A GaAs Micromachined Millimeter-wave Lowpass Filter Using Microstrip Stepped-Impedance Hairpin Resonator

Ju-Hyun Cho[1], Tae-Soon Yun[1], Ki-Byoung Kim[1], Tae-Jong Baek[2], Baek-Seok Ko[2], Dong-Hoon Shin[2], and Jong-Chul Lee[1]

[1]RFIC Education and Research Center, Kwangwoon University, 447-1 Wolgye-dong, Nowon-gu, Seoul, KOREA, sigma-12@kw.ac.kr
[2]Millimeter-wave INnovation Technology research center (MINT), Dongguk University, Pil-dong 3ga 26, Chung-gu, Seoul, KOREA

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content

I .Introduction

Recently, the development of RF passive devices using MEMS (MicroElectroMechanical Systems) technology is actively in progress. It takes advantage of possibility to make the device with very high frequency range by overcoming the construction problem in existing way. MEMS devices have high Q, low loss, and low dispersion, and can be integrated with active devices on the same substrate [1, 2]. There are two kinds of MEMS technology. One is a bulk-micromachining in which the pattern is formed on membrane by etching process of the substrate and the other is a surface micromachining in which the structure is made on

the air through etching process of the sacrificial layer [3].

In this paper, a new SIR LPF with aperture is suggested using GaAs surface micromachining in 30 GHz range. The microstrip line is elevated by the polyimide dielectric post using surface micromachining technique and then it has air-gapped area between the signal line and the ground metal. Hence, the substrate dielectric loss can be reduced because most of the electric field is confined in air region between the signal line and the ground, not in dielectric substrate. Therefore, the new low loss microstrip structure can be easily realized without the complex process such as via-hole and back metalization, Since the DAML structure is compatible with the conventional MMIC (monolithic microwave integrated circuit) technologies, it is possible to integrate the passive MEMS components on the active GaAs MMIC, which can make the cost lower and the size smaller with good performance [4].

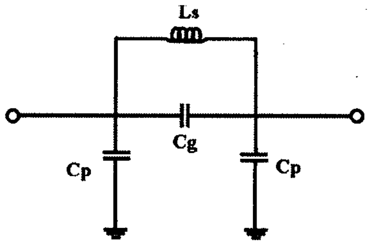
II. Analysis of the Stepped-Impedance Hairpin Resonator

The stepped-impedance hairpin resonator (SIR) consists of the two sections; a symmetrical parallel coupled line and a single line [5, 6]. One end of the coupled line is open and other end is connected in parallel by the single line. By selecting $Z_h >$ $\sqrt{Z_{0e}Z_{0o}}$, and employing aperture on the ground plane, the size of the SIR LPF is reduced as half of the original filter, where Z_{0e} and Z_{0o} are the even-mode and odd-mode impedance, respectively of symmetric capacitance-loaded parallel coupled lines, and Z_h is the characteristic impedance of the single transmission line.

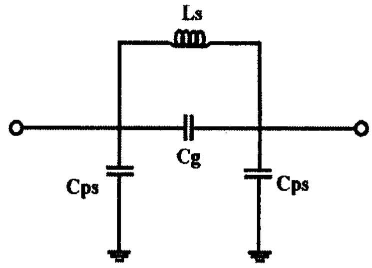
Fig. 1 shows the equivalent circuit of the microstrip stepped-impedance hairpin resonator low-pass filter with and without aperture. As it can be seen from the equivalent circuit in Fig. 1(a), L_s is the equivalent inductance of the single transmission line of the filter. C_g is the equivalent capacitance of the coupled lines and C_p is the equivalent shunt capacitance. Fig. 1(b) shows the equivalent circuit for the filter without aperture, where $C_{ps} = C_s' + C_p' + C_\Delta$. Here, C_s' is the capacitance related to the single transmission line, C_p' is the shunt capacitance related to l_c, and C_Δ is the capacitance related to the junction discontinuity between single transmission line and coupled lines. This is due to the fact that the aperture on the ground gets rid of parasitic capacitance of single transmission line and harmonic resonances. Also, adopting the inter-digital structure inside the coupled line section, very sharp skirt characteristic in frequency response can be obtained and the size of the device can be reduced.

The capacitance of inter-digital capacitance (IDC) with $n \geq 3$ structure inside the coupled line section may be presented as $\sum C = C_3 + C_n + C_{end}$, where C_3 is the sum of the capacitance of three-finger capacitor, C_n is the capacitances of periodical $(n-3)$ structures, and C_{end} is a correction term for the fringing fields of the ends of the strips, which are given by ref.[7].

It is assumed that the microwave wavelength in the substrate is much larger than the dimensions of the IDC. The models do not take into account parasitic inductances and resistances.



(a)

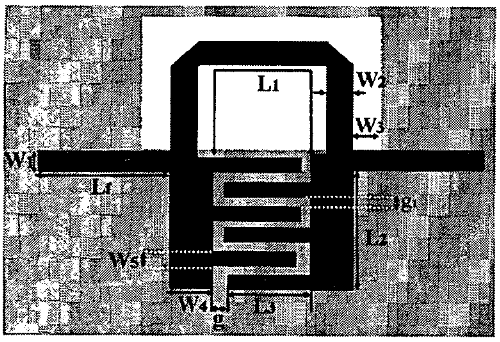


(b)

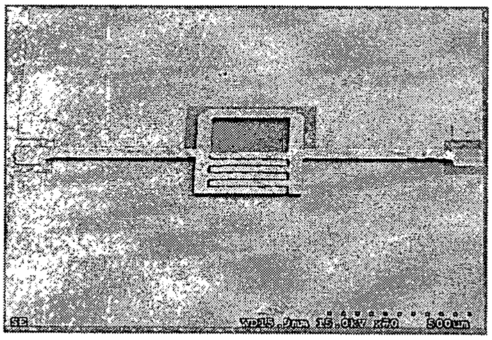
Fig. 1 Stepped-impedance hairpin resonator low-pass filters: (a) Equivalent circuit for the filter with aperture and (b) Equivalent circuit for the filter without aperture

Fig. 2 shows the geometry and SEM photograph of the SIR hairpin LPF with aperture and Fig. 3 is the SEM picture of the area of dielectric post. The SIR LPF with aperture on GaAs substrate, in which rectangular shape of defected pattern is etched off from the ground plane, is designed using 3-D simulation tool, HFSS, ver. 8.5. The low-pass filter is designed for 3-dB cutoff frequency of 33 GHz and fabricated on GaAs substrate. The optimized dimensions of the SIR LPF are L_f = *0.5 mm*, L_1 = *0.698 mm*, L_2 = *0.208 mm*, L_3 = *0.26 mm* W_1 = *0.044 mm*, W_2 = *0.044 mm*, W_3=*0.044 mm*, W_4 = *0.04 mm*, W_5 = *0.03 mm*, g = *0.01 mm and* g_1 = *0.01 mm*.

The signal line of DAML structure is consisted of ground metal, dielectric post, and signal line elevated on air. The proposed DAML structure is formed on a GaAs substrate with the thickness of 680 μm, and the ground metal of Au with the thickness of 1 μm while the transmission line has the thickness of 5 μm which is lifted on 10 μm from the ground metal .



(a)



(b)

Fig. 2. The SIR LPF with aperture. (a) Layout and (b) SEM photograph

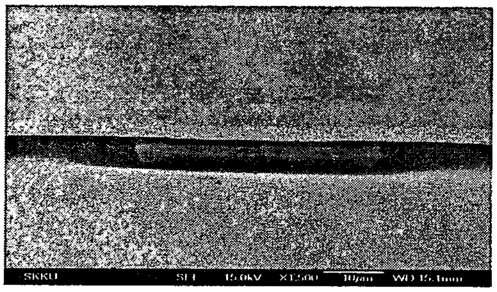


Fig. 3. SEM photography of the post area

III. Process of DAML Structure

The signal line of DAML structure is consisted of ground metal, dielectric post, and signal line lifted on air. Fig. 4 shows the process flow of the DAML structure using surface micromachining.

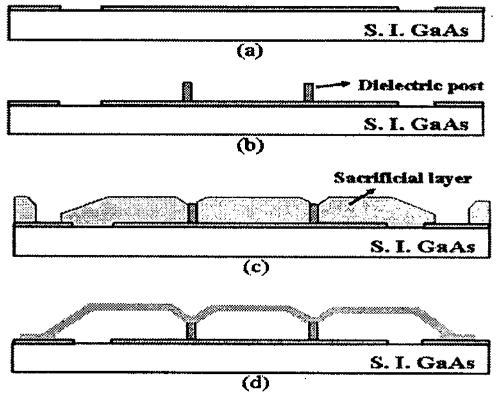


Fig. 4. Process flow of DAML structure [4] (a) Ground metal formation, (b) Dielectric post formation, (c) Sacrificial photo-resist patterning and baking, and (d) Metal patterning and sacrificial layer removal

First, Ti/Au layer by thermal evaporator [Fig. 4(a)] is deposited on the semi-insulating GaAs substrate, and then the dielectric posts with the height of 10 μm [Fig. 4(b)] are formed. Next, the circuit pattern is finished through the photo-lithography using AZ4903 photo-resist which has higher thickness than post height for the sacrificial layer [Fig. 4(c)]. Finally, the metal pattern can be obtained by lift-off process and the sacrificial layer is removed by acetone [Fig. 4(d)].

IV. Simulation and Measurement Results

Fig. 5 shows the simulation and measurement results for the SIR LPFs with and without aperture and IDC. Comparing with each other, the SIR LPF with aperture and IDC shows much broader stopband characteristic, lower return loss, and insertion loss in the pass band, and sharper cutoff frequency than the SIR LPF without aperture and IDC. From the figure, the SIR low-pass filter with aperture shows a 3-dB passband from dc to 33 GHz. The insertion loss is less than 0.82 dB, and the return loss is better than 17 dB from dc to 25.57 GHz. The rejection is greater than 10 dB within 43.05-100 GHz. The ripple is ±0.42 dB, as shown in the figure.

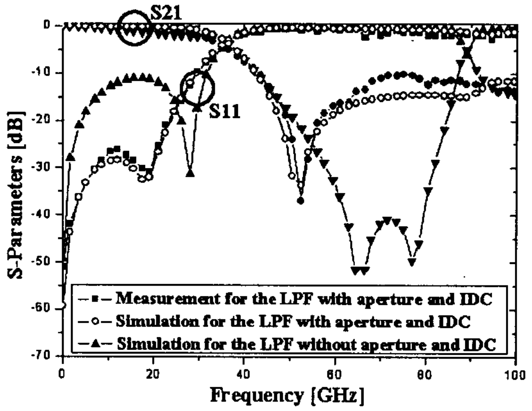


Fig. 5. Simulation and measurement results for the SIR LPF with aperture and IDC, and without aperture and IDC

V. Conclusions

In this paper, a new millimeter-wave microstrip stepped-impedance hairpin resonator low-pass filter with aperture using GaAs surface micromachining has been proposed. The low-pass filter has shown a sharp cutoff frequency response and low insertion loss. Moreover, with aperture, the low-pass filter shows a wide stopband bandwidth. The experimental results show excellent agreements with theoretical simulation ones.

Acknowledgment

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