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用于微机电系统的微型带阻滤波器

黄　闯[1]，陈　迪[1]，陈　翔[1]，刘景全[1]，朱　军[1]，魏雯婕[2]，魏泽勇[2]，李宏强[2]
（1. 上海交通大学 微米纳米加工技术国家级重点实验室 薄膜与微细技术教育部重点实验室，上海 200240；
2. 同济大学物理系，上海 200092）

摘要：为了实现微机电系统微波信号滤波，开发了适用于微机电系统的小尺寸左右手复合传输线微波带阻滤波器，对该滤波器的原理、结构特点、加工工艺等进行了研究。根据左手材料理论，介绍了具有蛇形槽单元的滤波器结构。以蛇形槽结构的一个单元为例，对比传统插指电容左手单元结构，提取了蛇形槽的等效电路，并分析了蛇形槽结构单元的优点，即在相同的面积内，可以获得更大的等效电路参数。最后，结合溅射、光刻、电铸、刻蚀等 MEMS 技术，设计了器件的加工工艺。使用 MEMS 工艺，加工了主体尺寸 5 mm×7 mm 的器件。相移常数的仿真和实验结果表明，在高频带部分(2.1～5.2 GHz)的相移常数为负(左手区)，相速度与群速度方向相反，左手区的相对带宽为 82.7%。结果显示，与其他设计相比，本文设计的器件尺寸小，左手区的相对带宽大，可以提供更大的工作频带范围

关　键　词：微机电系统；左右手复合传输线；带阻滤波器；左手材料
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Compact band reject filter for micro electromechanical systems

HUANG Chuang[1], CHEN Di[1], CHEN Xiang[1], LIU Jing-quan[1],
ZHU Jun[1], WEI Wen-jie[2], WEI Ze-yong[2], LI Hong-qiang[2]

(1. *State Key Laboratory of Micro/Nano Fabrication Technology*,
Key Laboratory of Thin Films and Microtechnology, *Ministry of Education*,
Shanghai Jiao Tong University, *Shanghai* 200240;
2. *Physics Department*, *Tongji University*, *Shanghai* 200092)

Abstract: In order to filtrate the microwave signals in micro electronic mechanical systems, a micro Composite Right/Left Handed(CRLH) transmission line band reject filter is presented, and the design theory, structure characteristics and fabrication process of the filter are also studied. According to the Left Handed Material (LHM) theory, the filter structure with a meander gap is introduced, and the equivalent circuit of the meander gap structure is obtained by comparing to the conventional interdigital capacitor structure. Then, the advantage of the meander gap structure is discussed by taking a cell of the meander gap as an example, and the results show that the equivalent circuit parameters in the meander gap structure are larger than that of the conventional interdigital capacitor structure. Finally,

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the fabrication process is introduced by combining different MEMS (Micro Electromechanical Systems) technologies, such as sputtering, lithography, electroplating and etching. By the MEMS technology, a band reject filter with the size of the main part of 5 mm×7 mm is developed. The simulated and experimental results show that the phase shift constant of the band reject filter is negative at the high frequency (2.1—5.2 GHz, left handed region), and the phase velocity flows just to the opposite direction of the energy flow in the left region. Moreover, the relative pass bandwidth in a left handed region is 82.7%. Compared with other designs, this filter shows his advantages in small sizes and large working bands at the left handed region.

Key words: Micro Electromechanic System(MEMS); Composite Right/Left Handed(CRLH) transmission line; band reject filter; left handed material

1 Introduction

As the development of Micro Electromechanical Systems (MEMS), decreasing the component sizes has become more and more important. Especially for RF-MEMS, the RF components are normally larger than other parts because of the relation between the components and electro magnetic wavelength. To resolve this problem, a compact micro Composite Right/Left Handed (CRLH) band reject filter based on MEMS technologies and the left handed material theory is designed and fabricated. The length of the main part is only 1/20 of the working wavelength. It can be integrated into RF-MEMS where micro RF components are necessary.

Over the past few decades, application of Left-handed Materials (LHMs) in the field of microwave has received considerable attention[1-4]. As the development of LHMS theory, a new study field was proposed. It is the transmission-line (TL) approach of LHMs, which integrate the LHMs theory into the design of microwave transmission-line. Many novel microwave components have been designed based on this theory [5]. Most of the proposed designs are fabricated by normal technics[6-11], so the devices are large and difficult to be integrated into microelectronic systems. The aim of this paper is to present a novel design of compact CRLH Composite Right/Left Handed Transmission Line (CRLH, TL) structure based on MEMS technologies. The new design works as a band reject filter design, which has a coupled meander gap and a meander line. Two circular patches are used as capacitors in series respectively. Compared with other designs, a relatively large inductance can be obtained by the meander line. With MEMS technologies, the device is easy to be fabricated and integrated into portable devices. The analysis of the structure and characteristics will be presented in the next part. Experimental results show the advantages of the LHMS.

2 Design and model analysis

2.1 Structure of transmission line

The proposed CRLH transmission line structure is shown in Fig. 1- Fig. 2.

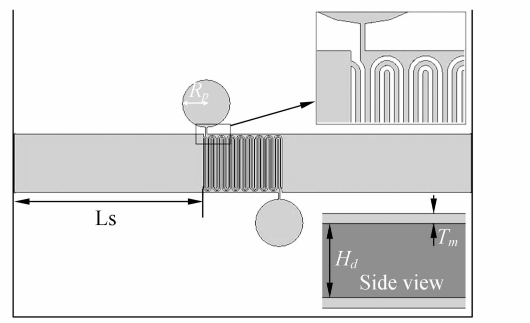

Fig. 1 Structure of the transmission line

This band reject filter has a coupled meander gap and a meander line. Two circular patches are

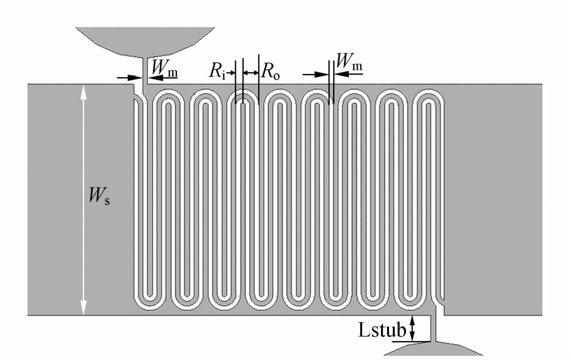

Fig. 2 Local view of dual structure

used as capacitors in series respectively. The whole structure is fabricated on the PCB substrate F4BM220[12]. The thickness T_m is 0.8 mm and the relative permittivity is 2.2. The feed line width W_s is 2.5 mm, which leads to the characteristic impedance of 50 Ω at two ports. The structure parameters are filled in Tab. 1.

Tab. 1 Structure Parameters

Parameters	Value(mm)	Description
L_s	8	Length of feed line
W_s	2.5	Width of feed line
L_{stub}	2.2	Length of stub
R_p	1	Radius of patches
T_m	0.005	Thickness of conductor
H_d	0.8	Thickness of dielectric
W_m	0.05	Width of meander lines
R_i	0.075	Radius of inner arc
R_o	0.175	Radius of outer arc
ε_r	2.2	relative permittivity

2.2 Equivalent-circuit model

Fig. 3 is a equivalent circuit model. The meander line inductor L_L and the meander gaps capacitor C_L belong to the left-handed components. The meander line inductor L_R and circular patch capacitor C_{RP} contribute to the right-handed components. C_R is the capacitor between the meander line and the ground. R_s is the resistance of copper. G_P refer to the loss of the substrate.

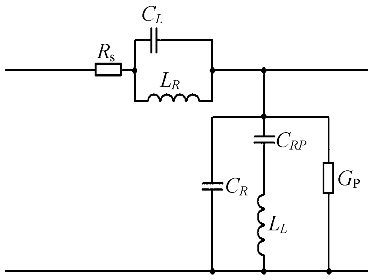

Fig. 3 Equivalent circuit model

2.3 Analysis of structure characteristics

Two parallel meander gaps and a meander line between them are the main structure of the band reject filter. This structure obtains larger inductance and capacitance in the same space of the conventional interdigital structure. Suppose adding the same length to a conventional interdigital structure and this design, the increased parts are shown in Fig. 4. The two parts belong to the new design (left) and the interdigital structure (right) respectively. The width of gaps and line in the new design are all W. The width of fingers and gaps of the interdigital structure are $W_1 > W$ and $W_g > W$ respectively. The two parts have the same dimension which width equal $8 \times W$ and length equal L. Suppose $L \gg W$, then the elbow of the meander lines can be ignored.

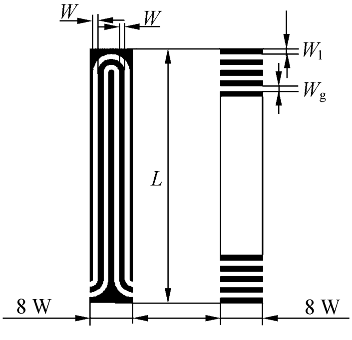

Fig. 4 Increased parts of two types. The left part belongs to the meander gaps, and the right part is for the interdigital capacitor

Comparing the increased capacitance and inductance of the two parts, the results are shown in formula (1)-(2):

$$\frac{C_m}{C_i} = \frac{(2 \times L/W)/2}{(8 \times W/W_g) \times 2} = \frac{L/W}{(8 \times W/W_g) \times 2} = \frac{W_g \times L}{4 \times W^2}, \tag{1}$$

$$\frac{L_m}{L_i}=\frac{2\times L/W}{(8\times W/W_1)/N}=\frac{2\times L/W}{(8\times W/W_1)/(L/(W_g+W_1))}=\frac{W_1\times L^2}{4\times(W_g+W_1)\times W^2}\ , \tag{2}$$

For the interdigital structure, the fingers will connect two parts beside them except the two fingers on the edge of the fingers array. One of the two fingers end are need to connected ground. So the effective parts of the capacitance are only contributed by the two special fingers. C_m, C_i, L_m and L_i are the capacitance and inductance of the meander gaps and interdigital structure. N is the number of the interdigital structure.

Multiplying formula (1) by (2), formula (3) is obtained:

$$\frac{L_m\times C_m}{L_i\times C_i}=\frac{W_1\times L^3\times W_g}{4\times(W_g+W_1)\times W^2\times 4\times W^2}=\frac{L^3\times W_1\times W_g}{16\times(W_g+W_1)\times W^4}\geqslant\frac{L^2}{16\times W^2}\ , \tag{3}$$

$L\gg W$ and $L>(W_g+W_1)$. It shows that the meander lines are more effective for decreasing the frequency of a filter which is the function of the product of inductance and capacitance. The comparing result of L/W is 50 times that of the previous design.

3 Fabrication process

There are 6 steps to complete the whole fabrication process. Fig. 5 gives a schematic of the fabricating process. Fig. 6 is the pictures of the prototypes.

Step 1: Cutting the wafers out of PCB which is single side metalized.

Step 2: Sputtering copper seed layer

Step 3: Spinning photoresist coating

Step 4: Lithography

Step 5: Electroplating copper

Step 6: Removing the photoresist and seed layer

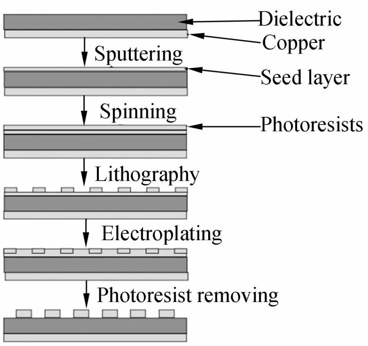

Fig. 5 Fabrication process

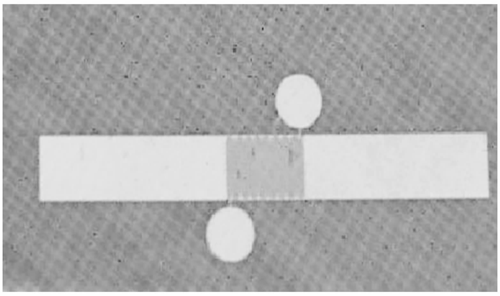

Fig. 6 Sample of the CRLHTL band reject filter

4 Transmission property measurement and results

The left handed material theory is the base of this design. As a promising theory, it has some important characteristics for RF components. The first step is to minimize the design. As the absolute value of phase shift constant will increase when the frequency decrease, so the electric length of the device can keep relatively stable without changing the real length. Then the device can work with a relatively short length compare to the wavelength. The second is wide bandwidth. The reason is that the phase shift constant will be changed to the opposite direction when the wavelength changes with the working frequency. This supplies a negative feedback to the electric length made by multiplying the phase shift constant and the length of the filter, so the left handed region has a wider bandwidth.

Fig. 7 is S_{21} results of the band reject filter.

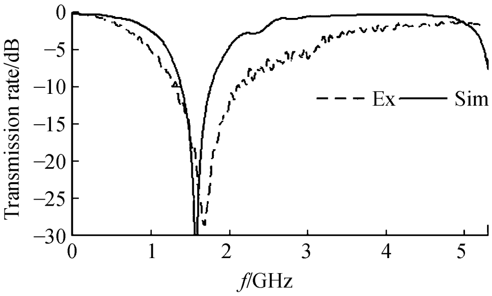

Fig. 7 S_{21} results of dual structure

The reject band is caused by the band gap between the left band and the right band. The left handed pass band is the high frequency part. It is different from normal LHMs. The pass band of the simulation result is 2.1 GHz to 5.2 GHz, central frequency is 3.75 GHz, and the relative bandwidth (3 dB) is 82.7%. This supplies a more width work range for the band reject filter. The pass band for the sample has some attenuation caused by the substrate.

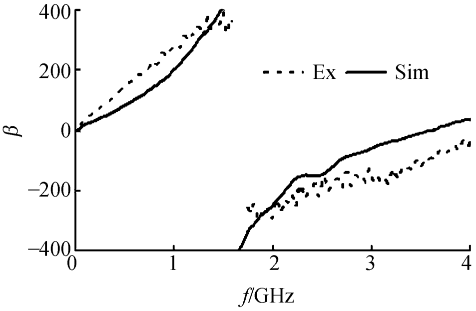

Fig. 8 Phase shift constant of dual structure

The simulated and experimental results of phase shift constant are also supplied by Fig. 8, which shows that the phase shift constant of the band reject filter is negative at the high frequency (left handed region). It indicates that the phase velocity flows backward, just transmitting to the opposite direction of the energy flow in the left region.

5 Conclusions

As the requirement of portable wireless microelectronics device, a novel CRLH TL band reject filter is designed and fabricated based on LHMs theory and MEMS technology. The structure of this design is smaller than that of conventional designs. The size of the main part is only 5 mm×7 mm, which is easy to be integrated into a wireless microelectronic system. On the other hand, this design takes advantage of the left handed theory by forming a band gap between the left hand region and the right hand region. The results show that this design has left handed properties at high frequencies and also has a wide pass band (2.1—5.2 GHz), which makes the band reject filter has a wide working frequency band. The MEMS technology is also very important to this kind of small device. For the structure with a minimal line width of 50 μm is difficult to normal fabrication process. And also the MEMS technology improves the precision of the fabrication, which makes the measurement results consistent with the simulation results.

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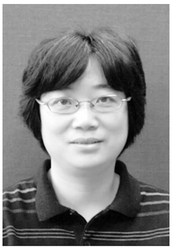
Authors' biographies:

HUANG Chuang(1978—), male, Ph.D. candidate, his research is focused on the meta-materials based on MEMS technology. **E-mail**: paull_huang@sjtu.edu.cn

CHEN Di(1961—), male, professor, his research fields are development and application of LIGA-like microfabrication technique, implantable microsystems, microfluidics and RF MEMS. **E-mail**: dchen@sjtu.edu.cn

CHEN Xiang(1974—), male, lectuer, his research fields are BioMEMS and microfluidics.

LIU Jing-Quan(1971—), male, professor, his research interests include MEMS, biomedical microsystems, and microfabrication processing technology.



ZHU Jun(1973—), female, associate professor, her research interests include MEMS and microfabrication processing technology. **E-mail**: junzhu@sjtu.edu.cn

WEI Wen-jie(1983—), female, received her M.S. degree from the Department of Physics, Tongji University in 2009. Her research is focused on the electromagnetic wave propagation characteristics in inhomogeneous medium. **E-mail**: wwjjiji@hotmail.com

WEI Ze-yong(1982－), male, Ph. D. candidate, his research is focused on meta-materials. **E-mail**: hqlee@tongji.edu.cn

LI Hong-qiang(1969－), male, professor of the Physics Department, Tongji University, received Ph. D. degree in philosophy from the Optical Physics Laboratory of the Institute of Physics, Chinese Academy of Science in 1997. His research fields are wave propagations in inhomogeneous media, optical physics *etc*. **E-mail**: hqlee@tongji.edu.cn

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●下期预告

几种氟化物薄膜材料的光学特性

薛春荣[1,2,3],易　葵[1],邵建达[1],范正修[1]
(1.中国科学院 上海光学精密机械研究所,上海 201800;2.常熟理工学院 江苏新型功能材料实验室,常熟 215500;3.中国科技大学 国家同步辐射实验室,合肥 230019)

为了进一步明确氟化薄膜材料在紫外(UV)—真空紫外(VUV)波段的光学常数,研究了 VUV 领域常用的基底材料和 6 种大带隙的氟化物薄膜材料. 分别在熔石英(JGS1)基底和氟化镁单晶基底上用热舟蒸发以不同的沉积速率和不同的基底温度镀制了 3 种高折射率材料薄膜 LaF_3、NdF_3、GdF_3 膜,和 3 种低折射率材料薄膜 MgF_2、AlF_3、Na_3AlF_6 膜;在国家同步辐射真空紫外实验站测定了 120～300 nm 的透射率光谱曲线,用商用 lambda900 光谱仪测量了它们在 190～500 nm 的透射率光谱曲线,两者相结合标定透射率的准确值。用包络法和模拟退火相结合研究了它们在 120～500 nm 的折射率和消光系数,给出了 6 种氟化物材料的光谱色散曲线。3 种高折射率薄膜的折射率在 157 nm 处约为 1.77～1.89,而 3 种低折射率薄膜的折射率在 157 nm 处约为 1.44～1.48。研究表明,所选高低折射率氟化物薄膜的折射率相差较大,在膜系设计中可以组成高低折射率材料对、设计各种实用的薄膜器件。