Novel K/Ka Bandpass Filters using LIGA Micromachined Process

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Abstract

New class of three dimensional (3-D) micromachined microwave planar filters at K and Ka-band are presented using LIGA micro-machined process. The K-and Ka-band filters show wide bandpass characteristics of ~36% and ~39% with the insertion loss of 1.26 dB at 19.11 GHz and 1.7 dB at 33.2 GHz, respectively. These filters can be applicable in high power MMIC or MIMIC.

Ⅰ. INTRODUCTION

Recently, application for commercial communication systems reaches to microwave and millimeter-wave range. Traditionally, microstrip transmission line has been used for the design elements for these system components. However, broad-band characteristics for the microstrip is hard to be obtained due to the large loss for the high frequency range. To overcome this disadvantage of the conventional transmission line, new topology of RF MEMS (micro-electro-mechanical system) has been suggested as an alternative for the high frequency application. As one of the low cost and most efficient miromachining processes, LIGA, a German acronym consisting of the letters LI (RöntgenLIthographie meaning X-ray lithography), G (Galvanik meaning electro-deposition), and A (Abformung meaning molding), has been attracted much attention for the microwave and millimeter-wave devices[1]. The LIGA process consists of the three basic process steps: deep-etch lithography by means of synchrotron radiation, electroforming and plastics molding. Contrary to Si-micromechanics, the LIGA process starts out from a quartz substrate which is covered by a resist layer up to 120 μm thickness. In general process, this resist layer typically consists of PMMA (Polymethyl methacrylate), but in this paper, SU-8 epoxy is used instead of PMMA. The desired microstructure is copied into the resist by synchrotron radiation using a special mask. The exposed parts of the resist are altered chemically in such a way that they are dissolved in an organic developer. This results in a primary structure with the lateral shape of the absorbing structure of the mask and a structural height of the resist thickness of up to 120 μm with very smooth and vertical walls.

Microstructures with extreme aspect ratios, which is the ratio of structural height to minimal lateral structure have been demonstrated. This primary structure is now object to an electroforming process. Since the Su-8 epoxy structure is deposited on a metallic substrate (Ti/Cu/Ti) or a special plating base, the gaps can be filled with three metal layers by deposition such as copper (up to 104 μm), nickel (1.5 μm), and gold (1 μm). After removing the remaining PMMA a complementary metallic structure is

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obtained. The structural characteristics for LIGA are the thick conductor (10 μm ~ 1mm) and the high aspect ratio of conductor side-wall (>89.9°), which give the effect of increased conduction interface to the circuit and the high coupling compared with the conventional integrated transmission line[2]~[4]. These advantages make the LIGA structure applicable for high-power monolithic circuits for the transmitter and the wide-band filter, which are hard to be realized in the case of conventional thin-film process.

In this paper, bandpass filters with very wide bandwidth at K/Ka-band using the LIGA-like process are designed, fabricated, and characterized.

Ⅱ. DESIGN AND FABRICATION

Since the impedance in LIGA structure is quite different from that in 2-D microstrip transmission line, the analysis for the characteristic impedance in LIGA microstrip structure is needed for the circuit design.

The design rule of 0.5 dB Chebyshev prototype using high coupling characteristics in LIGA structure is adopted for the wide bandpass filter. The parallel-coupled line has some advantages, such as easy procedure to design and fabricate, and wide bandwidth. In this structure, the relations for the ratio of strip width and gap, and characteristic impedances (Z_{oe} and Z_{oo}) should be known for the circuit design.

Maximum coupling is obtained between physically parallel microstrip-lines when the length of coupled region is $\lambda_g/4$. Also, the length of each resonator element should be $\lambda_g/2$ in length for resonance.

Fig. 1 shows the relationship between the characteristic impedance and microstrip width for the LIGA structure, which are obtained from FD (Finite Difference) analysis. From the figure, the characteristic impedance is decreased with increasing the width of the 3-D transmission line and with increasing the thickness of the conductor metal[5]. Fig. 2 illustrates the proportion of bandwidth for the LIGA-like filter according to the ratio (G/W), which are analyzed by FEM.

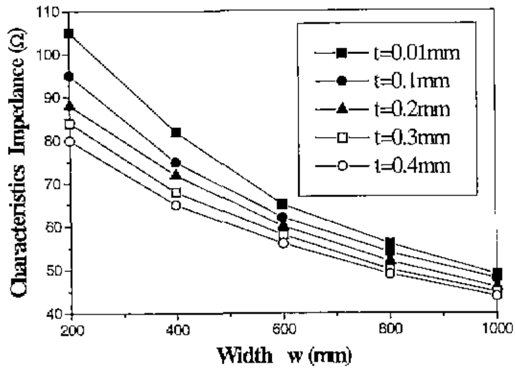

Fig. 1. Impedance characteristics for the LIGA microstrip.

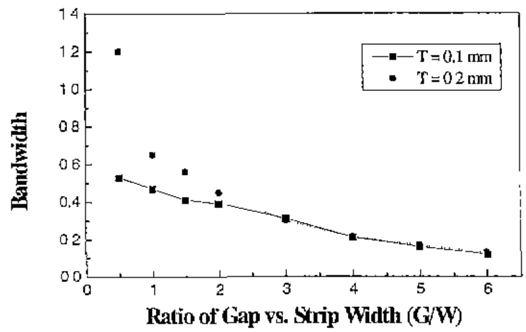

Fig. 2. The proportion of bandwidth according to the ratio of G/W for LIGA microstrip coupled-line section.

From the figure, we can observe the bandwidth proportion of tall conductor microstrip is varied due to the ratio of gap and strip width. For example, the bandwidth for the LIGA-like filter with G/W ratio of 1.5 is expected to be about 40 % when the conductor thickness is 100 μm. The design parameters are given as follows; the substrate is a 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 frequencies (f_0) of the filters are 18 GHz and 30 GHz, respectively, and the bandwidths in passband are about 40 % for both filters. Figs. 3 & 4 show the wide-band parallel-cou-

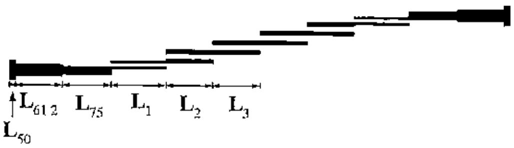

Fig. 3. Layout for the 18 GHz LIGA bandpass filter.

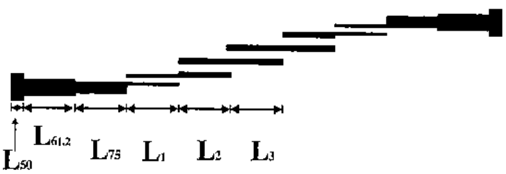

Fig. 4. Layout for the 30 GHz LIGA bandpass filter.

pled bandpass filters for K and Ka-band with 6- & 5- stage coupling section, respectively[6],[7].

The filters are designed with the characteristic impedance of 75 Ω. For the measurement with GSG (Ground-Signal-Ground) CPW (Coplanar Waveguide) 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. Similar one is used for the last part of the filter because it has symmetric structure. Here, the filters have the same width for the parts of 50 Ω, 61.2 Ω, and 75 Ω for these designs, which are $W_{50} = 1$ mm, $W_{61.2} = 600$ μm, and $W_{75} = 400$ μm, respectively.

In the case of the 18 GHz filter, the layout parameters are $L_{50} = 0.3$ mm, $L_{61.2} = 2.4$ mm, and $L_{75} = 2.51$ mm. The widths and lengths for the coupling part are given as follows: $L_1 = 2.7$ mm, $W_1 = 100$ μm, $S_1 = 150$ μm; $L_2 = 2.4$ mm, $W_2 = 200$ μm, $S_2 = 300$ μm; $L_3 = 2.35$ mm, $W_3 = 200$ μm, $S_3 = 300$ μm. The total size is determined to be 25.3 × 3.9 mm.

For the case of 30 GHz bandpass filter, the parameters of layout are $L_{50} = 0.3$ mm, $L_{61.2} = 1.3$ mm, and $L_{75} = 1.35$ mm. The widths and lengths for the coupling parts are given as follows: $L_1 = 1.26$ mm, $W_1 = 100$ μm, $S_1 = 150$ μm; $L_2 = 1.235$ mm, $W_2 = 200$ μm, $S_2 = 300$ μm; $L_3 = 1.26$ mm, $W_3 = 200$ μm, $S_3 = 300$ μm. The total size is 12.15 × 3.4 mm.

The LIGA bandpass filter has been designed by

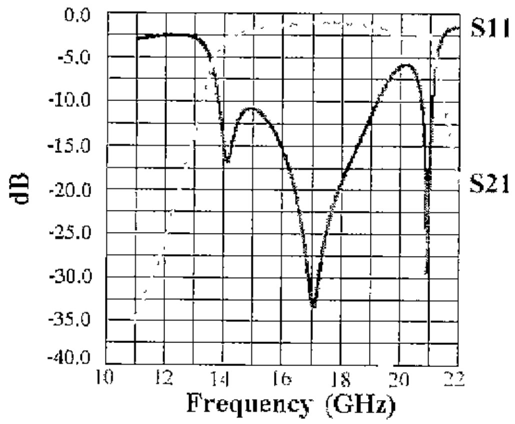

Fig. 5. Simulation result for K-band (18 GHz) filter.

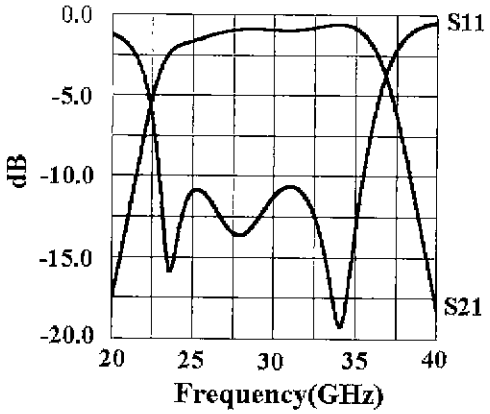

Fig. 6. Simulation result for Ka-band (30 GHz) filter.

HP HFSS ver. 5.5, which is a 3-D microwave simulation tool. Figs. 5 & 6 show the 3-D field simulation results for the wide bandpass filter at K and Ka-band, respectively. Fig. 5 shows 3-dB corner frequencies are 13.9~21.2 GHz, the minimum insertion and return losses are about 0.9 dB and 20 dB at the center frequency of 18 GHz, respectively.

Fig. 6 exhibits the simulation results for Ka-band bandapss filter. The 3-dB corner frequencies are 23.5 ~36 GHz, the minimum insertion and return losses are about 1.0 dB and 12.3 dB at Ka-band (30 GHz), respectively.

These bandpass filters are fabricated on the fused Quartz using LIGA-like process. First, the seed metals

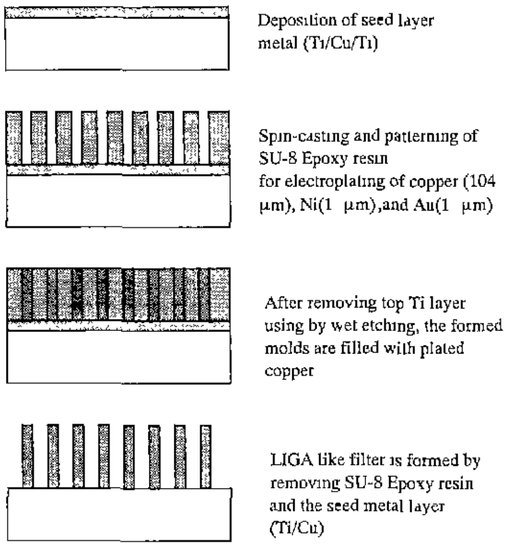

Fig. 7. Outline of fabrication procedure.

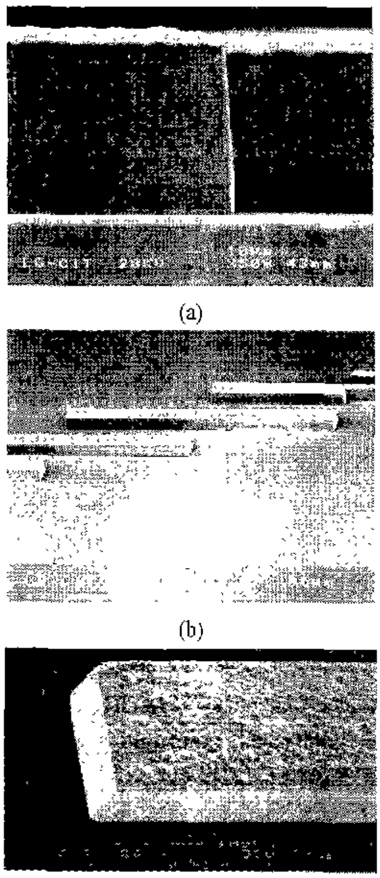

Fig. 8. SEM photographs for the LIGA bandpass filter.

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 for electroplating of copper (120 μm). After removing top Ti layer by wet etching. the formed molds are filled with plated copper. Finally, the LIGA filters are obtained by removing SU-8 epoxy resin and the seed metal layer (Ti/Cu). The above processes are depicted in Fig. 7. Fig. 8 shows the SEM photographs 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 close to the design value of 100 μm.

Ⅲ. EXPERIMENTS AND DISCUSSION

For the characterization of the filter with GSG probe which is matched to the characteristic impedance of 50 Ω, the microstrip-to-CPW transition is needed.

In this paper, the Probepoint™ 0503 test interface circuit from the Jmicro Technology Co[8]. 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.

Measurements have been done using different Network Analyzers. The K-band (18 GHz) bandpass filter has been characterized by Wiltron 360 B Network

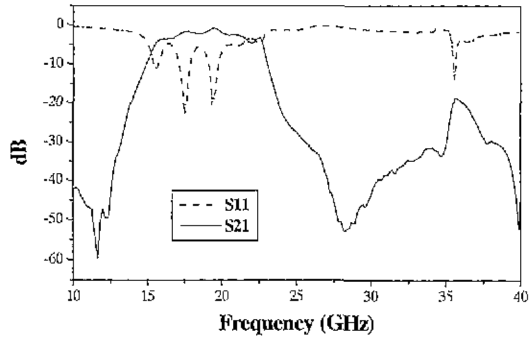

Fig. 9. Measurement results for K-band filter.

Analyzer. Fig. 9 shows the measurement results for the K-band micromachined bandpass filter. The 3-dB corner frequencies are observed to be 15.65~21.8 GHz, which are shifted toward upper-band 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. The return loss is varied from 5~23 dB within the passband.

The Ka-band (30 GHz) bandpass filter has been measured by HP 8510C Network Analyzer and shown in Fig. 10. The 3-dB corner frequencies are exhibited to be 27.0~39.8 GHz, which are shifted toward upper- band about 3.0 GHz and correspond to the bandwidth of ~39%. The minimum insertion loss is 1.7 dB at the center frequency of 33.2 GHz, which is quite close to the simulation value of 1.0 dB. Taking into account the fact that the part of adapter has not been considered for the simulation, the measurement result can be said to be very accurate compared with the design value. The return loss is varied from 8~18 dB within the passband.

The frequency shift in measurement results compared with the simulated ones is believed due to the fact of fabrication margin and high-frequency property. The difference in return loss between the simulation and the measurement comes mainly from the impedance mismatch, lack of considerations for transition, and wire-bonding effect between the adapter and the filter.

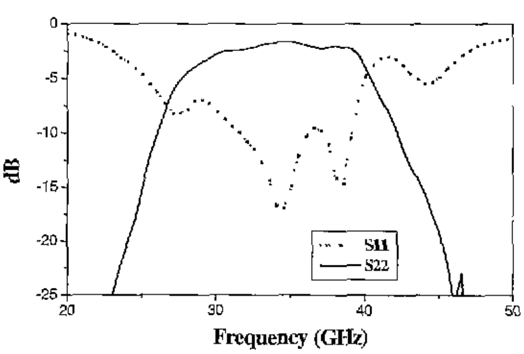

Fig. 10. Measurement results for Ka-band filter.

IV. CONCLUSION

We have demonstrated the new 3-D microstrip bandpass filters on quartz substrate (ε_r=3.82). These LIGA-like filters have been designed by 3-D microwave simulation tool, HP HFSS and fabricated with thick metal conductor (copper) of 100 μm. These filters show very wide bandwidth of ~36% and ~39% with the low insertion loss of 1.26 dB and 1.7 dB at K-band and Ka-band, respectively. Further improvement in microwave performance for the filters are expected if the circuit design and test environment with perfect impedance matching can be provided. These filters can be used in the high-power MMIC or MIMIC.

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