A Micromachined SiO_2/Silicon Probe for Neural Signal Recordings *

SUI Xiao-Hong(隋晓红)**, PEI Wei-Hua(裴为华), ZHANG Ruo-Xin(张若昕), LU Lin(鲁琳), CHEN Hong-Da(陈弘达)

State Key Laboratory on Integrated Optoelectronics, Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083

(Received 23 March 2006)

The development of an implantable five channel microelectrode array is presented for neural signal recordings. The detailed fabrication process is outlined with four masks used. The SEM images show that the probe shank is 1.2 mm long, 100 μm wide and 30 μm thick with the recording sites spaced 200 μm apart for good signal isolation. The plot of the single recording site impedance versus frequency is shown by test in vitro and the impedance declines with the increasing frequency. Experiment in vivo using this probe is under way.

PACS: 84. 37. +q, 07. 07. Df, 68. 55. Jk

Striking progress is made on the use of microelectrodes to record extracellular biopotentials generated electrochemically within individual neurons, which is crucial to study the central nervous system at the neuronal level.[1−3] One of the traditional microelectrodes is small diameter insulated microwire[4] such as stainless steel, tungsten or platinum prevalent at the early stage of system neuroscience. In order to accomplish the functional operation of the neural network, the microelectrode array with tens of uniform electrodes must be adopted. However, due to the difficulty of achieving so many uniform microwires and the feasibility of micro-electromechanical system (MEMS) technology, silicon-based microelectrodes are increasingly popular with neuroscientists. One of the desired features of this technology is the fact that it offers the potential of integrating signal processing circuits on the microelectrode to enhance the signal integrity and signal-to-noise ratio (SNR). Another important advantage is a high-yield, volume-production, and batch-fabrication process with reliable interconnects. In addition, silicon dioxide and silicon nitride are biocompatible with biological tissues. Hence the silicon-based microelectrode array offers several advantages over microwires due to the availability of sophisticated processing techniques and biocompatibility.

A two-dimensional (2-D) micromachined SiO_2/silicon probe is presented. Double metal Ti/Au (titanium/gold) is used as an interconnect wire. Inductively-coupled plasma (ICP) technology defines the probe shape, and the 30-μm-thick probe is obtained by ethylenediamine pyrocatechol water (EPW), which does not attack silicon dioxide or metals used. A sketch of a single probe shank is shown in Fig. 1 with dimensions marked.

The fabrication process of the micromachined probe is described in Fig. 2 and explained as follows. (a) Lower SiO_2 of 20μm is deposited on the (100) silicon wafer by low pressure chemical vapour deposition (LPCVD). (b) Double metal layers of 1000 Å-Ti and 4000 Å-Au are sputtered on the lower silicon dioxide successively and patterned as conductor traces by diluted BHF (NH_4F buffered HF) solution and mixed solution composed of iodin, iodic kalium, and water, respectively. (c) Upper 3000 Å SiO_2 is deposited by plasma enhanced chemical vapour deposition (PECVD) to insulate the metal layer from the outside saline solution. (d) BHF etch is performed to open contact holes (recording sites) at the tip to the Ti/Au conductor traces and bond pads at the rear. (e) With photoresist protecting the probe shank, ICP is used to etch the upper SiO_2 layer until the lower SiO_2-silicon interface, and the lateral dimension of the probe is determined. (f) Back of the bulk silicon is polished to 125 μm using various classes of abrasive and diamond polishing. (g) The 30-μm-thick probe is released by EPW taking one and a half hours at constant temperature of 80°C.

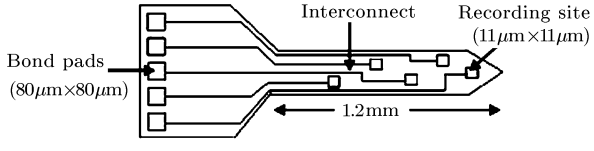


Fig. 1. Illustration of a single probe shank (not to scale).

The SEM images are shown in Fig. 3. It is clear that this probe is composed of 20 μm upper silicon dioxide and 10 μm bulk silicon which is added to configure the probe shaft because of the fragility of silicon dioxide and the flexibility of mono-crystal silicon.

* Supported by the National High Technology Research and Development Programme of China under Grant No 2005AA311030, and the National Natural Science Foundation of China under Grant No 60536030.

** Email: xhsui@mail.semi.ac.cn

©2006 Chinese Physical Society and IOP Publishing Ltd

To realize the recording of the extracellular biopotentials in vivo, the micromachined probe must be thin enough and almost volume-free to be implanted into the brain cortex. Following the procedures outlined in Fig. 2, the developed probe with the thickness of 30 μm is thin enough and implantable for neural signal recordings.

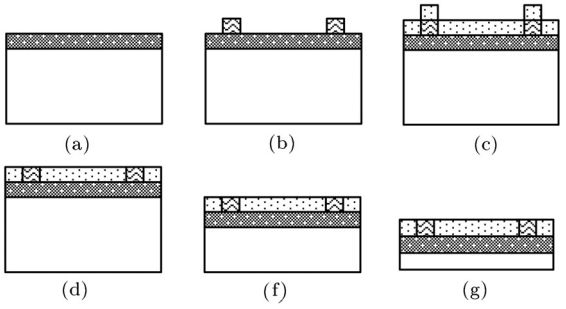


Fig. 2. Flow of fabrication process of the micromachined probe (not to scale).

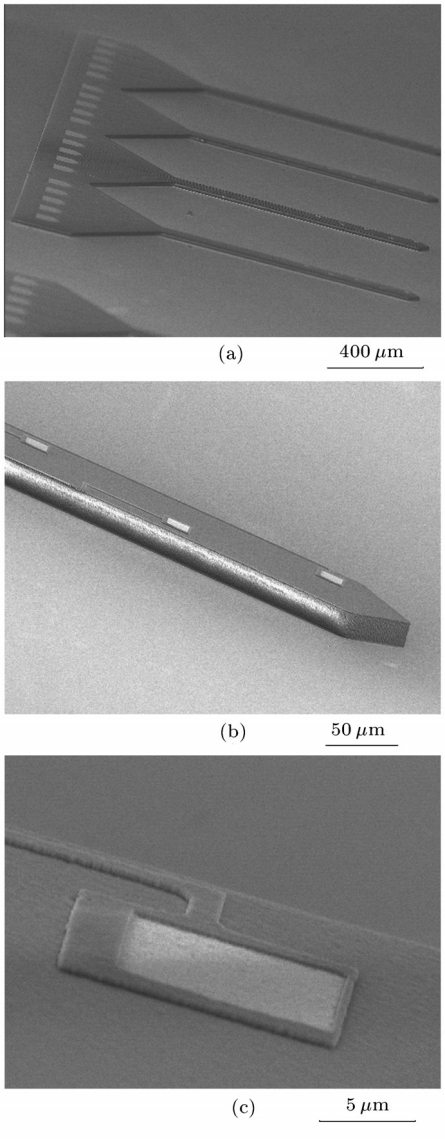


Fig. 3. SEM images of the micromachined probe: (a) Microelectrode array comprising four probe shanks; (b) a single probe shank; (c) recording site (contact hole).

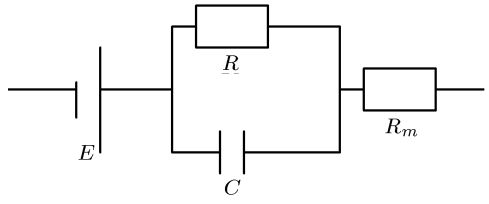


Fig. 4. The equivalent circuit of electrode-electrolyte interface.

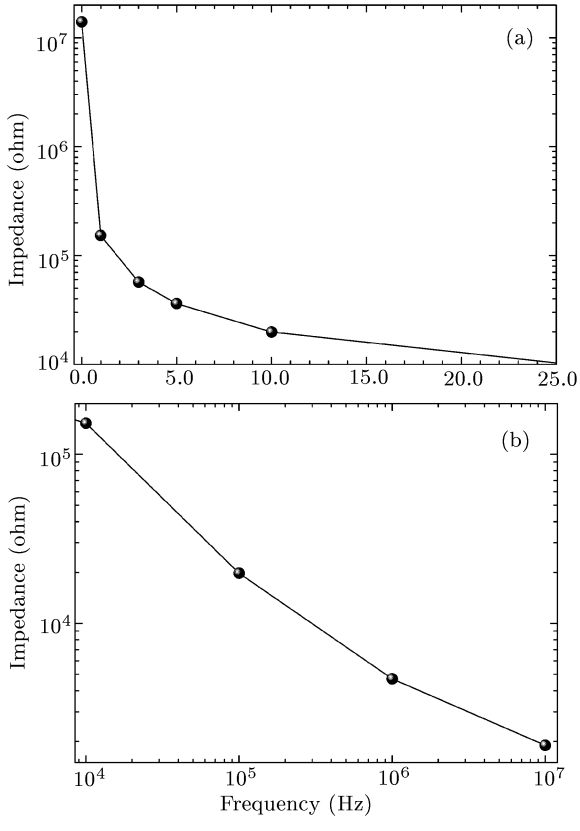


Fig. 5. Impedance versus frequency: (a) linear frequency characteristic; (b) logarithmic frequency characteristic.

In our study, the SiO_2/silicon probe firmly adheres to the print circuit board (PCB) by epoxy parts A and B, and 25 μm diameter golden wires connect the bond pads with traces on the PCB. This will be vertically implanted into the brain cortex to record neural signals through the recording sites. When the microelectrode is implanted in brain cortex, it must interface with tissue, and at every recording site of the probe, an electrode-electrolyte interface comes into being. The equivalent circuit[5,6] of the electrode–electrolyte is shown in Fig. 4. Owing to the oxidation–reduction

effect between metal and electrolyte, a double-charge layer exists at the electrode–electrolyte interface. C and R denote the double layer capacitance and the leakage resistance, respectively. E represents the half-cell voltage at the interface and R_m denotes the negligible Ti/Au resistance here. The characteristics of impedance versus frequency of the recording sites were also tested. From Fig. 4, if R and C are determined, then the impedance decreases with increasing frequencies. Herein in the experiment in vitro, PCB is moved to immerse the tip of the probe in the buffered phosphate solution. Through the pins of PCB, the impedance of any recording site can be determined by Hewlett Packard 4275A, and data are listed in Table 1. Figure 5 shows the impedance versus frequency. It is obvious that the recorded neural signal actually passes through a low-pass filter to arrive at the recording site, which is consistent with the theoretical analysis.

Table 1. Frequency and impedance measured.

Frequency (Hz)	Impedance $\|Z\|$ (Ω)
0	1.4×10^7
1×10^4	1.525×10^5
3×10^4	5.69×10^4
5×10^4	3.61×10^4
1×10^5	1.98×10^4
3×10^5	8.3×10^3
5×10^5	6.2×10^3
1×10^6	4.7×10^3
3×10^6	3.3×10^3
5×10^6	2.9×10^3
10×10^6	1.9×10^3

At present, the probe is being implanted into the rat cortex and the test results will be published soon. As far as this micromachined probe is concerned, there still exist some features to be improved. For example, the probe shank must be further lengthened to 3 mm and thinned to 20 μm or so in order to effectively record neural signals in brain cortex. Despite of 10 μm silicon incorporated, the probe is mainly composed of silicon dioxide and it is not as strong as the silicon probe when implanted into brain cortex. Therefore, another different process will be adopted to realize silicon-dominated probe for implantation.

References

[1] Mohammad M, David B, Benjamin B et al 2003 *IEEE Trans. Neural Syst. Rehab. Eng.* **11** 38

[2] Olsson R H, Buhl D L, Gulari M N et al 2003 *Proc. IEEE 25th Annu. Int. Conf.* **2** 1968

[3] Jit M, Murat O and Nathan J 2005 *J. Neurosci. Methods* **142** 45

[4] Miguel A L N 1998 *Methods for Neural Ensemble Recordings* (Boca Raton, FL: CRC Press) p 3

[5] Cai J X and Zhang W Z 1997 *Biomedical Electronics* (Beijing: Peking University Press) 23 (in Chinese)

[6] Sui X H, Liu J B, Gu M et al 2005 *Chin. J. Semicond.* **26** 2275