

Millimeter Wave CRLH BP Filter: Standard Photolithography vs. Laser Ablation

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Abstract

This work deals with the development and manufacturing of a Composite Right / Left Handed (CRLH) filter structure in the millimeter-wave range. The devices were microprocessed on a 0.5 mm thick silicon substrate with a 3000 Å Au / 500 Å Cr metallization layers using two technologies: standard photolithography and direct laser ablation. The results obtained by using these two microprocessing technologies were compared and the results were presented.

1. Introduction

The paper describes the design, manufacturing and measurement of a millimeter wave (MMW) CRLH filter structure on silicon substrate. In order to simplify and increase the efficiency of the technological process (elimination of masks on the glass) the use of laser ablation for microprocessing of interdigital capacitors, was considered. The experimental results depending on technologies employed in obtaining filter structures were analyzed.

2. BPF structure design

The elementary CRLH cell is depicted in Fig. 1 (a) while the equivalent circuit is shown in Fig. 1 (b). Using the known relations and notations for CRLH cell design, cf. [1] and [2], the following data were obtained: $f_{cLH} = 30$ GHz, $f_{cRH} = 52$ GHz, $f_0 \cong 40$ GHz and $k \cong 1,3$. Computing for $Z_C = 50 \Omega$, we obtain: $2C_L \cong 106$ fF, $L_R/2 \cong 0,3$ nH, $C_R \cong 45$ fF, $L_L \cong 0,13$ nH.

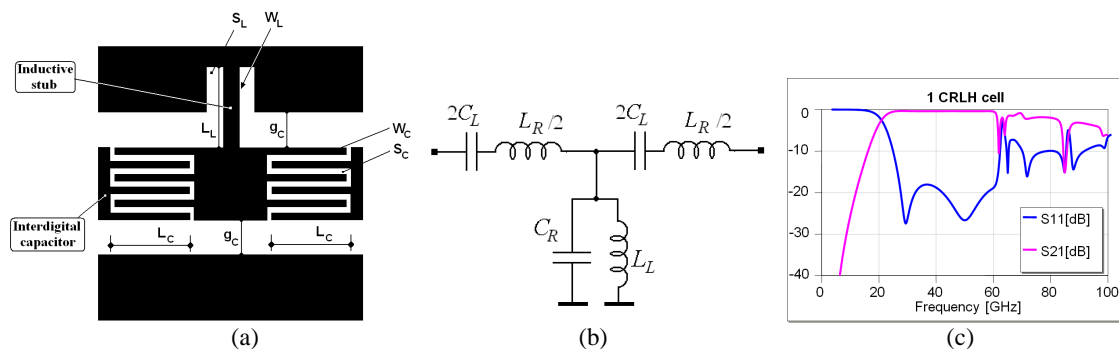


Fig.1 CRLH cell (a), equivalent circuit (b) and simulated S_{11} and S_{21} parameters of the BPF (c)

The CRLH cell layout was designed such as the length of the interdigitated capacitor be much smaller than the wavelength corresponding to f_0 . The value $2C_L = 106$ fF was obtained for the following geometrical dimensions $w_c = 10 \mu\text{m}$, $s_c = 5 \mu\text{m}$, $L_c = 250 \mu\text{m}$ and number of digits equal to 10. For

the inductive ground connected line we obtain: $L_L = 277 \mu\text{m}$, $w_L = 42 \mu\text{m}$ and $s_L = 10 \mu\text{m}$. The results of the device modeling with the above computed dimensions are presented in Fig. 1 (c).

3. Microprocessing technology

As substrate for CRLH filter was used a silicon wafer with $500 \mu\text{m}$ thickness and $5 \text{ k}\Omega\text{cm}$ resistivity. On the surface of this Si wafer a $1 \mu\text{m}$ thick SiO_2 layer, was grown. The Si wafer was plated through a sputtering process with a 2000 \AA Au / 500 \AA Cr metallization. Two technologies were used in the fabrication of the CRLH BPF structure: photolithography and laser ablation.

In Fig. 2 (a), (b), photos showing the result of BPF fabrication by photolithography, are presented. Fig.2 (a) shows the CRLH filter layout and Fig. 2 (b) shows a detail of an interdigitated capacitor. Concerning the photolithography, this technology is able to provide excellent layouts for all the microwave devices. Still, the definition limits of this technology are of about $2 - 3 \mu\text{m}$.

The same BPF layout with CRLH artificial lines was, also, processed using laser ablation. Fig. 2 (c) shows a Scanning Electron Microscopy (SEM) detailed image of the interdigitated capacitors made by laser ablation on the same silicon wafer.

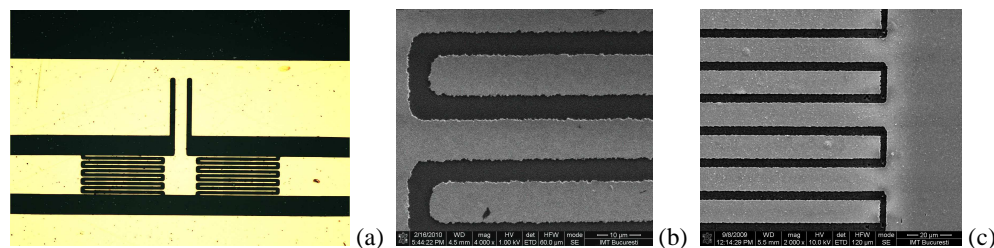


Fig. 2. CRLH BPF: (a) a single CRLH cell processed by photolithography; (b) SEM detail of an interdigitated capacitor; (c) SEM detail of an interdigitated capacitor processed by laser ablation

The ablation was processed with a laser system Clark CPA-2101, delivering ultrafast pulses of 200 fs duration, 775 nm wavelength, and 2 kHz repetition rate. The samples are precisely translated and positioned by a XYZ fine translation stage with accuracy of the order of hundreds of nanometers. The optimum scanning speed was established to be 0.2 mm/s for minimizing mechanical positioning errors and for a reasonable processing time.

The obtained geometry has the previously computed parameters: digit width $w_C = 10 \mu\text{m}$, interdigital width $s_C = 5 \mu\text{m}$, and the digit length $L_C = 250 \mu\text{m}$. As it may be seen from the SEM image in Fig. 2 (c) the line definition is better than for photolithography and no over-etching is present. The corners are not rounded and the processing quality is better.

A drawback of the photolithography is the tendency of metallic lines over-etching while through the process of ablation this phenomenon is eliminated. As it can be seen in example depicted in Fig. 3 (a), the ratio $10 \mu\text{m}$ metallization / $5 \mu\text{m}$ space between the metallic digits (interdigital width) respectively was not kept. As a result, correction factors must be introduced in the device mask design, in order to compensate for the over-etching effect.

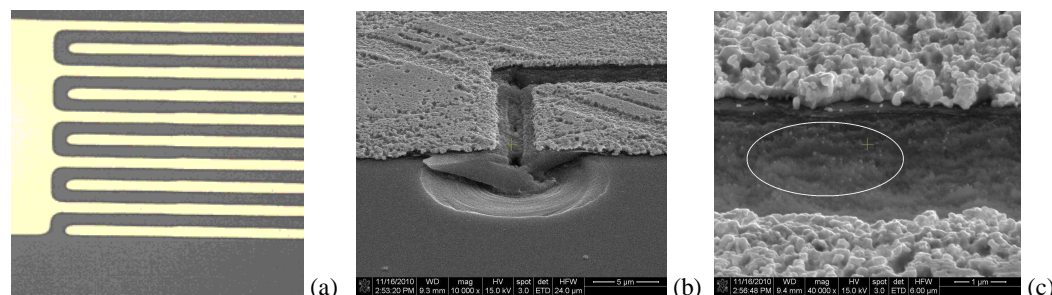


Fig. 3. Technological drawbacks.

In Fig. 3 (b) there is a SEM image of the damaged Si and SiO₂ layer after laser ablation with a too high power of the laser beam. Finally, during the laser ablation a cloud of metallic material removed by ablation is spread all over the interdigitated capacitor structure, including the interdigital space. These metallic particles may be observed as white dots in Fig.3 (c). This contamination causes a drop of the substrate resistivity increasing the losses of the device fabricated by laser ablation.

3. Measurements

The S_{11} and S_{21} parameters were on-wafer measured using a 37397D vector network analyzer (VNA) from Anritsu with a 110 GHz maximum working frequency capability equipped with PM5 on-wafer measurement set-up from Süss Microtec. The measurement results for the CRLH filter micro-processed by photolithography and laser ablation are shown in Fig. 4 (a) and (b).

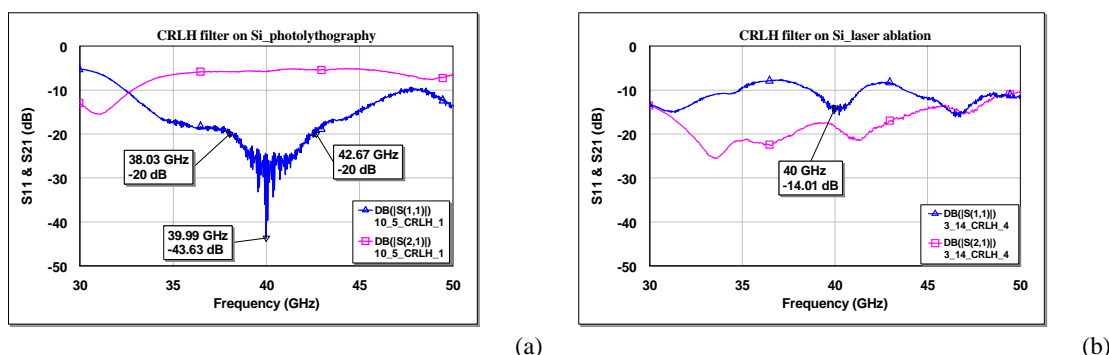


Fig.4. S parameters of the BPF structure made by photolithography (a) and by laser ablation (b).

Measurements on filters microprocessed by photolithography show a return loss $S_{11} < -20$ dB in the frequency range between 38.03 GHz and 42.67 GHz with the maximum value of -43.63 dB at 39.99 GHz. The return losses in the same frequency range are about 6 dB. The frequency band is 4.64 GHz (for $S_{11} < -20$ dB). The measurement of S parameters on the BPF structure made by laser ablation is shown in Fig.4 (b) in the same frequency band. Due to technological limitations previously described, the losses are in the range of -20 dB, being unacceptably high.

4. Conclusions

The design, construction and measurements of a band-pass (BPF) filter in the millimeter wave (MMW) band is presented. The device was made on a silicon substrate using two technological approaches: standard photolithography and laser ablation. Despite technological limitations, acceptable BPF characteristics were obtained by photolithography at 40 GHz in a frequency band of 4.64 GHz. A comparison between the results obtained by using these two technologies highlights the following data:

- The line definition and the ratio metal lines / interdigital space are much better for the laser ablation technique due to the absence of over-etching;
- In the laser ablation technology the losses are high due to the metallic powder contamination. Better results are expected to be obtained following some technological improvements.

References

[1] C. Caloz, T. Itoh, „Electromagnetic metamaterials: Transmission line theory and microwave applications”, *John Wiley & Sons, 2006, Cap.5.*
 [2] S. Simion, G. Sajin, R. Marcelli, F. Craciunoiu, G. Bartolucci, “Microwave Directional Coupler with CRLH cells on Silicon Substrate”, *Proceedings of the 50th International Symposium “Electronics in Marine” ELMAR-2008, Zadar, Croatia, 10 – 13 Sept. 2008, pp. 195 – 198; ISSN 1334-2630; ISBN 978-953-7044-06-0.*