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Studies on MEMS Vacuum Sensor Based on Field Emission of Silicon Tips Array

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***Abstract*—In this paper, we present our recent works on the fabrication and testing of a novel MEMS (micro electro mechanical systems) vacuum sensor based on field emission of silicon tips array. The prototype vacuum sensor had been fabricated and tested under some conditions. It worked as a diode, having the voltage as the input and field emission current as output, with threshold voltage of approximate 7V and breakdown voltage of about 265V. When the pressure fell from 0.037Pa to 0.0077Pa, the field emission current increased from80.3μA to 96.3μA. This work suggests a potential application of field emission to vacuum sensor.**

Keywords- vacuum sensor; field emission; silicon tip

I. INTRODUCTION

A wide variety of MEMS sensors were suggested to measure the vacuum, with the deeply application of the MEMS technology to vacuum measurement. The measuring mechanisms used in traditional vacuum measurement such as thermal conductivity, gas friction, gas force and ionization couldn't be adopted completely to MEMS vacuum sensor, because of the unique machining technology of MEMS and the sub-mm dimension. But this phenomena has got better, due to the rapid development of micromachining technology in the past several years. More papers concerned to the vacuum sensors based on thermal conductivity, gas friction, gas force and ionization have been presented. And many vacuum sensors such as micro-Pirani sensor [1] based on thermal conductivity, micro-friction sensor [2] based on gas friction and micro-capacitance sensor [3] based on gas force have been fabricated by many researchers, except sensor based on ionization. Some researchers had made some theory calculation in their papers about the vacuum sensor based on ionization and present a reasonable and promising design, but there was no prototype fabricated because of the difficulty of micromachining process [4].

Field emission structures are a promising new electron sources and their development has led to a new field of technology, the vacuum microelectronics [5]. These devices based on field emission typically consist of silicon micro-tips array cathode and metal anode, with a distance of micrometers between the two electrodes. When the anode is supplied with strong enough charge field, the electrons are extracted from silicon tips array. Field emission has been applied to many fields.

We designed a field emission structure like a diode, which has Al (aluminum) as the anode and silicon tips as cathode. This work suggests a potential application of field emission to vacuum sensor. Some similar works have also been done by someone others [6-8].

II. PROCESS AND TESTING SYSTEM

A. Process

The silicon tips array was fabricated on the N-type <100> silicon wafer, which must be cleaned by silicon standard cleaning process before employed it. The fabrication process of silicon tips array was shown in Fig.1.

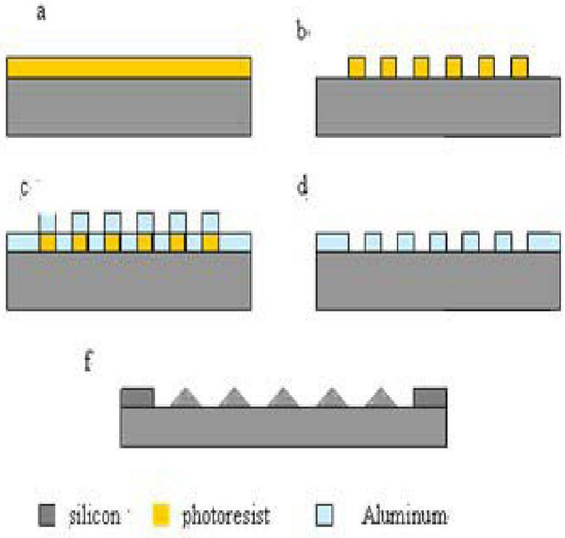

Fig.1 The schematic of fabricating silicon tips array

After cleaning and the 15 minutes pre-baking at 90°C which was used to keep the wafer surface dry and active, the BP212-type photoresist was coated onto the wafer with 3000r/min rotating speed and 30sec duration. Then, there formed 200×42 circular holes array with 4μm diameter, after photolithography process. Post-exposure baking with 15minutes at 135°C was necessary to evaporate redundant water contained in photoresist. With that, 150nm thick aluminum was sputtered onto the wafer by reactive magnetron sputtering process. After lift off process, there formed 200×42 circular aluminum islands array with 4μm diameter as the hard mask. At last, the wafer was etched by RIE (reactive ion etching) [9] with the conditions of W_1=300W, W_2=100W, P=10Pa, SF_6=50sccm, O_2=10sccm and 4-minutes etching time, and got the 200 × 42 silicon tips array with the tip of approximate 50nm curvature diameter. With that, the silicon tips array was sharpened by dry oxidation at 950°C for one

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hour in programming control diffusion furnace system and removal of the grown oxidation by hydrofluoric acid ($HF:NH_4F:H_2O=3:6:10$) for 30 seconds. Fig.2 was shown the SEM of the silicon tips array after oxidation and Fig.3 was shown the silicon tips array after wiping the silicon oxidation off. At last, the silicon tip was approximately 3μm height and about 100nm curvature diameter.

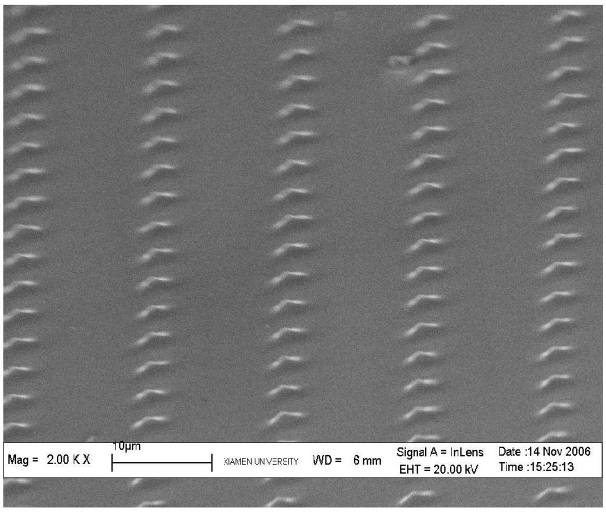

Fig.2 The SEM of the silicon tips array after oxidation

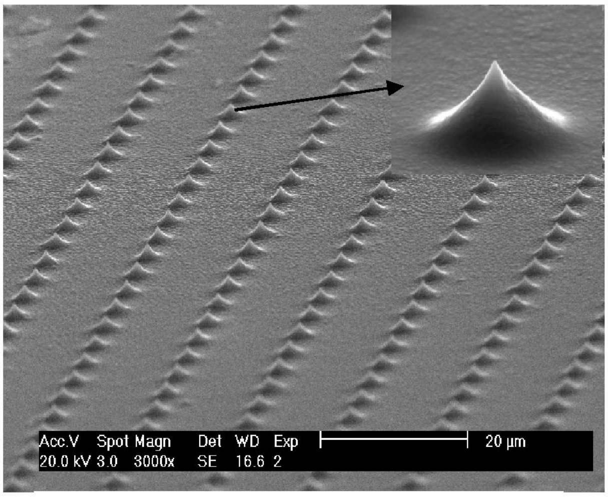

Fig.3 The SEM of the sharpened silicon tips array

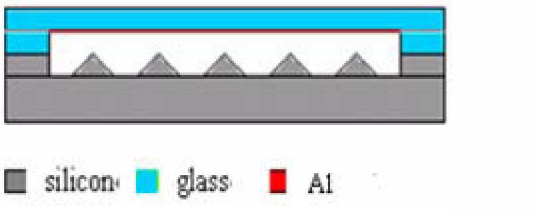

Fig.4 The schematic view of prototype sensor

The anode was fabricated on pyrex-glass. Because the pyrex-glass which has the nearly same expanding coefficient as silicon has a better performance in bonding process, we chose it as the substrate of the anode metal. After cleaning, the pyrex-glass was etched [10-11] by hydrofluoric acid (HF: H2O=1:1) with 9 minutes to form a about 5.4μm-deep gap. After sputtering 30nm-thick Ti (Titanium) aimed at enhancing the adsorbability between the anode metal and the substrate, 300nm-thick Al (Aluminum) because of its excellent conductivity and cheap price was sputtered into the glass gap to act as the anode metal by reactive magnetron sputtering process.

The glass and silicon wafer was bonded by silicon-glass anode bonding process. Firstly, put the glass and silicon wafer together and aim the silicon tips array at the Al electrode. Then put them onto the work plate of bonder and heat. When they were heated to 390°C, 1000V voltage was brought between the silicon wafer and the glass where the anode was the silicon wafer and the cathode was the glass. After the circuit current fell to zero, switch off the power supply. Then drop the temperature down to surroundings gently. At last, there was a about 5μm distance between the anode and cathode. The last structure was shown in Fig.4.

B. Testing System

The testing system composed of vacuum testing chamber, power supply, multimeter and vacuum pump. The schematic view of testing system was shown in Fig.5. The prototype sensor was fixed to vacuum chamber which was made of stainless steel. The field emission current was measured by Multimeter made by Agilent which could measure the current of nA grade. We test the prototype sensor at different charge field and pressure, and found something.

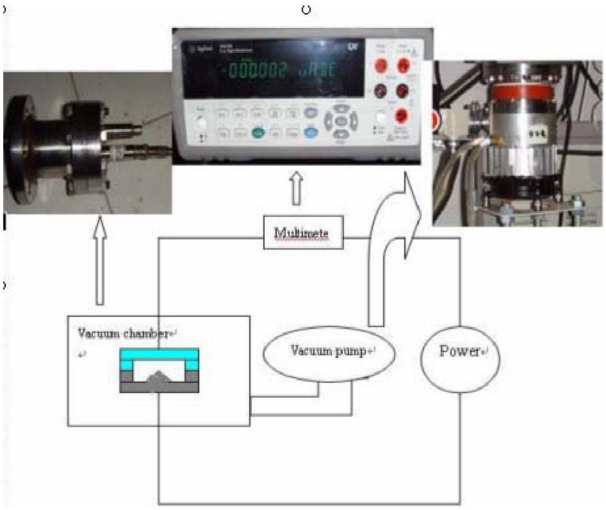

Fig.5 The schematic view of testing system

III. RESULT AND CONCLUSION

A. Result

As we known, the field emission is described by Fowler-Nordheim plots as follows:

$$J = \left(\frac{AE^2}{(\phi t^2(y))} \right) \times \exp\left(\frac{-B\phi^{3/2} v(y)}{E} \right) \tag{1}$$

If J is the current density (in A/cm^2) and E is the field strength at the emission area of the cathode electrode (in V/cm), then $A=1.54\times10^{-6}$, $B=6.87\times10^{7}$, and $y=3.79\times10^{-4}E^{0.5}/\phi$. ϕ is the work function of cathode material(in eV). $t^2(y)$ and $v(y)$ are the field-dependent correction factors which are available in tabulated form [12] or can be approximated by $t^2(y)$ =1.1 and $v(y)$ =0.95-y^2[13]. The factor β in reciprocal centimeters is a measurement of the field enhancement given by

$$E = bV \tag{2}$$

V is the applied voltage. The measured current I and the current density J are related via the apparent emitting area α (in cm^2). The equation is below.

$$J = \frac{I}{\alpha} \tag{3}$$

From equation (1), (2) and (3), the following expression can be got:

$$I = aV^2 \exp\left(\frac{-b}{V}\right) \tag{4}$$

Where

$$a = \left(\frac{\alpha A \beta^2}{1.1\phi} \right) \exp(B \times 1.44 \times 10^{-7} \phi^{-0.5}) \tag{5}$$

And

$$b = \frac{0.95B\phi^{3/2}}{\beta} \tag{6}$$

The emission current was measured as a function of applied voltage for the 200×42 silicon tips array with anode-cathode distance of 5μm under the pressure of 6×10^{-3}Pa.

Fig.6 showed two curves "up" and "down" with typical histeresis on the I-V characteristics of silicon tips array[14]. The "up" one was measured with the voltage applied from zero to high, and the "down" one was reverse. In Fig.6, the threshold voltage to produce an emission current value of 1μA was approximately 7V for approximately 0.12nA emission current per tip, and the breakdown voltage was approximately 265V. When the supply voltage was higher than the breakdown voltage, the emission current would increase rapidly, but the voltage increased a little even got down.

Fig.7 showed the characteristic of the field emission current, when the voltage was 100V. With the pressure downed from 0.037Pa to 0.0077Pa, the field emission current changed from 80.3μA to 96.3μA.

B. *Conclusion*

In our work, we suggested a potential application of field emission function to vacuum sensor. The silicon tips array was fabricated and the prototype sensor was finished. The prototype vacuum sensor worked as a diode and was tested in the vacuum testing system.

From the testing result, we could found that the field emission current was correlated with the pressure. When the charge field applied to the sensor was proper, there would get a smooth curve. When the pressure fell off from 0.037Pa to 0.0077Pa, the field emission current increased from80.3μA to 96.3μA. A farther more research is under going now.

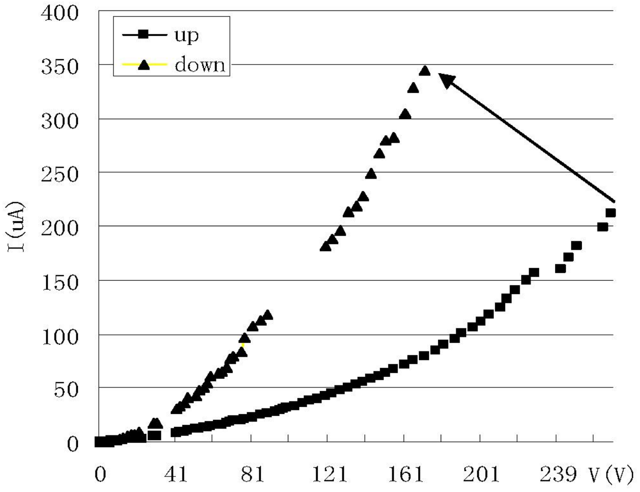

Fig.6 The emission characteristics of tips array

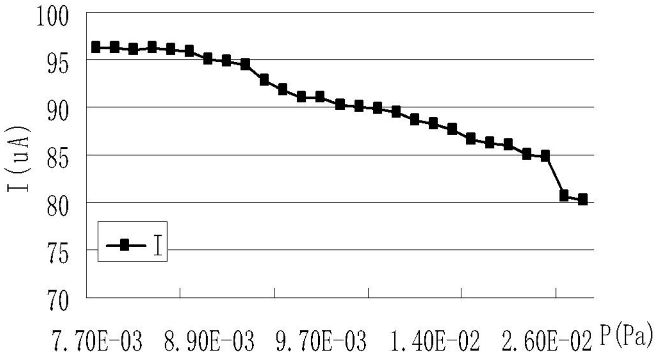

Fig.7 The chart of I-P

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