filter using multilayer with different materials that suitable for multilayer filter to improve the insertion loss and better performance as the dielectric layer is added by structures. This also can be done with the new material substrate to achieve metamaterial since construct of structure to make the effective dielectric constant become lower. They also well suited to use in applications such as lumped element matching network for input and output of amplifiers at microwave frequencies, also filter structure which incorporate series capacitor at the center of this filter to produced compact L-C-L combination.

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