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A New Micromachined Bandpass Filter on a Quartz Substrate

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A new class of three dimensional(3D) micromachined microwave planar filter at K-band is presented. The filter shows a wide bandpass chracteristic of 36% with the insertion loss of 1.2 dB at 19.11 GHz, and can be applicable in high power monolithic microwave integrated circuits (MMIC).

KEYWORDS: bandpass filter,micromachining, K-band, MMIC

1. Introduction

Recently, applications in the field of commnication systems have reached the microwave and millimeter-wave range. Traditionally, microstrip transmission line has been used for the major design element for the system. However, it is hard to obtain a broad-band characteristic for the microstrip due to the large losses in the high frequency range. To overcome this disadvantage in the case of the conventional transmission line, a new transmission line topology of Radio Frequency Micro-ElectroMechanical System (RF MEMS) has been suggested as an alternative for the high frequency application. As a low cost and highly efficient micromachining process, LIGA, a German acronym consisting of the letters LI (RöntgenLIthographie meaning X-ray lithography), G (Galvanik meaning electrodeposition), and A (Abformung meaning molding), has been attracted much attention for application in microwave and millimeter-wave devices.[1)] In the LIGA process, a polymethyl methacrylate (PMMA) resistor is spin-coated on the substrate, and the pattern for the circuit is generated through deep X-ray lithography and plated metal for the conductor. The structural characteristics for LIGA are the thick conductor (10 μm $\sim$ 1 mm) and the high aspect ratio of conductor side-wall (steep side-wall $> 89.9°$), which give the effect of increased conduction interface to the circuit and high coupling compared with the conventional integrated transmission line.[2,3)] These advantages make the LIGA structure applicable for high-power monolithic circuits for the transmitter and the wide-band filter, which are hard to realize in the case of conventional thin-film processes. In this study, a bandpass filter with a very wide bandwidth at K-band using the LIGA-like process is designed, fabricated, and characterized.

2. Filter Design and Fabrication

In this letter, a 3D microstrip bandpass filter with a wide bandwidth is presented. Since the impedance in the LIGA structure is quite different from that in a 2D microstrip transmission line, analysis of the characteristic impedance in the LIGA microstrip structure is required for the circuit design. Figure 1 shows the relationship between the characteristic impedance and microstrip width for the LIGA structure, which are obtained from finite difference (FD) analysis. From the figure, the characteristic impedance is decreased with increasing width of the 3D transmission line and with increasing thickness of the conductor metal.[4)] The design rule of the 0.5 dB Chebyshev prototype using high coupling characteristic in the LIGA structure is adopted for the wide bandpass filter. The design parameters are given as follows: the substrate is fused quartz with the dielectric constant of 3.82 at 30 GHz and the thickness of 625 μm. The thickness of the conductor metal (Cu) is 100 μm. The center frequency (f_0) of the filter is 18 GHz and the bandwidth in the passband is 40%. Figure 2 shows the wide-band parallel-coupled bandpass filter with a six-stage coupling section.[5,6)] This filter is designed with the characteristic impedance of 75 Ω. For the measurement with a ground-signal-ground(GSG) coplanar qaveguide (CPW) probe, the impedance transformer ($Z_t = 61.2\,\Omega$) is inserted between the first stage of 50 Ω part and the third stage of 75 Ω part. A similar structure is used for the last stage of the filter because it has a symmetric structure. Here, the widths and lengths corresponding to the parts of 50 Ω, 61.2 Ω, and 75 Ω for this design are $L_{50} = 0.3$ mm, $W_{50} = 1$ mm, $L_{61.2} = 2.4$ mm, $W_{61.2} = 600\,\mu$m, $L_{75} = 2.51$ mm, and $W_{75} = 400\,\mu$m, respectively. Also, the widths and lengths for the coupling parts are; $L_1 = 2.7$ mm, $W_1 = 100\,\mu$m,

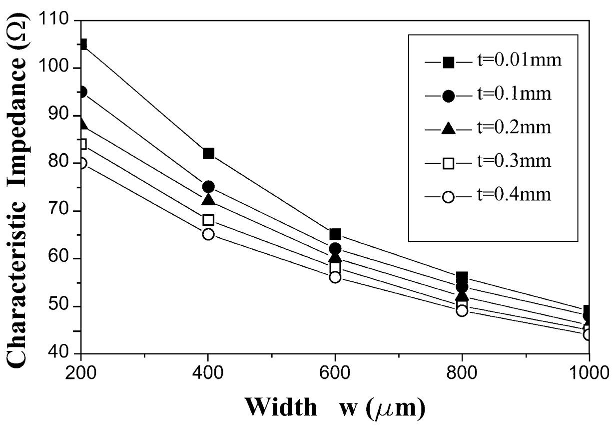


Fig. 1. Impedance characteristics for the LIGA microstrip.

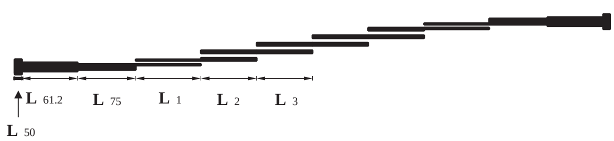


Fig. 2. Layout for the 18 GHz LIGA bandpass filter.

$S_1 = 150\,\mu$m; $L_2 = 2.4$ mm, $W_2 = 200\,\mu$m, $S_2 = 300\,\mu$m; $L_3 = 2.35$ mm, $W_3 = 200\,\mu$m, $S_3 = 300\,\mu$m . The LIGA bandpass filter has been designed using HP HFSS ver. 5.4, which is a 3D microwave simulation tool. Figure 3 shows the 3D field simulation results for the wide bandpass filter at the K-band. The 3-dB corner frequencies are 13.9 $\sim$ 21.2 GHz, and the minimum insertion and return losses are about 0.9 dB and 20 dB at the center frequency of 18 GHz, respectively. This bandpass filter is fabricated on fused quartz using a LIGA-like process. First, the seed metals of Ti (300 Å)/Cu (1500 Å)/Ti(300 Å) are deposited on the Quartz substrate. Then, SU-8 epoxy is spin-coated and patterned (120 μm) for electroplating of copper. After removing the top Ti layer by wet etching, the formed molds are filled with plated copper. Finally, the LIGA filter is obtained by removing SU-8 epoxy resin and the seed metal layer (Ti/Cu). Figure 4 shows the SEM micrographs for the bandpass filter. From the figures, the conductor metal is observed to be very steep and clear, and the thickness is measured as 104 μm which is close to the design value of 100 μm.

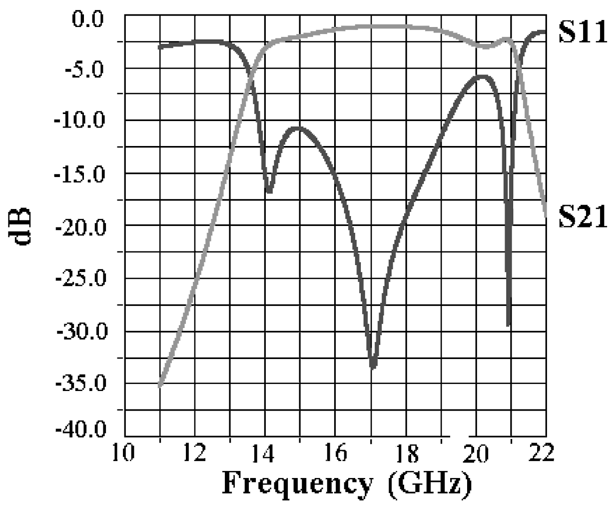
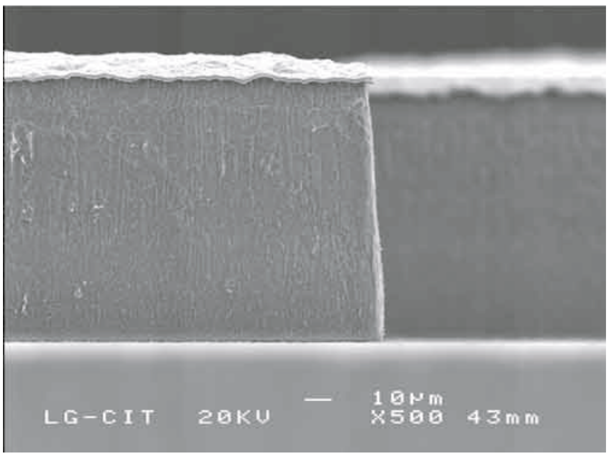
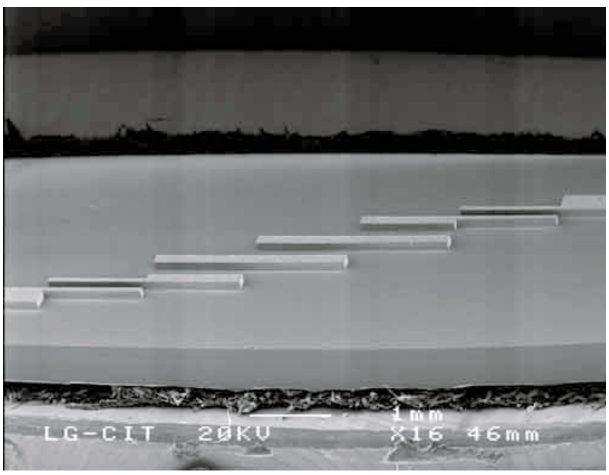


Fig. 3. Simulation results for the filter.



(a)



(b)

Fig. 4. SEM micrographs of the LIGA bandpass filter (a) Vertical shape of the conductor and (b) the LIGA-like bandpass filter.

3. Experiments and Discussion

For the characterization of the filter with a GSG probe which is matched to the characteristic impedance of 50 Ω, the microstrip-to-CPW transition is needed. In this letter, the Probepoint[7] 0501 test interface circuit is used between the microstrip filter and the GSG CPW probe. This circuit works as a CPW-to-microstrip transition adapter without loss up to 40 GHz. The connection between the adapter and the filter has been done by gold wire bonding. The bandpass filter has been characterized by a Wiltron 360B network analyzer. Figure 5 shows the measurement results for the filter. The 3 dB corner frequencies are observed to be 15.65–21.8 GHz, which are shifted toward the upper band by about 1.5 GHz and correspond to the bandwidth of 36%. The minimum insertion loss is 1.26 dB at the center frequency of 19.11 GHz, which is quite close to the simulation value of 0.9 dB. Taking into account the fact that a part of adapter has not been considered for the simulation, the measurement result can be considered very accurate compared with the design value. The return loss varies from 5–23 dB within the passband. The frequency shift in the measurement results compared with the simulated ones is believed to be due to the fabrication margin and lack of consideration of transition. The difference in return loss between the simulation and the measurement arises mainly from the impedance mismatch at the adapter and the filter.

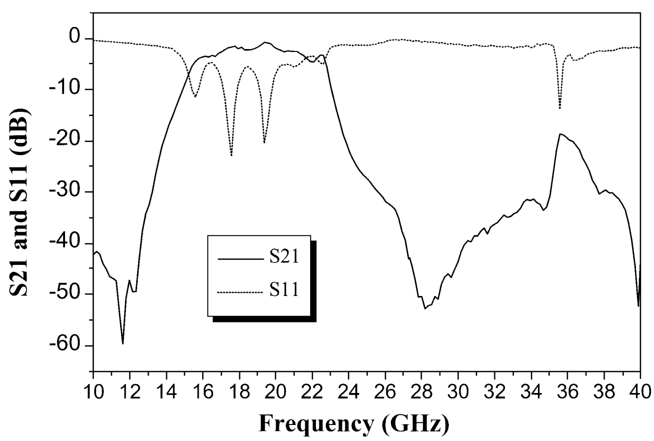


Fig. 5. Measurement results for the filter.

4. Conclusion

We have demonstrated a new 3D microstrip bandpass filter on a quartz substrate. This LIGA-like filter has been designed by a 3D microwave simulation tool, HP HFSS and fabricated with a 100 μm thick metal conductor. It exhibits a very wide bandwidth of 36% with a low insertion loss of 1.26 dB at K-band. Further improvement in the microwave performance for the filter is expected if a circuit design and test environment with perfect impedance matching can be provided. This filter can be used in the high-power MMIC.

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