NOVEL MICROMACHINED LIGA MICROSTRIP TRANSMISSION LINES AND FILTERS

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ABSTRACT

The LIGA-micromachined microstrip line is introduced. This transmission line and the filters presented in this paper are fabricated using the LIGA micromachining process. This process allows tall (10μm-1mm), high-aspect ratio metal structures to be very accurately patterned and is compatible with integrated circuit fabrication processes. The tall metal transmission lines will enable the development of high-power monolithic circuits as well as couplers and filters that require very high coupling levels. In this paper, low-pass and bandpass filters fabricated using 120 and 160μm-tall nickel microstrip lines are demonstrated.

INTRODUCTION

This paper introduces a new micromachined transmission line, the LIGA microstrip line (fig. 1) which is fabricated using the LIGA micromachining process. In the LIGA (a German acronym for lithography, electroforming, and molding in English) process, tall (10μm-1mm) metal structures with steep sidewalls are precision-formed on an arbitrary substrate material using depth x-ray lithography and plated metal [1,2]. LIGA-micromachined transmission lines will enable several important advancements in microwave and millimeter-wave integrated circuits. The tall metal transmission lines, when bounded by a good thermal conductor, are perfect for high-power applications due to the increased conduction interface which allows development of high power monolithic circuits for commercial transmitter applications. The tall, vertical metal structures may be placed within microns of each other, resulting in circuits with very high coupling levels that are impossible to attain with conventional integrated transmission lines. These vertical-walled coupling structures will allow the development of several new integrated coupler and filter circuits [3,4] as well as new interdigital capacitors [4]. Additionally, it is possible to create a wide variety of three dimensional circuits with multiple x-ray exposure steps.

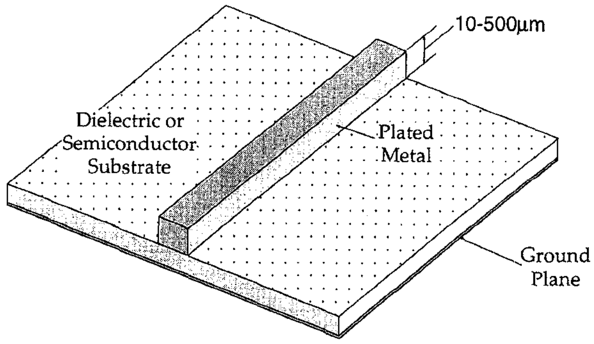

Fig. 1. The LIGA microstrip transmission line.

THEORY AND DESIGN

A finite difference analysis [5] of LIGA microstrip lines on 420μm-thick fused quartz (e_r=3.81 at 30 GHz) shows that a wide range of

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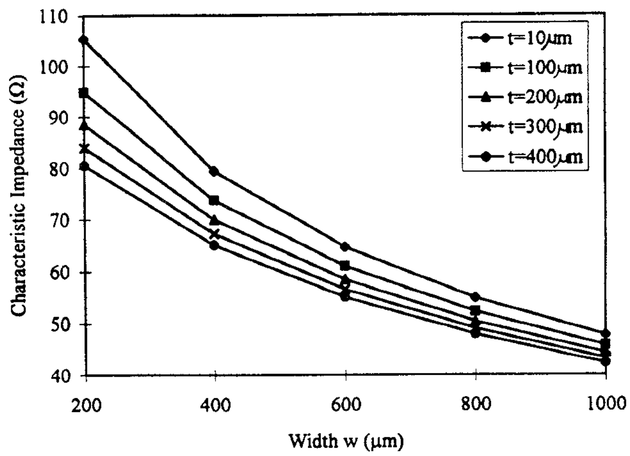


Fig. 2. Characteristic impedance of the LIGA microstrip line on 420μm-thick fused quartz vs. conductor strip width and thickness.

characteristic impedances are available for use in integrated micromachined circuits (fig. 2). As expected, the characteristic impedance decreases as the thickness of the metal is increased.

Due to the potentially high capacitance between tall, closely-spaced adjacent lines, LIGA-fabricated lines are ideal for couplers and filters. A finite difference analysis [5] of a vertical sidewall microstrip coupled-line structure has been performed (fig. 3).

Figure 3(a) demonstrates that the even-mode characteristic impedance is dominated by total transmission line width while figure 3(b) shows

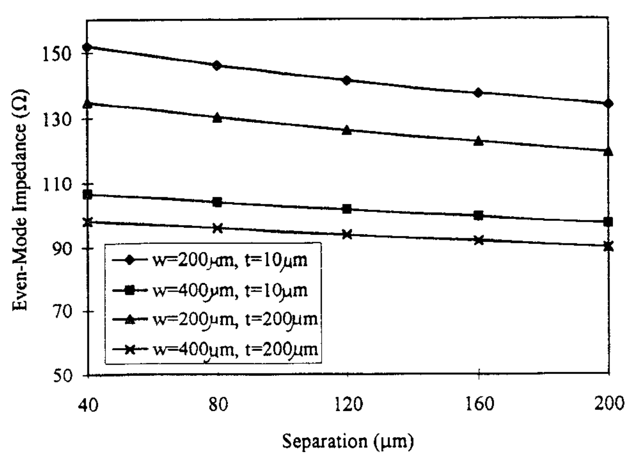


Fig. 3(a). Even-mode impedances of coupled-LIGA microstrip line vs. separation (t=thick.).

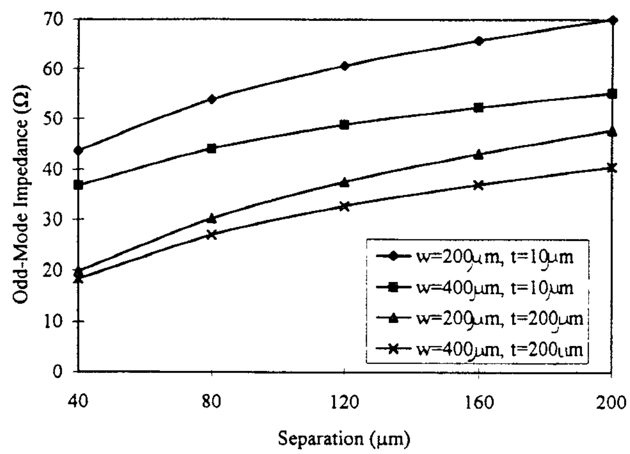


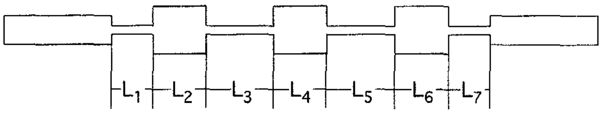
Fig. 3(b). Odd-mode impedances of coupled-LIGA microstrip line vs. separation (t=thick.).

that the odd-mode impedance is primarily controlled by the metal thickness. Since multiple x-ray exposures will allow different metal thicknesses within the same circuit, this fabrication process will allow nearly independent control over the even- and odd-mode characteristic impedances of coupled LIGA microstrip lines. A fused quartz substrate (e_r=3.81) is chosen for this analysis to minimize the difference between the even- and odd- mode phase velocities.

The minimum analyzed coupled-line separation of 40μm is an order above the resolution limits for this fabrication process. The limitation on the element-to-element spacing is set by the angle of the metal sidewall. At worst case, a 100:1 sidewall slope may be expected [2]. This corresponds to less than a 0.6°-angular variation from vertical. Even with this maximum variation from vertical, 200μm-tall conductors may be placed within 5μm of each other.

Low-pass and bandpass LIGA microstrip filters have been designed, fabricated and tested to demonstrate the potential of this novel micromachined transmission line. A stepped impedance low-pass filter with 200μm-thick conductors was designed to have a 0.5dB Chebyshev response (fig. 4). This seven section

Section	Width	Z_O
1 and 7	100μm	106Ω
2 and 6	1500μm	35Ω
3 and 5	100μm	106Ω
4	1500μm	35Ω

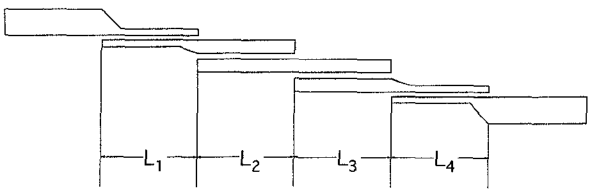


$L_1=L_7=2520\mu m$
$L_2=L_6=2700\mu m$
$L_3=L_5=3825\mu m$
$L_4=2885\mu m$

Fig. 4. LIGA microstrip 10 GHz low-pass filter design for 200μm metal. The input/output lines are 800μm-wide (50Ω design).

low-pass filter was designed to have a 3dB cut off frequency of 9.4 GHz and 20dB of attenuation at 11.8 GHz [6]. A coupled-line bandpass filter was also designed to use 200μm-thick conductors. To ease the fabrication tolerances of the first filters, a minimum coupled-line gap spacing of 150μm was enforced on the design (fig. 5). The four-coupling element wideband bandpass filter was designed to have a center frequency of 10 GHz, a 3dB bandwidth of 36% of the center frequency, and 20dB attenuation at 6.6 GHz and 14.0 GHz [6]. For these first designs, length corrections to offset the edge capacitance of the lines due to the thickness of the conductors have not been attempted. Therefore, the actual response of the filters is expected to be shifted downward in frequency.

Section	Width	Gap	Z_{oe}	Z_{oo}
1 and 4	200μm	160μm	123Ω	43Ω
2 and 3	400μm	200μm	90Ω	41Ω



$L_1=L_4=5063\mu m$
$L_2=L_3=4845\mu m$

Fig. 5. LIGA microstrip 10 GHz bandpass filter design for 200μm metal. The input/output lines are 800μm-wide (50Ω design).

FABRICATION

The LIGA fabrication process utilizes coherent synchrotron x-ray radiation and a poly(methyl methacrylate) (PMMA) resist system with thickness ranging from 1μm to 1mm. In LIGA, a metal thin film is applied to a substrate followed by solvent-welded PMMA sheet resist [7]. The resist is exposed and immersion developed. Metal is then electroplated onto the metal film within the resist recesses and the

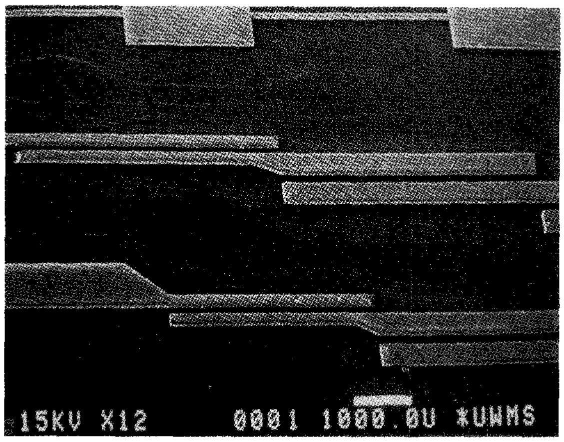


Fig. 6. 120μm-thick coupled-line bandpass filters.

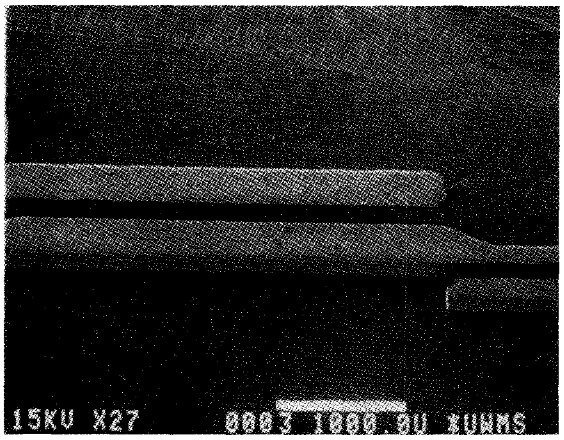


Fig. 7. Close-up of a 160μm-thick coupled-line bandpass filter. The sidewall roughness is <0.1μm; top surface roughness is ~1-5μm.

resist is removed. The metal film is etched away to electrically isolate the plated structures.

The goal of this process was the fabrication of the 200µm-thick LIGA microstrip filters on a 420µm-thick 3" double-polished fused-quartz; however, the process yielded actual thicknesses of 120µm and 160µm (figs. 6,7) Nickel was chosen as the strip conductor metal for the first fabrication runs although gold or copper may also be plated.

FILTER MEASUREMENTS

The filters were measured using an HP 8510C network analyzer with a microstrip test fixture. A Short-Open-Load-Thru (SOLT) calibration was performed using coaxial HP calibration standards. The 160µm-think low-pass LIGA microstrip filter has a measured 3dB cutoff frequency of 9.0 GHz and demonstrated 20dB of attenuation at 11.1 GHz (fig. 8). Both results are within 6% of the theoretical values and the differences are most likely due to the open end effects of the low-impedance transmission line sections. The 120µm-thick bandpass filter has a minimum insertion loss of 0.4dB at 9.1 GHz (fig. 9). The 3dB cutoff frequencies of 7.8 and 10.5 GHz result in a 30% bandwidth, and the filter demonstrates 20dB of attenuation at 6.8 and 12.8 GHz. The bandpass

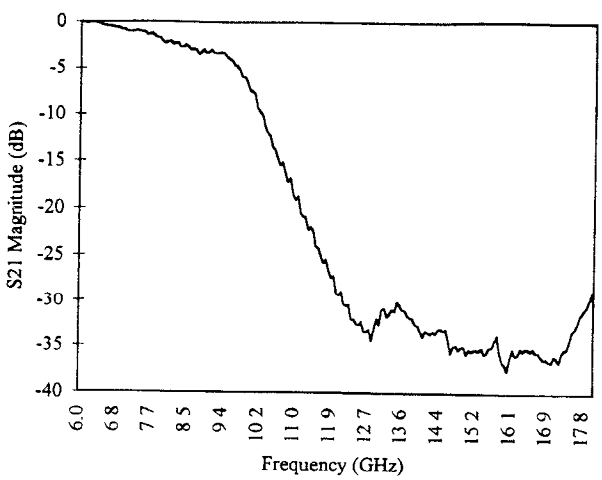


Fig. 8. Measured filter response of 160µm-thick low-pass filter.

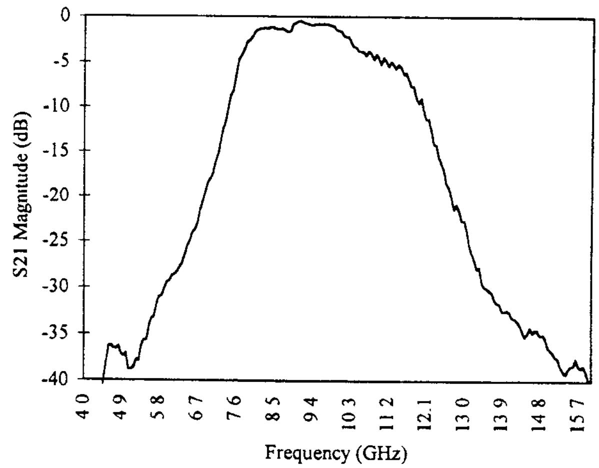


Fig. 9. Measured filter response of 120µm-thick bandpass filter.

filter response is dependent on element-to-element coupling and is therefore more sensitive to conductor height variations. Regardless, the agreement between theory and experiment is quite good. Future work will concentrate on improvement of the plating process and demonstration of new circuit topologies requiring vertical sidewall structures and tight coupling such as microstrip resonators and interdigital capacitors [3,4].

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