A HIGH DENSITY MICROMACHINED ELECTRODE ARRAY FOR AUDITORY NERVE IMPLANTS

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This paper presents the design and fabrication of a novel high density penetrating microelectrode array for auditory nerve stimulation and recording. This array is designed to enable flip-chip bump bonding to a digital processing and wireless communication chip, and thereby eliminating electrical wire interconnects from the system. In the past twenty years, cochlear implants have partially restored hearing function to deaf persons by electrically stimulating discrete populations of the auditory nerve fibers inside the cochlea (Fig. 1) [1]. Current cochlear implants are still limited because the stimulating electrodes are inserted into the scala tympani, relatively far for the cochlear nerve, which increases the impedance while decreasing fidelity. An alternative to cochlear implant is to interface directly with the auditory nerve with penetrating electrode arrays. A more accurate tonotopic representation may be functionally restored if an electrode array with very small contact area is placed directly within the auditory nerve instead of the scala tympani. Microelectrode arrays have previously been fabricated with the intention of implantation in both the central and peripheral nervous systems by multiple research groups [2-5]. These state-of-the-art research-reported electrode arrays have a shank-to-shank distance of at least 400 microns, which is too large for implantation in the 1.5 millimeter diameter of the auditory nerve near the cochlea. Current researches also generally recognize that there remain major technical challenges to realize auditory nerve recording and stimulation, including assembly of the micro electrode arrays, integrating it with CMOS circuitry and the difficulties with interconnects and packaging. In this paper, we will report improvements in the fabrication of the three-dimensional array that will allow a high electrode density without post-process assembly (Fig. 2).

The fabrication process begins with a bump bonding silicon wafer to CMOS chip (Fig. 3a). 750 micron tall pillars are created by bulk micromachining this silicon wafer with deep reactive ion etching (DRIE) (Fig. 3b). At this height the final electrodes can penetrate to the center of the auditory nerve, thereby stimulating and recording from the maximum number of neurons. Since the number of

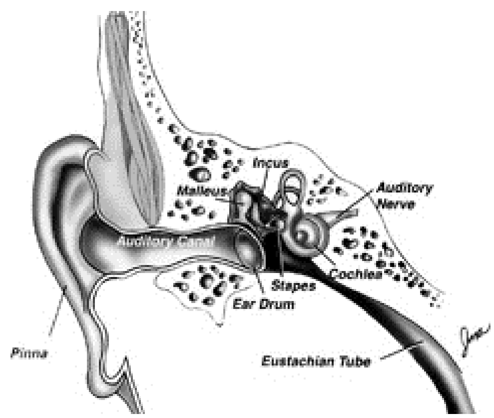


Figure 1. Cross-sectional drawing of the human ear (Source: National Institutes of Health)

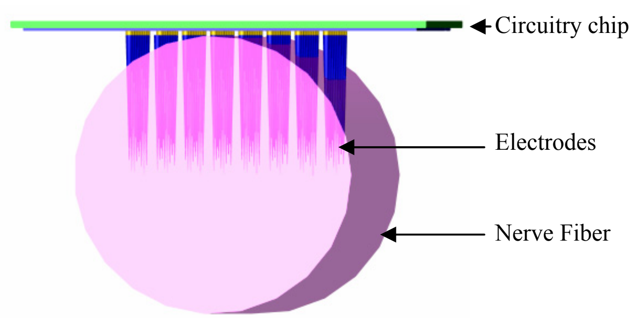
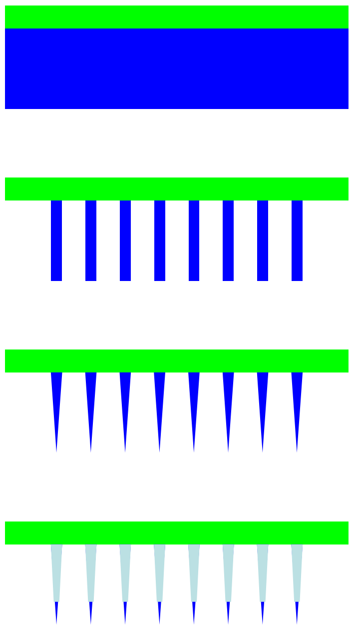


Figure 2. Conceptual model of the electrode array integrated with on-chip circuitry



(a) A doped wafer with COMS chip bonding on the top

(b) DRIE dry etch

(c) Two step isotropic etch

(d) Tips post-process

Figure 3. The process flow of electrode arrays

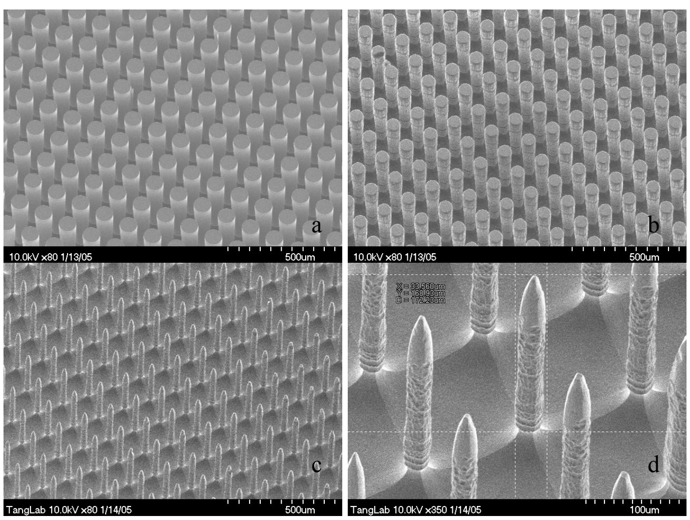


Figure 4. SEM pictures of micromachined electrode array: a. DRIE; b. RIE; c. HNA etch; and d. enlarged electrodes (All pictures are tilted with 30 degree)

stimulated neurons correlates to the fidelity of the implant, this process may elicit better sound sensation than current cochlear implants. Also, DRIE etching uses a photo-definable masking layer that enables a substantially higher density of electrodes than the use of dicing saws [2]. As a result, we are able to achieve more than 100 electrodes in a 1.5 square millimeter area. Each electrode has a diameter of 80 microns and the space between two adjacent electrodes is 50 microns (Fig. 4a). The pillars are sharpened into a needle shape with a two-step isotropic etching, reactive ion etching (RIE) and HNA wet etching (Fig. 3c). Figures 4b, 4c and 4d are SEM pictures of the etching result. The passive array is activated by deposition of iridium to form the electrode tips and conformal coating with a layer of biocompatible Parylene C. The tips are exposed in the final step by selectively removing Parylene C from the tip area. Note that in Figs. 4c and 4d, the surface roughness on the probes can be reduced by refinement of the tip-sharping process. Also, the Parylene C coating will contribute to further reduce or eliminate the surface roughness.

Unique to this design, a CMOS chip fabricated with vender process (top layer in Fig. 3a) will be flip-chip bump bonded to a silicon wafer before the electrode array fabrication. The CMOS chip will have both wireless communication and digital signal processing (DSP) functions for neural recording and stimulation. This on-chip circuitry will also eliminate the need for an interconnection between the electronic chip and the MEMS electrode. The most significant advantages of using of wireless link and on-chip DSP instead of transcutaneous electrical wires include ease of implant surgery, vastly improved mechanical robustness, and enabling chronic implantation with minimal complications.

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