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Sensors and Actuators A 130–131 (2006) 609–615
SENSORS AND ACTUATORS A PHYSICAL
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Fabrication of pyramid shaped three-dimensional 8 × 8 electrodes for artificial retina

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Received 25 October 2005; received in revised form 10 November 2005; accepted 25 November 2005
Available online 19 January 2006

Abstract

This paper presents a pyramid shaped three-dimensional 8 × 8 multi-electrode array for artificial retina application. Each electrode features a pyramid shape composed of one (1 1 1) plane and two vertical planes. The cone angle between the (1 1 1) plane and the vertical plane is 19.5°, which is the sharpest angle, as far as reported [1–7]. The sharp pyramid shaped electrode is capable of penetrating the inner limiting membrane with minimal invasiveness, which in turns can stimulate retina cells more effectively than a square shaped two-dimensional electrode. The characteristic measurement of impedance magnitude and the phase shift of a single electrode are 1.19 MΩ and −80.8° at 1 kHz, respectively. Although the single three-dimensional electrode covers only 145 μm^2 of the base area, its magnitude of impedance is as low as a 900 μm^2 area two-dimensional electrode indicating that the three-dimensional electrode has higher signal-to-noise ratio than the two-dimensional electrode.

Keywords: Artificial vision; Microelectrode array; Three-dimensional electrode

1. Introduction

Retinal degenerative diseases such as age-related macular degeneration (AMD) and retinitis pigmentosa (RP) give currently great pain to tens of millions of people worldwide. A normal photoreceptor cells initiate the neural signal process in response to light. However, this phenomenon cannot be observed among the RP and AMD patients who are in the advanced stages. In some cases, they could lead to blindness. In the past several decades, retinal prosthesis has been primarily focused on the replacement of the degenerative photoreceptor cells with a microelectronic chip. Humayun et al. have demonstrated that the visual function of such RP patients can be recovered to some degree by the proper electric stimulation of degenerated retinal neurons [8]. These results clearly support the possibility of recovering vision by the neuroprosthetic implantation approach [8].

Considering the distal gap between the retinal neuron and the two-dimensional electrode, the two-dimensional electrode may act as a hindrance in effectively stimulating the damaged retinal neurons. Therefore, it is expected that three-dimensional electrodes will penetrate the inner limiting membrane, and then stimulate the damaged retinal neurons more effectively than the two-dimensional electrodes as shown in Fig. 1. Mokwa et al.

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doi:10.1016/j.sna.2005.11.070

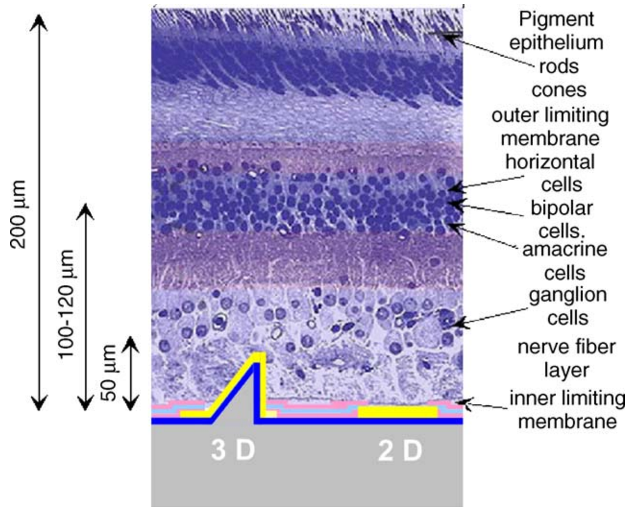

Fig. 1. Comparison between three-dimensional and two-dimensional electrode.

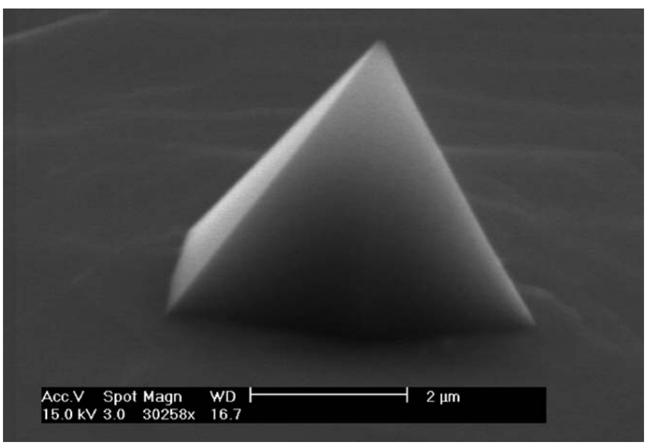

Fig. 2. Three-sided pyramid shaped silicon tip bounded by three {1 1 1} planes.

have fabricated pillar structured three-dimensional electrode for artificial retina [9]. In this paper, we present a pyramid shaped three-dimensional 8×8 multi-electrode array with a 120 μm pitch.

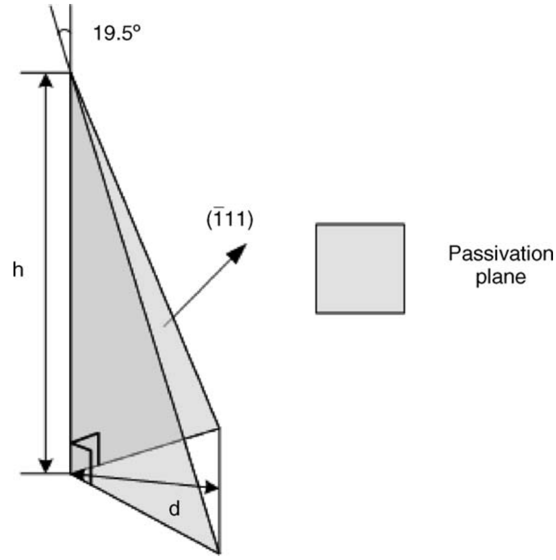

Fig. 4. Schematic representation of single electrode.

2. Design concept

Silicon has eight {1 1 1} planes, which have the slowest etch rate in various aqueous alkaline etchants. This fact has been widely utilized in (1 0 0) silicon for fabricating pyramid shapes, by exposing four of the eight {1 1 1} planes that are tilted at 54.7° from the wafer top [1–4]. In this case, the total pyramid cone angle is 109.4°. There has been some reported cases that pyramid shapes were fabricated on (1 1 0) [5] and (1 1 1) [6,7] silicon wafers. Fig. 2 shows a pyramid shape that consists of three intersecting {1 1 1} planes on (1 1 1) silicon. The total pyramid cone angle is 54.7°. On (1 1 1) silicon wafer, six {1 1 1} planes intersect the (1 1 1) plane at ±19.5°, as shown in Fig. 3. Therefore, the pyramid shape in Fig. 2 is the sharpest tip that can be fabricated using only {1 1 1} planes. A sharper structure can only be achieved using one (1 1 1) plane and two vertical planes on (1 1 1) silicon wafer as reported in our previous research [7]. In this case, the cone angle is 19.5°.

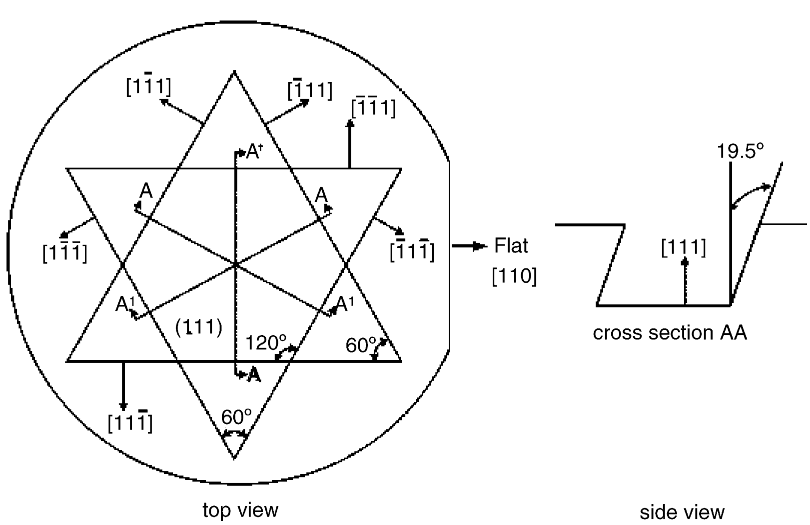

Fig. 3. The cross section of six {1 1 1} planes that intersect the (1 1 1) wafer top plane.