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Silicon-based Microneedle Array Electrodes For Biopotential Measurement

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Abstract. Biopotential signals in shin tissue reflect the body's healthy conditions. So the measurement of these signals can diagnose whether the body has diseases or not. Traditional technology used to measure these signals results in pain, bleeding, infection, etc. Recently, the microneedle electrodes are used to measure these signals owing to their advantages, such as painless, low cost, easily made, etc. This paper presents a new method to fabricate the silicon-based microneedle array electrodes intended for measuring biopotential signals in the skin tissue. The arrays consist of a 5 mm x 5 mm silicon base with gold film, and 49 silicon needle-type electrodes with gold film in a 7 x 7 array on the silicon base. Each needle is approximately 700 μm long, 70 μm in diameter at the base. The 1mm-thick silicon wafer is cut to form 300 x 300 x 700 μm rectangular micro-column by dicing saw. Then the 5 mm x 5 mm silicon base with these columns is cut off to form the whole substrate. The rectangular micro-columns are etched in the mixture acid solution (HNO_3 and HF) until getting sharp microneedles. Then the surface of the microneedles is sputtered the gold film, the microneedle electrodes are formed. One array of these electrodes exhibits low impedance for measuring biopotential signals.

Introduction

Microneedles have many advantages: small, sharp enough and moderate long to pierce the Stratum corneum of the skin with painless, low cost, etc. Recently, microneedles are used in a wide range of applications. Besides in drug delivery [1], they are used in transdermal allergy testing [2], monitoring biopotential in the skin tissue [3, 4], etc.

For these applications, microneedles may vary in materials, fabrication process, geometry and size. Microneedle arrays can be classified into in-plane structures [5] and out-of-plane structures [6]. In the drug delivery, out-ot-plane microneedle arrays are often used because they can make more drugs into the body than the in-plane type. In the biopotential measurement, the length and impedance are very important because electrodes need to pierce the Stratum corneum of the skin surface and transduce biosignals from the skin tissue to the amplifier circuit.

Materials in microneedles are silicon [7], metals [8], polymers [9]. Silicon is fabricated easily by MEMS process, so the silicon microneedles are widely used. Metals are used for microneedles often by electroplating. Polymers is shaped easily, but very soft. The common and easily fabricated methods for microneedles are wet etching and dry etching. Wet etching is low cost, but it can not control the profile of the microneedle well. However, dry etching can control the profile well, its cost is very high.

In this paper, we present a method to fabricate the silicon-based microneedle array electrodes intended for measuring biopotential signals in the skin tissue. We use dicing saw to cut silicon wafer into electrodes micro-columns, then etch to obtain the microneedles array, last sputter gold film on the surface of the microneedles to get the microneedle array electrodes.

2. Fabrication of the microneedle electrodes

2.1. Process

Fig.1 illustrates the process flow for the fabrication of the microneedle array electrodes. (a) One mono-crystalline thick silicon wafer are spinned positive photoresist on its two sides. (b) A dicing saw is used to cut the enough depth of the micro rectangular micro-columns in the wafer. (c) The mixture acid solution (HNO_3 and HF) is used to isotropic and anisotropic wet etch these micro-columns to form sharp microneedles. (d) Gold film is sputtered on the microneedles to form the microneedle electrodes.

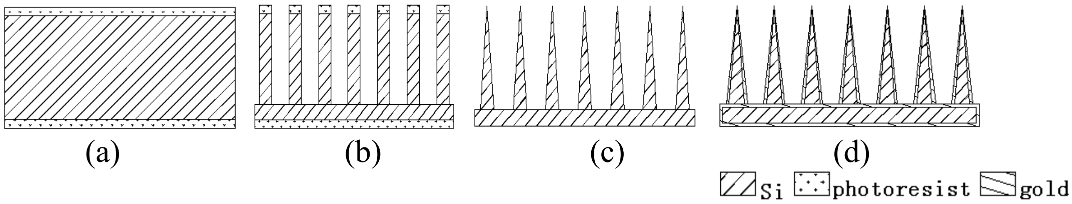


Fig.1 The process of the microneedle electrodes.

2.2 Dicing micro-columns

First, micro-columns are fabricated by dicing saw. The 1mm-thick single crystal (100) N-type silicon wafer which is spinned photoresist on its two sides is cut to form 300 x 300 x 700μm rectangular micro-column by dicing saw. Then the 5 mm x 5 mm silicon base with these micro-columns is cut off to form the whole substrate. Fig.2 shows the schematic diagram of the micro-columns and the SEM image of a micro-columns array after dicing.

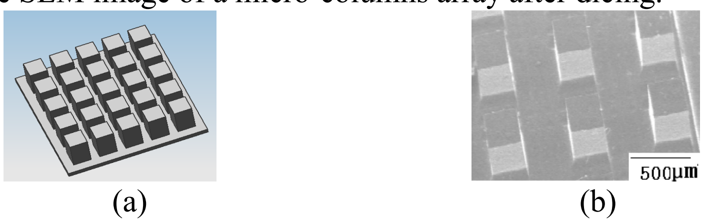


Fig.2 The schematic diagram of the micro-columns and its SEM image after dicing.

2.3.Etching and sputtering

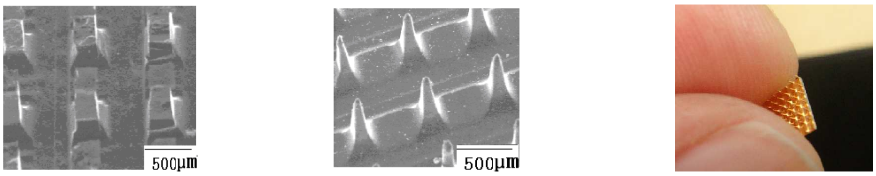
The rectangular micro-columns are transformed into microneedles by isotropic and anisotropic wet etching in mixture acid solution (65%HNO_3 and 40%HF, the ratio in volume is 19:3). This etching process includes two steps: dynamic etching and static etching [10,11]. In the dynamic etching, the mixture acid solution is stirred at 500 rpm and the micro-columns array which is immersed in the mixture acid solution in the holder is also rotated at 20 rpm. During this etching, the size of the micro-columns reduces quickly, and the etching rate is more than 20μm/min. The dynamic etching is carried out 4 minutes. The SEM image after the dynamic etching shows in Fig.3 (a). During the static etching, neither the mixture acid solution nor the micro-columns array is rotated. The static etching lasts 12 min for etching the top of the micro-columns in order to get sharp tips. The SEM image after static etching shows in Fig.3 (b).

The following two equations illustrate the etching reaction taking place to etch silicon [12]:

$$\mathrm{Si}+4\,\mathrm{HNO_3}\rightarrow \mathrm{SiO_2}+2\,\mathrm{H_2O}+4\,\mathrm{NO_2} \tag{1}$$

$$\mathrm{SiO_2}+6\,\mathrm{HF}\rightarrow \mathrm{H_2SiF_6}+2\,\mathrm{H_2O} \tag{2}$$

HNO_3 oxidizes silicon to form a SiO_2 layer and HF is used to dissolve the SiO_2 layer. After etching, the surface of the microneedles is sputtered the gold film to form microneedle electrodes. The image of a microneedle array electrodes shows in Fig.3 (c).



(a) (b) (c)

Fig.3.SEM image of the fabrication result. (a) SEM image after dynamic etching, (b) SEM image after static etching, and (c) Microneedle array electrodes image after sputtering gold film.

3. Result and Discussion

The impedance of microneedle array electrodes is measured in the 0.9% saline solution with the instrument of CHI660C. The result shows in Fig.4. In 0.1~100Hz, the impedance of the microneedle array electrodes is 1.99~2.52Ω.

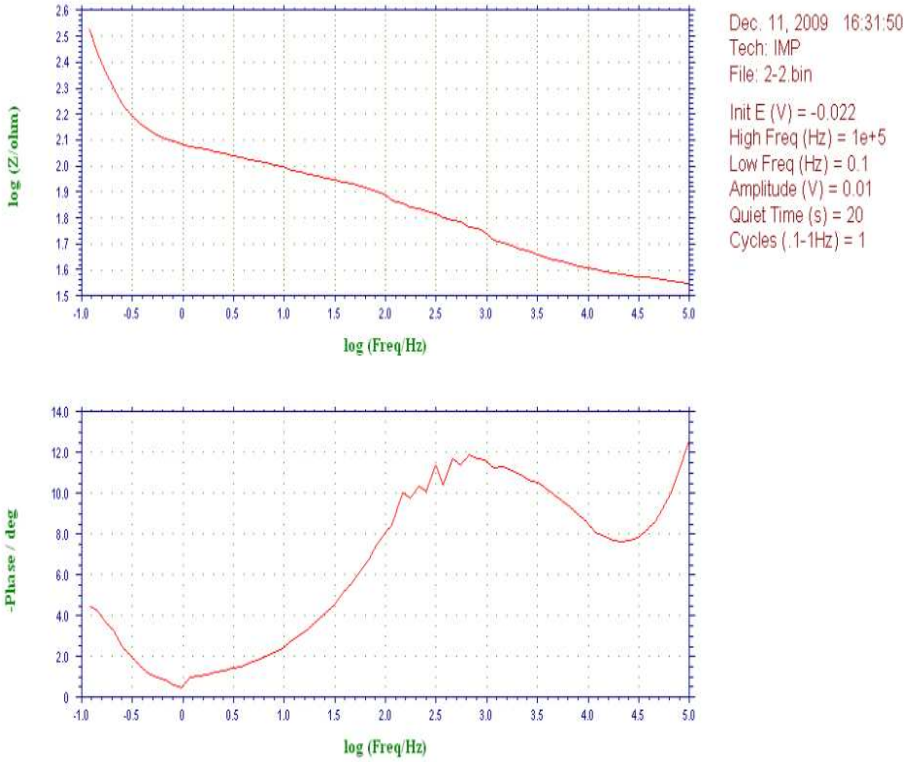


Fig.4.The impedance and phase diagram of a microneedle array electrodes.

During the dicing process, if the blade moves quickly, the surface of the micro-columns is rough, so its speed should be controlled well. In our experiment, its speed is 30,000 rpm. The positive photoresisit coated on the silicon wafer can improve the rough during the dicing.

In this paper, the mixture acid solution is HNO_3 (65%) and HF (40%). The etching rate needs to discuss. First, we used some micro-columns arrays to test. The test micro-columns is 350x350x700 µm, the center spacing is 350 µm. Without rotating the mixture acid and the wafer, the etching rate is slow and the uniformity is bad. So in the first step, the mixture acid solution and micro-columns should be rotated to reduce the microcolumns' size quickly. With the different concentration of the HNO_3 and HF, the etching rate of the micro-columns is different. Fig.5 illustrates the different etching rate with different concentration of the HF. The more part of the HF, the more etching speed is. In our experiment, the dynamic etching rate with 20~60 µm/min is good. The moderate recipe is HNO_3:HF=19:3. By this recipe, the dynamic etcing rate is more than 20 µm/min ,the static speed is about 5 µm/min.

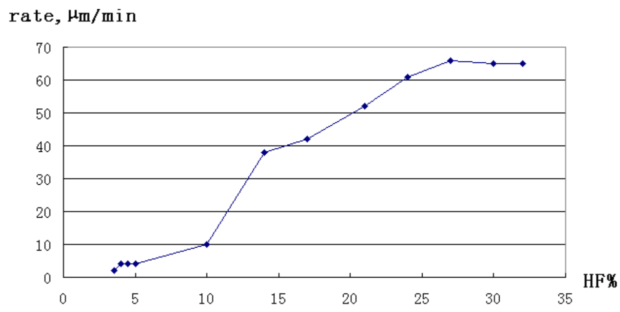


Fig.5.The etching speed with the concentration of HF in the mixture acid solution

4. Conclusions

We find one method to fabricate the silicon-based microneedle array electrodes intended for measuring biopotential signals in the skin tissue. This method is very flexible enough to control the size of microneedle electrodes and the number of electrodes on the array. This array is fabricated easily and low-cost.Also it has sharp tips to pierce the Stratum corneum of the skin surface and has low impedance to transduce biosignals from the skin tissue to the amplifier circuit.

Acknowledgments

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