文章编号　1004-924X(2009)06-1300-06

浮动电极型单向声表面波驱动器的设计与制造

张俊峰[1]，李以贵[1]，惠　春[2]

(1. 上海交通大学 微纳米科学技术研究院 薄膜与微细加工技术教育部重点实验室
微米纳米加工技术国家级重点实验室，上海 200240；
2. 上海交通大学 生命科学技术研究院，上海 200240)

摘要：考虑声表面波驱动器直接驱动工作物体，能量损失小，传动误差小，且尺寸小，噪声低，抗电磁干扰等特点，基于 MEMS 技术并采用在 $LiNbO_3$ 基底上加工微型电极的方式制作了一种声表面波微驱动器。为了更加有效地控制驱动方向，提出了一种新型叉指结构，即浮动电极型单向换能器，然后利用 ANSYS 软件，对声表面波换能器进行了优化设计和分析，制作出了孔径尺寸为 5 mm，电极厚度为 0.8 μm，指宽为 6.7 μm，周期为 80 μm 的浮动电极型单向换能器。该声表面波驱动器比以往的驱动器具有更高的谐振频率(接近 50 MHz)和更有效的方向可控性，从而有助于微光学控制系统的进一步微型化和可控化。

关　键　词：声表面波驱动器；微机电系统；浮动电极型单向换能器

中图分类号：TB51；TM384　　**文献标识码：**A

Design and fabrication of floating electrode unidirectional SAW actuator

ZHANG Jun-feng[1], LI Yi-gui[1], HUI Chun[2]

(1. *National Key Laboratory of Micro/Nano Fabrication Technology, Key Laboratory for Thin Film and Microfabrication Technology of the Ministry of Education, Research Institute of Micro/Nano Science and Technology, Shanghai Jiao Tong University, Shanghai* 200240, *China*;
2. *College of Life Science & Technology, Shanghai Jiao Tong University, Shanghai* 200240, *China*)

Abstract: Surface Acoustic Wave(SAW) actuators have been dramatically required for a micro actuator not only due to their direct driving objects, low energy losses and drive errors, but also their higher work frequencies, shorter SAW waves, small dimensions, and low noises. In this paper, an applicable (SAW) micro actuator is implemented by fabricating microelectrodes on a $LiNbO_3$ substrate and by using MEMS technologies. In order to control the drive direction more effectively, a new type of IDT, Floating Electrode Unidirectional Transducer (FEUDT) is developed and the optimal designs are proposed and compared with others by ANSYS. The dimensions of the FEUDT are 5 mm in the aperture size, 80 μm in the pitch, 6.7 μm in the strip width, and 0.8 μm in the thickness. In comparison with other types of SAW actuators, the floating electrode unidirectional SAW actuator has a higher frequency vibration near to 50 MHz and more effectively controllable drive direction ability,

Received date: 2009-01-20; **Revised date:** 2009-04-30.

Foundation item: Supported by the National Natural Science Foundation of China (Grant No. 60777016)

which will be very useful for micro optical controlling systems in microminiaturization and controllability.

Key words: Surface Acoustic Wave(SAW) actuator; MEMS; Floating Electrode Unidirectional Transducer(FEUDT)

1 Introduction

Recently micro optical controlling systems have been used for the optical communication networks. It is specifically desired that the fabrication for each device is simplified in order to integrate lots of small devices. As one of its important components, the micro actuator has many applications, such as optical switching and optical cross-connects[1-3]. The Surface Acoustic Wave(SAW) micro actuator is a device to produce drive power through frictional force by a Rayleigh wave, which is a type of DAW. The conventional SAW actuators are made of fixed bidirectional IDTs, which work at about 10 MHz on piezoelectric materials and have subnanometer positioning[4-5]. To miniaturize the actuator size and control the drive direction more effectively, we design a Floating Electrode Unidirectional Transducer(FEUDT) on the piezoelectric substrates, which will be operated by a higher frequency up to 50 MHz. The driving frequency is more than 4 times higher than that of the transducers used in the conventional SAW motors. Therefore, the vibration amplitude of the floating electrode unidirectional SAW device is more than 4 times smaller than that of under the same vibration velocity conditions. Instead of conventional SAW actuators, floating electrode unidirectional SAW actuators enable the high-output force and high-speed characteristics. Moreover, they have the advantage of the high-resolution direction drive in the micro optical controlling systems. Even the miniaturized SAW actuator with 100 MHz drive frequency was reported[6], it also can not avoid the immanent disadvantage of bidirectional IDT, i. e. the high insertion loss. On the contrary, the unidirectional transducer has the advantage of the low-loss. Due to only a part of the wave energy is used to drive a slider and the rest of the energy is dissipated into absorbers, someone takes use of the energy circulation driving method[7], but the complicated influencing factor will cause the uncertain phase shift to influence the energy circulation. For all of these reasons, it is necessary for us to take a research on the floating electrode unidirectional SAW actuator.

2 Theoretical analysis

The structure of FEUDT is shown in Fig. 1. It makes use of floating electrodes to obtain directivity[8]. This transducer has six electrodes per period. These electrodes all have a constant width and spacing. Electrodes 1 and 4 are fixed on the bus bars and connected to the RF electrical power, electrodes 2, 3, 5 and 6 are floating, and electrodes 2 and 5 are connected to each other. The fixed electrodes and the connected floating electrodes play an important role in the stimulation of the SAW. This makes the center of stimulation λ/12 away from the center of reflection, and the amplitude of leftward SAW is not equal to the rightward. As shown in Fig. 2, the

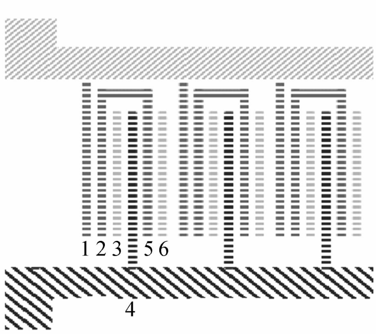


Fig. 1 Structure of FEUDT

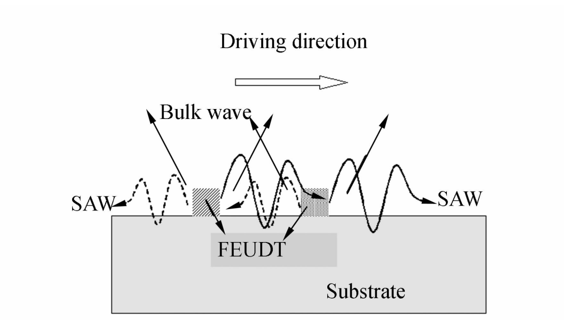


Fig. 2 Principle of FEUDT on 128° *Y*-*X* $LiNbO_3$ substrate

bulk wave and SAW are created by stimulating the FEUDT on the substrate. When bulk wave scatters to the space or the deeper substrate, only the SAW propagation on the surface of piezoelectric materials is useful to the drive. We can see the real line SAW to the right has greater amplitude than that of the dotted line SAW to the left. Consequently, the feature of FEUDT results in directivity to the right.

3 Experimental setup

3.1 Design of the FEUDT

To get a better directivity, this section presents an FEUDT model mentioned above, the SAW actuator is made of a 128° *Y*-rotated and *X*-propagation $LiNbO_3$ substrate with a diameter of 7.5 cm(3 in) and a thickness of 500 μm. FEUDTs are fabricated with Al in the thickness of 0.8 μm by means of the vacuum deposition. The dimensions of the FEUDT are $\lambda = 80$ μm in the pitch, 6.7 μm in the electrode strip width and gap i.e. $\lambda/12$, and 5 mm in the aperture. The FEUDT is composed of 4 strip electrode pairs.

3.2 Simulation of the FEUDT

The analysis of FEUDT is very complex, as shown by previous algebraic and numerical work[9]. David proved his simplified quasi-static theory was one of the analytical methods for FEUDT[10]. But they all did not illustrate the relationship between the frequency and the structure characteristics. The modal, static and transient analysis of the FEUDT model with an ANSYS software are carried out by us. The view of the FEUDT model after meshing is illustrated in Fig. 3. Having taken use of the piezoelectricity analysis, the relationship between the frequency and the impedance is obtained. Due to the existence of floating electrodes 3 and 6, the analytical results show that there are two trough of impedances, the corresponding frequencies are 49.7 MHz and 50.2 MHz. Fig. 4 shows the analytical result of the FEUDT model at a frequency of 47 MHz.

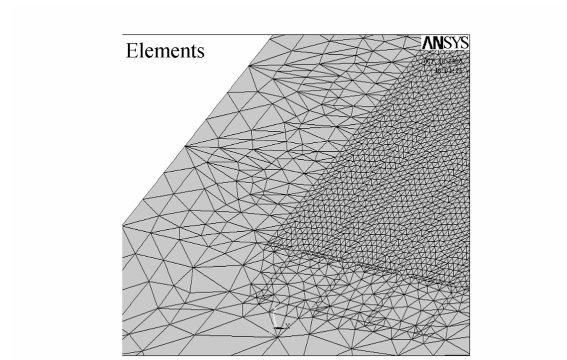


Fig. 3 View of FEUDT model after meshing

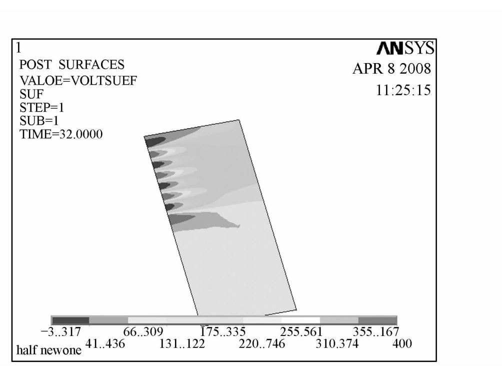


Fig. 4 Analytical result of FEUDT model at frequency of 47 MHz

3.3 Fabrication of the FEUDT

The fabrication of the FEUDT is similar to that of the conventional IDT process. In experiments, the FEUDT is succeeded to fabricate as follows: Firstly, Al is sputtered onto a 128° *Y*-rotated and *X*-propagation $LiNbO_3$ substrate by a radio frequency sputtering with the device of 2440-C made by Comptech Ltd., America. It takes 40 min to get a Al coating in a thickness of

0.8 μm at a RF power of 600 W and with a low temperature no higher than 200 ℃. Secondly, photoresist with a thickness of 5 μm is obtained on the Al by the spin-coating processing and a pattern is transferred from a mask by exposure with the device of MA6/BA6 made by Karl Suss Ltd., Germany. Thirdly, Al is removed in 20 min by a wet etching process at the normal temperature with the certain solution, which is obtained by mixing H_3PO_4, CH_3COOH and HNO_3 with mol ratio 85 : 13 : 2 to prevent the Al electrodes from undercutting. Finally, the rest photoresist is removed from acetone solution with a supersonic wave. Fig. 5 shows the fabricated FEUDTs with different dimensions on trial. The packaged FEUDT is shown in Fig. 6.

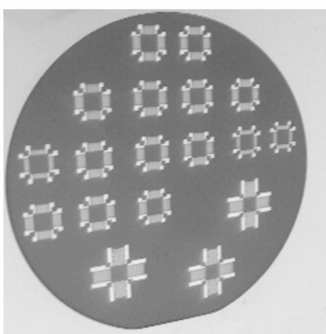


Fig. 5 Fabricated FEUDTs with different dimensions

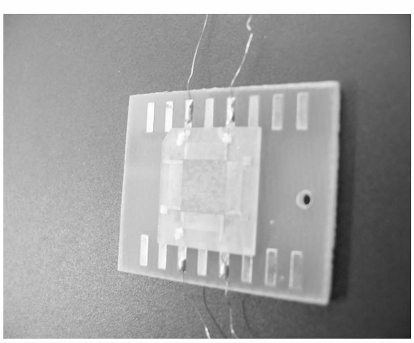


Fig. 6 Packaged FEUDT actuator

4 Experimental results and discussions

When the frequency responses of the FEUDT SAW actuator are measured by means of Impedance/Frequency Analyses Device (Agilent E4991A), the relationship between the frequency and the impedance is obtained, as shown in Fig. 7. 49.7 MHz and 50.2 MHz are the resonance frequencies of the FEUDT actuators. line 1 and line 2 are the results of two different FEUDT actuators. From this diagram, we found that not only the test results were according with the results of simulation, but also the FEUDT devices have a good consistency.

The test system of the floating electrode unidirectional SAW actuator is set up, as shown in Fig. 8. It includes a signal generator, an adjustable power amplifier, a FEUDT actuator and a digital microscope. If we adjust the signal generator around 50 MHz, which is near to the resonance frequency, we will get the maximal driving efficiency.

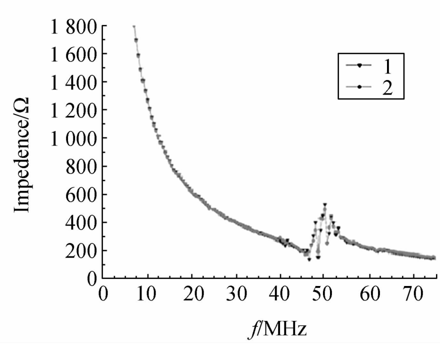


Fig. 7 Relationship between frequency and impedance

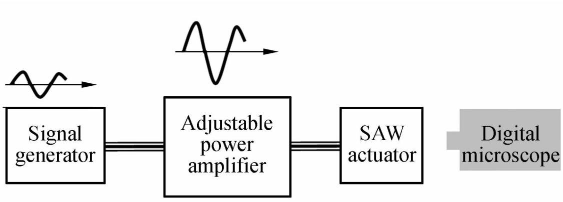


Fig. 8 Test system of floating electrode unidirectional SAW actuator

5 Conclusions

A new kind of floating electrode unidirectional

SAW actuator is presented. The designed FEUDT is simulated and fabricated in the experiment. The FEUDT has not only the feature of high operation frequency near 50 MHz, but also the high-resolution direction drive. From the results of test and simulation, the resonance frequency is finally obtained and used for the unidirectional drive. There are several advantages observed in our experiment. Firstly, the design can obtain the high-resolution direction controlling; secondly, the higher operation frequency would afford further miniaturization; thirdly, the power consumption is lower compared with that of the conventional IDT. This work is still at an early stage and there are more space to improve the following work.

References:

[1] WU Z Z, QIAN X X, LI X Y, *et al.*. MOEMS device and its applications [J]. *Opt. Precision Eng.*, 2004, 12(Supp.): 36-39. (in Chinese)

[2] ZHANG Y, PAN W. Design and analysis of a MEMS horizontal torsion micro mirror with folded springs [J]. *Opt. Precision Eng.*, 2005, 13 (Supp.): 81-85. (in Chinese)

[3] ZHA Y, SUN D G, LIU T G, *et al.*. Rearrangeable nonblocking 8×8 optical matrix switch with extended BANYAN network [J]. *Opt. Precision Eng.*, 2007, 15(1): 50-56. (in Chinese)

[4] KUROSAWA M K. State-of-the-art surface acoustic wave motor and its future applications[J]. *Ultrason.*, 2000, 38: 15-19.

[5] SHIGEMATSU T, KUROSAWA M K, ASAI K, *et al.*. Sub-nanometer stepping drive of surface acoustic wave motor[C]. *IEEE-NANO*, 2003, 1: 299-302.

[6] SHIGEMATSU T, KUROSAWA M K. Miniaturized SAW motor with 100 MHz drive frequency[C]. *IEEE J*, 2004: 482-485.

[7] ASAI K, KUROSAWA M K. Surface acoustic wave motor using an energy circulation driving method[C]. *IEEE Ultrasonic Symp.*, 2001: 525-529.

[8] YAMANOUCHI K, FURUYASHIKI H. New low-loss filters using internal floating electrode reflection types of single-phase unidirectional transducer[J]. *Electron, Lett.*, 1984, 20(24): 989-990.

[9] TAKEUCHI M, YAMANOUCHI K. Coupled mode analysis of DAW floating electrode type unidirectional transducers[J]. *IEEE Trans.*, *UFFC*, 1993, 40: 648-658.

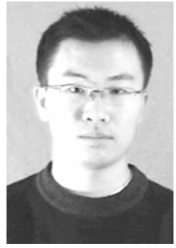
[10] MORGAN D P. Quas-static of floating-electrode unidirectional SAW Transducers[C]. *IEEE Ultrasonics Symp.*, 2001, 48(5): 1289-1297.

Authors' biographies:

ZHANG Jun-feng (1979－), male, Ph. D. of the Research Institute of Micro/Nano Science and Technology, Shanghai Jiaotong University, his researches now focus on the SAW actuation of solid&liquids and the FEM simulation analysis of SAW actuation. **E-mail**: guitar22@163.com

LI Yi-gui (1965－), male, professor of the Shanghai Jiaotong Univiersity, his researches now focus on SAW actuation and microneedle and MEMS industrial application. **E-mail**: ygli@sjtu.edu.cn

HUI Chun, male, professor of the Shanghai Jiaotong Univiersity, his research focuses on the piezoelectric sensors used in biochips. **E-mail**: chhui@sjtu.edu.cn



GAO Yang (1984 —), male, M. S. in Shanghai Jiaotong University, his researches now focus on SAW actuation of solid&liquid , SAW atomization , SAW mixtures, SAW heating applications in biomems. **E-mail**: heartsme@sjtu.edu.cn

●下期预告

基于太阳电池测试的太阳模拟技术

王志明，龚振邦，魏光谱，刘李明

(上海大学 精密机械工程系，上海 200072)

为了提高太阳模拟器的性能，更准确地对太阳电池的特性参数进行测试，在模拟器的光源辐照利用率、辐照均匀度、辐照度与辐照稳定性的控制等进行了研究。选取同轴光学系统结构作为模拟器光学系统，通过改进光学系统的结构排布，增加光积分器的方法，改善光源辐照利用率与辐照均匀度；然后，在分析现役模拟器控制线路的基础上，采用光反馈技术对控制线路进行重新设计，提升系统对辐照度与辐照稳定性的可控性。实验结果表明：新型的太阳模拟器能有效地控制辐照度与辐照稳定性，在直径 250 mm 范围内，标准光强为 1000 W/m^2 的条件下，辐照均匀度指标为 2.5%，辐照的稳定性指标为 1%，较大地提高了太阳模拟器的性能指标。