A Metamaterial Directional Antenna Fabricated Using MEMS Technique *

HUANG Chuang[1], *CHEN Di*[1*], *CHEN Xiang*[1], *LIU Jing-quan*[1], *JING Xiang-meng*[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* 200030, *China*;
2. *Physics Department, Tongji University, Shanghai* 200092, *China*)

Abstract: A directional emission antenna was fabricated using MEMS process. Its size was effectively decreased by a sub wavelength resonance cavity. Metamaterial is included as one part of the cavity. The antenna can be used in power transmission of micro system for high power density and small size. The thickness is less than 1.5 mm and work on 10 GHz. This made it easily integrated with micro system. The simulation and experimental results are carried out, and the fabricating process is also introduced.

Key words: Antenna; MEMS; resonance cavity; metamaterial
EEACC: B20

基于 MEMS 工艺的异性材料定向天线 *

黄 闯[1], **陈 迪**[1*], **陈 翔**[1], **刘景全**[1], **靖向萌**[1], **朱 军**[1], **魏文婕**[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 200030;
2. 同济大学物理系, 上海 200092)

摘 要: 制备了一种基于 MEMS 工艺的定向天线。以异性材料为基底的亚波长谐振腔结构有效降低了天线体积。这种天线可以用于要求高能量密度的微系统的能量传送。本文中的天线厚度为 1.5 mm, 可工作于 10 GHz 频段。这使得其易于与微系统集成。文中也给出了仿真及实验的结果, 并介绍了天线的加工过程。

关键词: 天线; MEMS; 谐振腔; 异性材料
中图分类号: TN TN603.5 **文献标识码: A** **文章编号: 1004-1699(2008)03-0533-03**

Energy supply is a problem during the development of MEMS technology. Battery is a normal way to resolve it[1-3]. But it become inappropriate in some special situation, for example when a device needs to implant into human body, battery is inappropriate and dangerous. Microwave is a promising method to supply power. In this paper, a directional emission antenna was introduced to build a base for microwave power transmission. The directivity decreases disturbance between signals and increases power density, which made it possible to get enough energy for a small size MEMS (receiver).

1 Theory and Structure of the Antenna

1.1 Theory of the Antenna

The conventional antenna to achieve directivity is based on the Fabry-Perot (FP) cavity, which requires a precise thickness with half of the working wave-length[4]. If the normal plate of the resonance cavity is replaced by a high impedance surface, the reflection phase difference can be reduced to zero[5-6]. It means that an antenna only need a thickness of $1/4\lambda$, λ is the working wavelength. The antenna presented here is similar to that described in Ref. [5]. The antenna size is decreased by the metamaterial substrate[7], for the metamaterial can reflect with arbitrary phases.

A mushroom structure (the high impedance substrate[8]) was introduced in 1998. This structure has two important characters, one is that the surface can reflect an input wave without reflection phase[9]. The other is the surface wave can be restrained by its high impedance surface structure. The surface wave can largely increase backward emission, and the efficiency of the antenna[10].

The high impedance substrate is showed in

基金项目: 上海市科委重点基础研究项目资助(05JC14061); 微米/纳米加工技术国家级重点实验室基金资助(9140C7903060706)
收稿日期: 2007-09-30 **修改日期**: 2007-12-27

Fig. 1. To analyze the reflection phase of the mushroom structure, two mushroom can be regarded as the model. It is a LC circuit. The patch between the adjacent two cells formed an inductance (L). The capacitance composed of three parts, one is between the adjacent fringes of two mushroom (Ca), the others are the plates of the mushroom with the ground (Cp1 and Cp2, Cp1 = Cp2 = Cp). So the surface impedance of the structure is: $Z = j \cdot L \cdot \omega / (1 - L \cdot (Cp/2 + Ca) \cdot \omega^2)$.

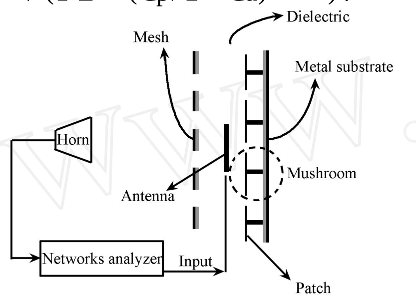

Fig. 1 Structure of the Antenna

It will change with the frequency and also the value of L, Cp and Ca. The reflection phase can be expressed as $\theta = \text{Arg}[(Z - Z_0)/(Z + Z_0)]$, $Z_0 = (\varepsilon_0/\mu_0)^{1/2}$. (Arg is the operator to get V compound angle) So θ can be changed by adjusting the structure.

1.2 Structure of the Antenna

The structure size described in Ref. [5] was decreased by MEMS techniques to adapt to the use of micro system. The metallic mesh [period = 4 mm, line width = 0.1 mm] printed on a 0.5 mm-thickness printed circuit board substrate ε = 2.2. The period of the mushroom structure is 6 mm, the gap of each patch is 0.5 mm and the length of metallic via is 0.5 mm. The inner dielectric layer is also the same kind of PCB material. The diameter of the whole antenna is 68 mm. We also made a small patch (4 mm * 5 mm) as the emission part.

2 Fabrication Process

The fabrication process of the antenna will be introduced in this part. There are 6 steps to complete the whole process. Fig. 2 gives a schematic of fabricating process.

Step 1: Cutting down the wafers from the PCB on which has already copper layer (30 μm thickness).

Step 2: Spin photoresist over the wafer.

Step 3: Lithography.

Step 4: Etching the copper on the wafer. After these steps, we get all the parts of the antenna.

Step 5: Remove the photoresist.

Step 6: Assemble the antenna.

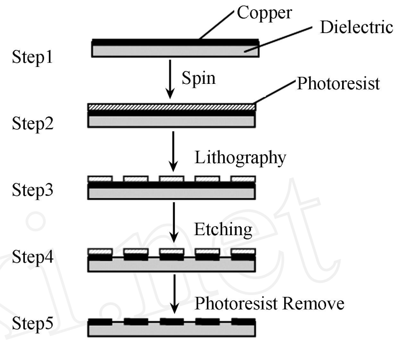

Fig. 2 Fabrication process of the directional antenna

3 Simulation and Experimental Results

CST-Microwave Studio 5.2 is used as the simulation tool. It is based on FDTD (finite-difference-time domain) arithmetic. The parameters of the simulation model are according to the above setting, and also using periodic boundary condition. Sweeping frequency is from 8-13 GHz. From Fig. 3, the resonance frequency is around 10.6 GHz. Fig. 1 is the Schematic of the experiment. The mesh and the mushroom layer formed a F-P cavity. The networks analyzer input signal to the antenna and receive the signal by a horn. Fig. 4 is a photo of the directional antenna. Fig. 5 is the structure of mushroom & mesh surface. The mushroom can hold back the surface wave and decrease energy loss. The mesh is used to partially reflect the microwave, it works with the mushroom layer, just like the device to produce laser.

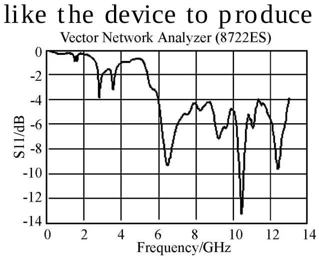

Fig. 3 Experimental result of S11

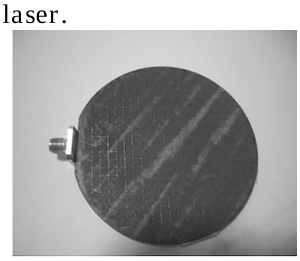

Fig. 4 Photo of the directional antenna

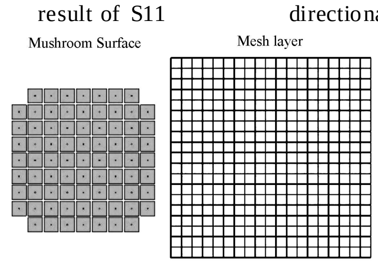

Fig. 5 Structure of mushroom & mesh surface

From the results (Fig. 6), the E plane has a relatively good directivity. But the H-plane has clear sideward emission. It is caused by the input part.

The samples with different thickness were also measured. Fig. 7 is the results for antennas with different mesh thickness, which shows a unit property of direction, this testify that the resonance frequency is much larger than the thickness, because the property was little affected by the change.

Fig. 8 is the S11 results for different dielectric and mesh thickness. The glass with $\varepsilon = 3.3$ was used as the dielectric. S11 curve with different thickness of the antenna shows that the antennas have a unit resonance frequency, and also testify that the resonance frequency is much larger than the thickness. On the other hand, the line for the glass has a low resonance frequency. It is because the glass has a higher permittivity.

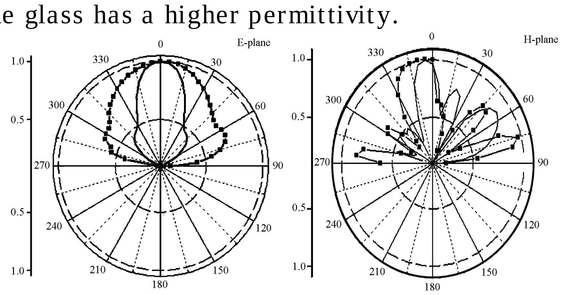

Fig. 6　Comparison of experimental and simulated results of emitted power in E- and H-planes. The curves with '- -' stand for experimental results, and the line stand for simulated results

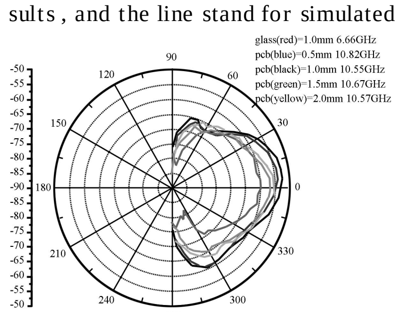

Fig. 7　The results for antennas with different mesh thickness

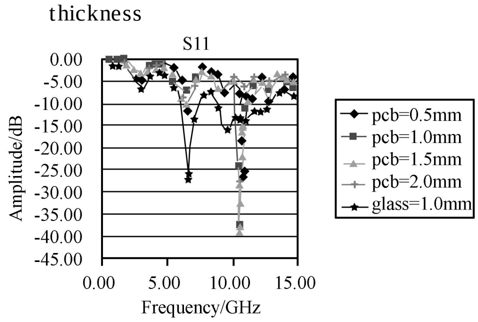

Fig. 8　S11 curves with different mesh thickness

4　Conclusions

In this paper, we introduced the process to fabricate a directional emission antenna used for power transmission in micro system. It is thin and small, can easily be integrated. And also, we noticed the input part from lateral side has a disturbance with the result. So how to input the signal from backward is the future work.

参考文献:

[1] John N H, Rodney M L, Richard H S, Microbatteries for Self-Sustained Hybrid Micropower Supplies [J]. Journal of Power Source, 2002, 104(I):46-51.

[2] Neudecker B J, Dudney N J, Bates J B. 'Lithium-Free' Thin Film Battery with in Situ Plated Li Anode [J]. J. Electrochem. Soc., 2000, 517:147-152.

[3] Kelley S C, Deluga G A, Smyrl W H. Miniature Methanol/Air Polymer Electrolyte Fuel Cell [J]. Electrochemical and Solid State. letters, 2000, 3(9):407-409.

[4] Akalin T, Danglot J, et. al. IEEE Trans. Ant. Prop. [J], 2003,51:3137.

[5] Zhou L, Li H Q, Qin Y Q, Wei Z Y. Directional Emissions from Subwavelength Metamaterial-Based Cavities [J], Applied Physics Letters 2005,86:101101.

[6] Sievenpiper D, Zhang L, Broas R, Alexopolous N G, Yablonovitch E. IEEE Trans. Microwave Theory Tech[J]. 47, 2059, 1999.

[7] Sievenpiper D F, Angeles L. University of California: Ph. D. Thesis[D], 1999.

[8] Sievenpiper, Yablonovitch E. Eliminating Surface Currents with Metal-Lodielectric Photonic Crystals [C]// IEEE MIT-S Symp. Dig., 663-666, June 7-12, 1998.

[9] Yang F, Rahmat-Samii Y. IEEE Trans. Antennas Propagat. [J], 51, 2691, 2003.

[10] Qian Y, Sievenpiper D, Radisic V, et al. A Novel Approach for Gain and Bandwidth Enhancement of Patch Antennas [C]// IEEE Rawcon. Symp. Dig., 22 1-224, Aug. 9-12, 1998, Colorado Springs, CO.

黄　闯(1978-),男,博士研究生,研究方向为 RF MEMS,chuang_huang@sjtu.edu.cn

陈　迪(1961-),男,教授,博士生导师,研究方向为准 LIGA 技术,dchen@sjtu.edu.cn