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Design and fabrication of stiff silicon probes: A step towards sophisticated cochlear implant electrodes.

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Abstract

Cochlear implants work on the principle of direct electrical stimulation of the auditory nerve. It has advantages to replace their traditional wired electrodes by a high-density thin-film multielectrode stimulation array which is relatively small in dimensions, stable, resistant to electrolysis, and offers batch fabrication capabilities with good electrical and mechanical properties. In this paper a development review of cochlear implants (CI's) along with the fabrication of stiff silicon probes using silicon micromachining is described. The initial design for a new microelectrode array is described with microfabrication steps for stiff silicon probes which is a step towards a future flexible CI-electrodes . These stiff probes were fabricated in order to study the problems involved in fabrication and the behaviour of the probes when inserted perpendicular to the auditory nerve. The probes were fabricated with lengths ranging from 3.5 mm to 10.5 mm with thickness between 60 to 70 microns.

Keywords: Cochlear auditory prosthesis, electrical stimulation, stiff probes, silicon micormachining.

1. Introduction

Cochlear Implants (CI's) are auditory prostheses, which have become a standard rehabilitation technique for severely to profound hearing impaired children and adults. The main success of CI is in conveying speech information, especially in silent conditions. Perception of more complex signals, such as music or speech in background noise still needs improvement. The device is implanted under the skin and includes an electrode array (with 12-22 stimulation sites in commercial devices) inserted into the scala tympani (ST) of the non-functional inner ear. It directly stimulates the auditory nerve, thereby

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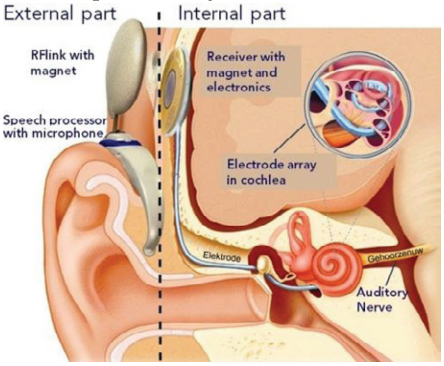
bypassing the peripheral auditory system. An external detachable speech processor comprises of a microphone, a small battery powered signal processing device, and a magnet which holds in position the induction coil responsible for transmitting the processed signal through the skin to the implant (Fig. 1). Current multichannel devices successfully make use of the so-called tonotopy in the cochlea and the auditory nerve by conveying low-frequency information to more apical contacts in the cochlea, and high-frequency information to more basal ones (Fig. 2) [1]. Previously the electrodes were fabricated with copper and gold wires, but the modern electrodes are all made of platinum or platinum-iridium alloy. The process of stimulation is performed by the stimulation sites present on the microelectrode array. Unfortunately, the limited spatial resolution due to spread of current in the highly conductive perilymph in the ST imposes a major limitation to the encoding of pitch in present devices.



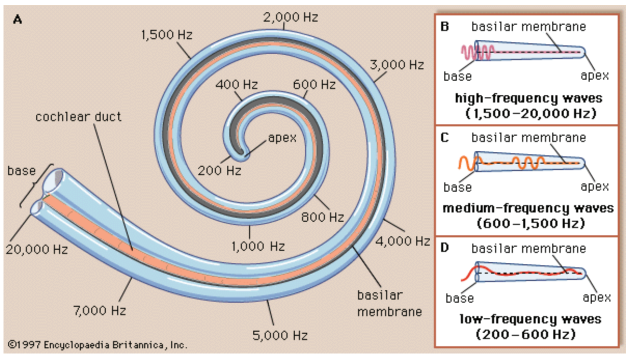


Fig. 1. Human ear with the implant. Fig. 2. Analysis of sound frequencies inside the cochlear duct.

These arrays are hand-fabricated and assembled from bundle of fine wires which are coated with biocompatible material. There are several disadvantages of microelectrode arrays fabricated from fine wire bundles. It's a difficult task to manufacture repeated fine wire bundle microelectrode arrays with similar dimensions maintaining their stability and properties. The dimensional tolerances of the arrays are beyond the limits to achieve with these fine wires. Also the electrical impedance of each microelectrode depends primarily on the exposed metal area, necessitating metal contacts (stimulation sites) to be attached to the wires. As seen from Fig. 3 for safe stimulation the electrode placement inside the ST chamber of the cochlea must also be controlled and maintained in the order of 100-200 micron which is difficult to achieve with the present electrodes. Finally, to aim mechanical and electrical properties of the array using fine wires is only possible to a limited extent.

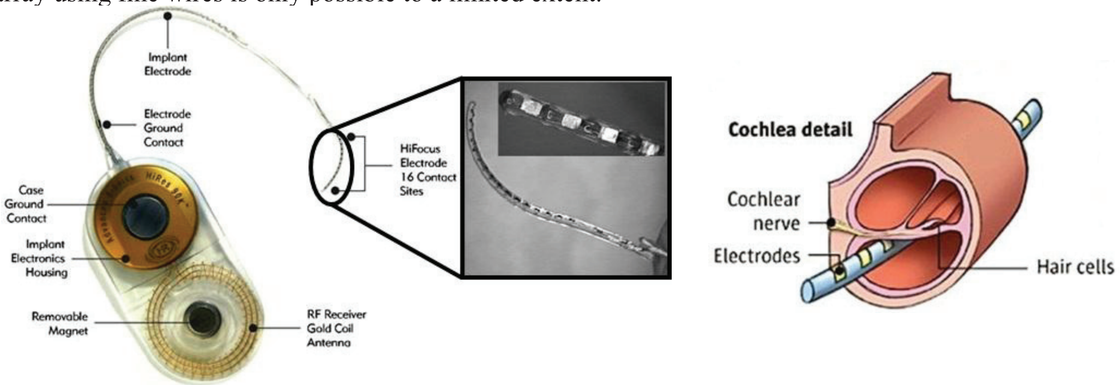


Fig. 3. A closer view to cochlear electrode with its placement (Courtesy: Advanced Bionics Corp.)

The number of electrode leads in the array is limited by both, the available space and the requirement to limit the mechanical stiffness of the array to minimize insertion trauma. Alternatively, the semiconductor industry is equipped enough to batch-fabricate devices in microns and reproducibility in properties. Therefore most of the research groups working in this area shift to photolithographic techniques for fabrication. F. Blair Simmons in 1965 performed the first multichannel auditory prosthesis stimulation study with five stainless steel electrodes insulated with Formvar inserted into the auditory nerve (and not into the ST) and emerging out from cochlea [2]. Interestingly, in recent years the interest in alternative electrodes, to be inserted directly into the auditory nerve, has revived. In recent research conducted at University of Michigan, a batch-fabricated cochlear electrode array with stacked layers of parylene and metal was fabricated by silicon micromachining techniques. The 32-site array contained IrO (Iridium oxide) stimulation sites with a centre-to-centre site spacing of 250µm [3].

This paper describes the design and microfabrication of alternative stiff probes for auditory nerve stimulation. Potentially this array can be modified in the future to become flexible and would allow for ST insertion.

2. Requirements and design considerations for the silicon probes.

Total number of stimulation sites and their placement is essential. We have to decide how much channels need to be put in; with the new fabrication techniques several limitations of current wired implants are eliminated. For proper encoding of the speech signal, at least the frequency range between 200 Hz and 6 kHz needs to be covered. To achieve these it's necessary to facilitate the surgeon to place the array into ST up to an insertion angle of 450º deep without damaging the basilar membrane. A balance needs to be found between the inter contact distance and the obtained distance from the neural tissue. A larger distance to the neurons will increase electrical interaction and limit the benefit of finer electrode spacing. The dimensions of stimulation sites should be such that the stimulating electrical field is optimum at a given stimulus intensity. In addition the stimulation area of stimulation site is to be optimum for safe electrical stimulation. Fulfilment of the requirements for long term stimulation also depends on the selection of a suitable biocompatible material used for coating the electrodes which protects them from degeneration due to the perilymph present in ST.

To investigate to what extent photolithographic techniques can meet the above mentioned criteria we came up with an initial design of a cochlear silicon microelectrode array. This electrode array consists of silicon substrate material with 16 platinum-iridium stimulation sites (Fig 4). The array is of 11 mm length and 50 µm thickness without stimulation sites. These sites are 250 µm in diameter with 500 µm centre distance. At the end of the fabrication process the whole device is coated with a biocompatible material to avoid deterioration of the device. Three different design variations with respect to the stimulation sites are considered. This was to observe the electric charge density distribution at the stimulation points. Our first step towards achieving the final microelectrode was to fabricate the stiff silicon probe (Fig 5).

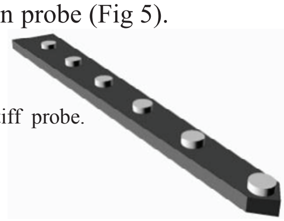


Fig. 5. Schematic view of the stiff probe.

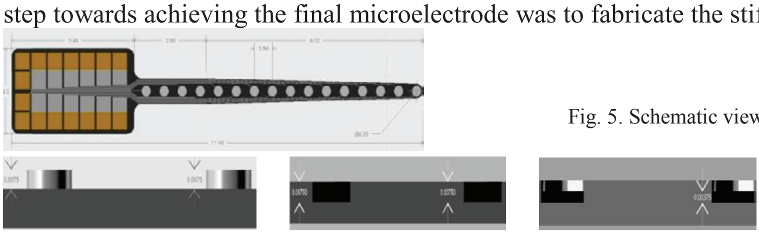


Fig. 4. Initial silicon cochlear electrode design with three design variations.

The idea was to check whether we can attain the specified dimensions through micromachining methods. Another aspect is to check the mechanical stiffness of the device when it is punctured in perpendicular direction to the auditory nerve fibres rather than placing inside the ST of the cochlea. The stiff probe was fabricated with various lengths ranging from 3mm to 10 mm with thickness variations between 50 to 70 µm.

3. The fabrication sequence.

The fabrication step involves lithography, sputtering of aluminium and platinum-iridium metal followed by deep reactive ion etching (DRIE) Fig. 5. The crucial DRIE step in which the machine parameters such as gas flow and temperature has to be tuned in order to achieve required anisotropy and thickness of the probe. Aluminium on front side acts as sacrificial layer during DRIE process. The probes are released by aluminium wet etch. The wet etching bath contains a mixture of phosphoric acid (H_3PO_4), nitric acid (HNO_3), acetic acid (CH_3COOH) and deionised water. Initially in the process, before dicing the structures are coated with parylene to increases stiffness and to act as a biocompatible material in biocompatibility tests. Prior to fabrication simulation results of the stiff probe in the cochlear model gives the stimulation pattern of stimulation sites on the electrode array [4].

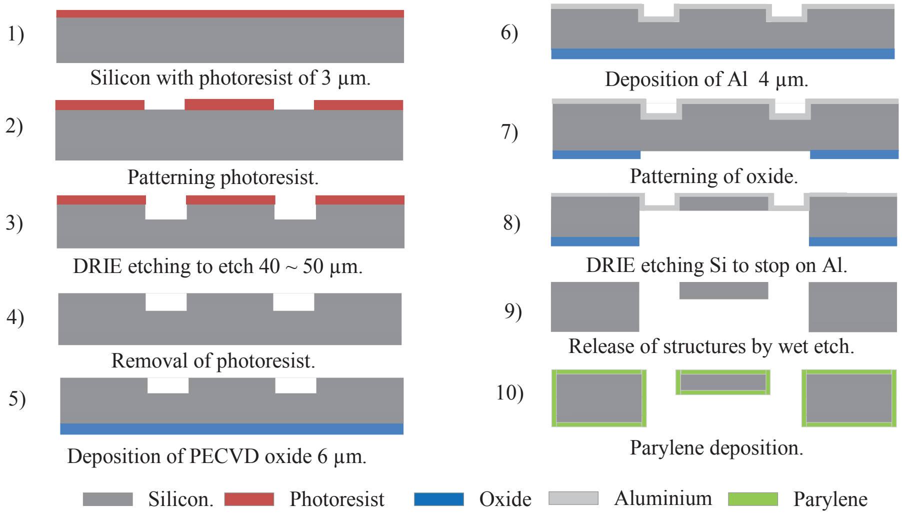


Fig. 5. Fabrication steps for stiff probe without stimulation sites

Conclusions

This work shows the initial results for the new generation of cochlear implants. Work will continue towards fabricating flexible implants for insertion inside the ST of cochlea.

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