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Substrate Integrated Waveguide based RF MEMS Cavity Filter

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Abstract: RF Micro-Electro-Mechanical System is one of the most promising technology as it provides potential of wide operational bandwidths, negligible interconnect losses, and almost ideal responses of switches and resonators. Structures such as low insertion loss and high Q-filters and tuners, resonators, and low-loss tunable phase shifters are few examples of revolutionary RF/microwave components that can be realized by using RF-MEMS technology. The given work focuses on the design and fabrication of multi-cavity high quality factor K-band MEMS filter, which employs substrate integrated waveguide (SIW) and micro-machined via-hole arrays by Inductively Coupled Plasma etching process. Non-radiation dielectric waveguide (NRD) will be formed by metal filled via-hole arrays and grounded planes. The three dimensional (3D) high resistivity silicon substrate filled cavity resonator is fed by current probes using CPW line. It will be designed and fabricated (if possible). Cavity filters are the basic circuitry behind a duplexer and are sharply tuned resonant circuit that allows only certain frequencies to pass. Filter of this kind are known as notch filters. Physically a cavity filter is a resonator inside a conducting "box" with coupling loops at the input and output. These cavities are constructed as cylinders, with an axial tuning capacitor.

Index Terms: SIW, Via holes, cavity filters.

I. INTRODUCTION

The key objective of this paper is to design such a filter on silicon substrate that gives very high Q, minimum insertion loss and small size [1,2]. However, on the other hand, traditional air cavity wave guide takes up a large circuit area and it cannot be compatible with planar circuits. A solution is used to use substrate integrated wave guide technique. In this filter frequency depends upon the dimensions of cavity means number of via holes, spacing between via holes. These kinds of waveguide are composed by two parallel arrays of metalized via holes drilled in a dielectric substrate or Si wafer metalized on both sides [3]. The holes act as the side walls of a conventional rectangular waveguide and the metallization of the substrate act as the top and bottom walls of the waveguide. The resonant frequency is designed 21.5GHz. Resonator shows minimum insertion loss@ 22GHz and maximum return loss@ 22GHz. The present study focused on the design optimization of cavity based high Q microwave Ka band MEMS resonator on the silicon substrate it includes the substrate integrated waveguide (SIW). DRIE is used to form the square via holes of SIW cavity. Silicon substrate filled cavity resonator is fed by current probes using coplanar waveguide (CPW) [4,5] line and CPW is designed for 50Ω. CPW and SIW are fully integrated on same substrate and they are interconnected via a simple transition.

The coupling between the cavity and CPW is made with current probes. This thesis describes S-parameter variation with the structure of coupling probes, depth of cavity, no of via holes, spacing between via holes and thickness of upper and bottom metal plate.

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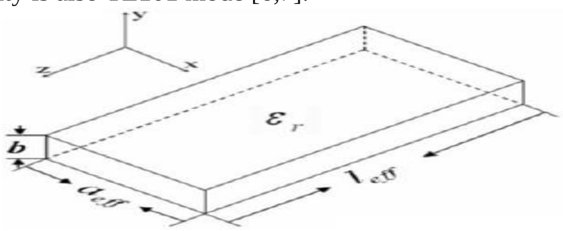
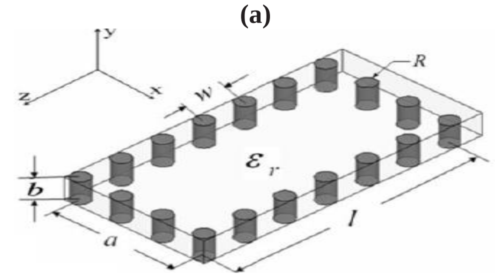
II. SIW AS A RECTANGULAR WAVEGUIDE

The schematic geometry of a SIW resonance cavity is illustrated in Figure 1(a). *a* and *l* are the width and length of SIW cavity, *b* is the substrate height, and _*r* is the relative dielectric permittivity. The researches about SIW have indicated that the SIW structure nearly preserves all the performances of its equivalent RW structure, the SIW can be analyzed as an equivalent RW. Figure 1(b) indicates the geometry of an equivalent RW resonance cavity, *a*eff and *l*eff are the width and length of equivalent RW cavity and *b* is the substrate height. In this way, in following analysis, it is assumed that the dominant resonant mode in SIW resonance cavity is also TE101 mode [6,7].



(a)



(b)

Fig .1 The schematic geometries of SIW and its equivalent RW resonance cavity. (a) SIW resonance cavity; (b) SIW as RW resonance cavity

In SIW fields are just like that in rectangular waveguide and resonator work in TE_{101} mode. TE_{101} mode is the dominant mode for rectangular wave guide.

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The lowest resonant frequency of resonator:

$$f_{101} = \frac{c}{2\pi\sqrt{\mu_r\varepsilon_r}}\sqrt{\left(\frac{\pi}{w_{eff}}\right)^2 + \left(\frac{\pi}{l_{eff}}\right)^2}$$

III. WHY SIW

SIW is a new form of transmission line that has been popularized in the past few years by some researchers. A rectangular guide is created within a substrate by adding a top metal over the ground plane and caging the structure with rows of plated via holes on either side. One attraction to SIW is that the amount of metal that carries the signal is far greater than it would be in micro-strip or strip-line. Therefore conductor loss α_C is lower[9]. Fig shows the structure of the SIW resonator. The rectangular resonant cavity is built using many rows of via holes in a high resistivity silicon substrate. These vertical via holes are fabricated by DRIE (Deep Reaction Ion Etch) process. The coupling of the cavity with the planar circuit is achieved by an aperture through common metallic plane.

There are many advantages of SIW then other ordinary circuits. So we are chosen the SIW technology[10]. Major advantages of this technology are High Quality factor, power capacity, Low insertion loss, Reduced size, Light weight, These are reliable and cost is reduced, Easy to fabricate, Easily to be integrated with planar circuits, They can easily be connected to micro strip or coplanar wave guide (CPW) circuit using simple transition, SIW are widely applied to all kinds of different filters design.The rapid development and great influence of SIW technique in designing of many passive components and active devices:Waveguide short array Antennas, Filters, Diplexers, Oscillators, Couplers, Six-port junctions,Bent and Tee structures.

IV. CONCEPT OF VIA HOLES

Via holes are used to connect the upper and bottom metal plates. Via holes are act as the vertical side wall of a rectangular wave guide. Metal is posted in each via so that it works as vertical side walls of rectangular wave guide. We are using the gold to filled the via holes.

These kinds of structures require considering and adjusting some parameters, such as the diameter **d** of via hole, the distance **p** from center to center between two adjacent via holes and h is the height of the substrate that is shown in Fig. These are the parameters that define the position of an “equivalent wall”, a straight wall that, under certain conditions, can be substituted to the vias array so that the simulations of the SIW can be performed by considering an equivalent rectangular waveguide [7,8] that is easier to compute, from which then it is pretty easy to obtain the relative SIW (more difficult to simulate because of the holes).

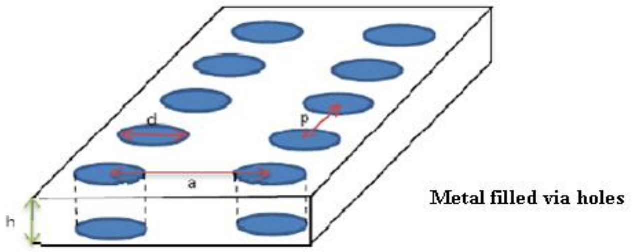

Fig. 2 metal filled via holes

V. DESIGN PARAMETERS OF SIW

We are describing here the design parameters of SIW cavity. The rectangular waveguide is synthesized by placing rows of metalized holes in the substrate. The diameter D of the holes, the spacing b between the holes and the spacing W between the two rows are the physical parameters necessary for the design of the guide. The pitch b must be kept small to reduce the leakage loss between adjacent posts [11,12]. However, the post diameter D is also subject to the loss problem. As a result, the ratio D/b is considered to be more critical than the pitch length because the post diameter and the pitch length are interrelated. Due to the synthesis, the can no longer be regarded as a normal homogeneous waveguide, and it is in fact an artificial periodic waveguide. Therefore, the post diameter may significantly affect the return loss of the waveguide section in view of its input port. Two design rules related to the post diameter and pitch that are used to neglect the radiation loss are formulated. These rules have been deducted from simulation results of different SIW geometries [13].

$$D < \lambda_g / 5$$
$$b \le 2D$$

These two rules are sufficient but not always necessary; a diameter larger than one fifth of guided wavelength or a pitch larger than two diameters can be used but with more care. These two rules ensure that the radiation loss be kept at a negligible level. In this case, the SIW can be modeled by a conventional rectangular waveguide (RW). When following the two above rules, the mapping from the SIW to the RW is nearly perfect in all the single mode bandwidth. All the existing design procedures and theoretical frameworks developed for the rectangular waveguide are directly applicable to its synthesized counterpart. Nevertheless, dielectric filling effects and geometrical particularity of the synthesized waveguide should be accounted for coupler and antenna designs. In addition, the SIW can only support the TE modes propagation while the TM modes cannot be guided due to the nature of the structure [10].

There are proposed design parameters of SIW cavity these are given below:

Width of resonant SIW cavity (w) is 2950µm, length of resonant cavity (l) is 2950µm, diameter of via holes (D) is 150µm, spacing between via holes (b) is 250µm, height of cavity (h) is 500µm, thickness of upper metal plate is 5µm, thickness of bottom metal plate is 5µm.

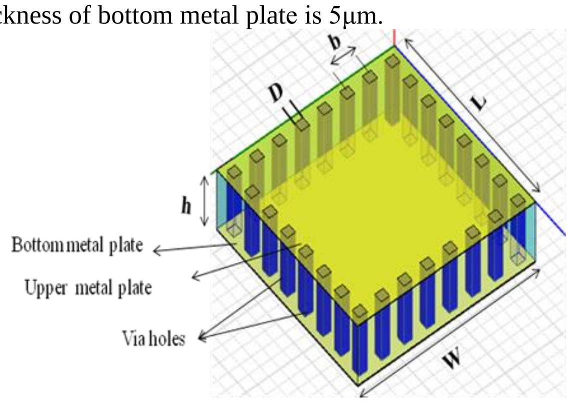

Fig .3 design of SIW cavity by HFSS

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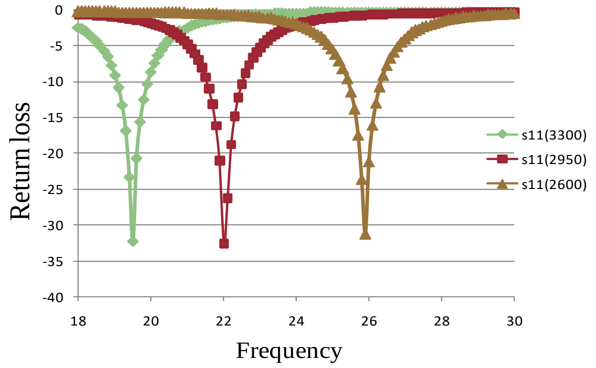
VI. RESULT AND DISCUSSIONS

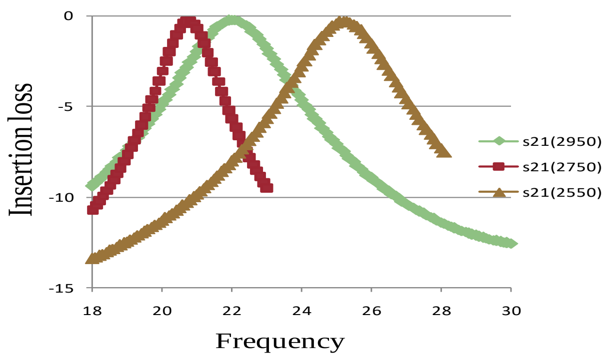
Now I am defining here different types of iterations and variation in the S-parameters. Different configurations have been compared here by changing the dimensions of the micro-machined via-holes used for the ground connection, as well as their number and separation, to get the optimal electrical matching conditions. Size of cavity is varying with chaining the dimension of via holes and their separation and also change in the number of via holes. Here discussing about the S-parameter variation with (a) cavity depth (b) size of via holes

➢ Variation in the spacing between via holes:

Cavity height is affected by the variation in spacing between via holes or size of the via holes because cavity dimension is determine by the via holes and the separation between them. Also cavity dimension affect the frequency range if the cavity size is reduce frequency is increased and if the cavity size is increased frequency is reduced by the following formula which shows the relation between frequency and the cavity dimension[14].
From the design it is clear that filter is made for the ka band or basically it is tuned at 22 GHz frequency. At that frequency losses should be minimum. Insertion loss should be near to zero and return loss high as possible as.



(a)



(b)

Fig .4 S-parameter with the variation in the spacing between via hole

Graph and table both are indicating that losses are minimum at the frequency 22 GHz. And the filter is tuned for 22 GHz frequency.

Table .1 Comparison of the losses when the variation in the via holes spacing

Cavity size (spacing) µm	Frequency (GHz)	Insertion loss (db)	Return loss (db)
3300 (300)	19.5	-0.248	-32.28
2950 (250)	22	-0.245	-32.53
2600 (200)	25	-0.297	-32.29

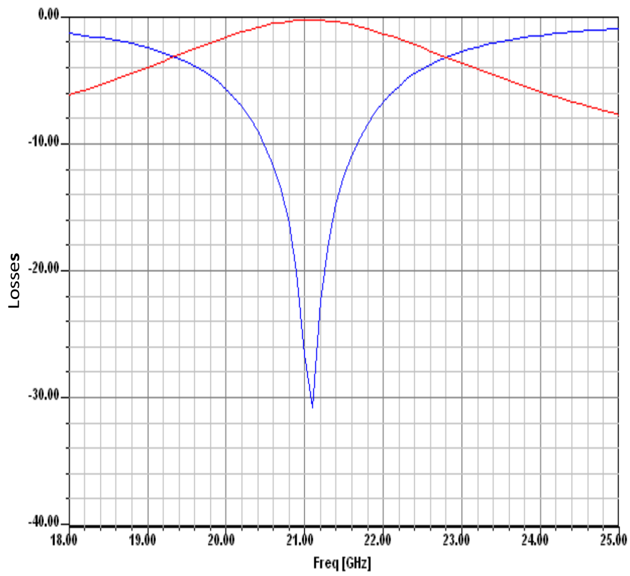


Fig.5 simulated S-parameters

VII. CONCLUSION

From all these iterations we have chosen the best parameters and found the better result and after these iterations making a complete structure of filter that give better losses then other filter. That is the final graph of filter and it gives value of insertion loss 0.245db and the value of return loss is 32.53db between the frequency 21GHz to 22 GHz. Red line indicates the insertion loss and blue one indicates the return loss.

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