# FABRICATION OF ELECTROPLATED NICKEL MULTIELECTRODE MICROPROBES WITH FLEXIBLE PARYLENE CABLE

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## ABSTRACT

We have designed, fabricated and characterized nickel-based multielectrode microprobes with flexible parylene cable employing low-cost nickel electroplating and parylene etching techniques, used for chronic recording of neural signals. Electroplated nickel microprobes, which are encapsulated with parylene for biocompatibility, are more mechanically robust than silicon-based ones. The parylene cable facilitates the connection with external circuit and reduces the packaging requirements. Moreover, the bump-shaped electrodes allow a better contact with neural tissues and consequently improve the signal to noise ratio of recording signals. The impedance magnitude of 25μm×25μm electrodes at 1kHz is ~1.0MΩ. *In-vitro* penetration of the fabricated microprobes into the muscle tissue has been successfully demonstrated.

## INTRODUCTION

Since the neural probe has become a key tool to record action potentials from neurons and stimulate specific biological tissues, a wide range of silicon-based microprobes have been developed [1]. However, these silicon-based microprobes are brittle and easy to break when implanted [2]. The rigid silicon with large stresses can damage the tissue due to the micro-motion of probes, which limits the chronic application of probes. In addition, the fabrication process is normally time-consuming and expensive, because the most in-plane silicon substrate has to be removed using wet etching [3] or DRIE [4].

In general, microprobes made of ductile metals have higher mechanical performance than silicon-based ones in chronic applications. Recently, metal-based microprobes were reported [5-6] to address these issues, but their process and performance are yet to be improved.

Electroplating techniques are widely used in deposition of thick metal films, among which nickel and its alloy are most robust. In order to provide sufficient strength to penetrate the tissue, electroplated nickel can be utilized as a good mechanical support material in probes.

Parylene C, a USP (United States Pharmacopeia) Class VI polymer, is widely used as a coating material for biomedical implants due to its transparency, low process temperature, low Yong's modulus (~3.2GPa) and high electrical and moisture insulation performance. Parylene C, differing from other biocompatible polymers, can be conformably deposited [7] and readily patterned by $O_2$ plasma etching [8]. It is possible to fabricate a complex multilayer flexible structure using these techniques [9-10].

In this paper, nickel-based microprobes with flexible parylene cable are fabricated with inexpensive nickel electroplating and parylene etching techniques and characterized. The proposed multielectrode microprobes, which offer high mechanical performance, biocompatibility and an integrated flexible parylene cable, can be used for recording neural signals.

## DEVICE DESIGN

Fig. 1 presents the design of proposed microprobes and the close-up view of the probe tips. The device consists of three components: electroplated nickel probes, parylene cable and bonding pads.

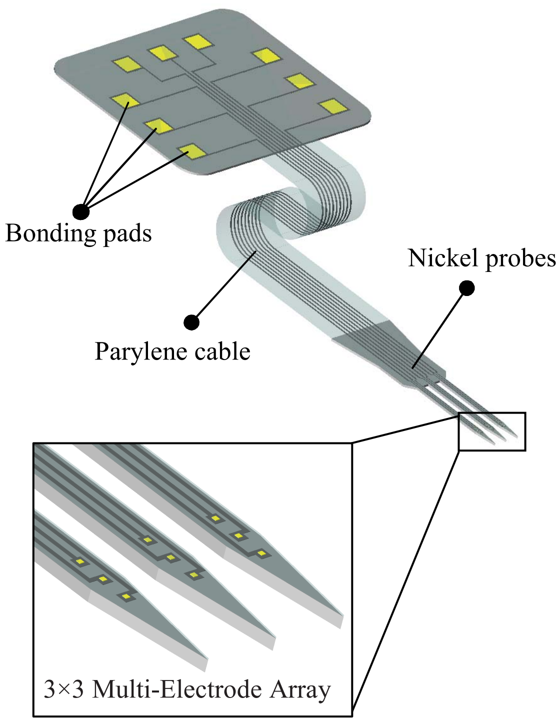


*Figure 1: Schematic view of proposed microprobes with flexible parylene cable.*

### Electroplated Nickel Probes

The proposed microprobes have three shanks, 180μm in width with 140μm spacing. Each shaft hosts three 25μm×25μm recording electrode sites with 120μm center to center spacing and thus 3×3 multielectrode array is obtained. The electroplated nickel probes have sufficient mechanical strength to penetrate the tissue without using other guide tools and have no buckling or fragmentation defects, which easily occurs for silicon. The whole nickel probes are encapsulated with parylene insulator, which ensure biocompatibility for chronic applications.

### Parylene Cable and Bonding Pads

The integrated parylene cable is 80mm long, 9μm thick and 1mm wide, which connects the distal electrodes to bonding pads. All pads arranged on another piece of nickel support are easy to connect with external circuit.

The nickel support is also encapsulated with parylene insulator. The monolithically micromachined cable and bonding pads can be designed in demand and reduce the packaging requirements.

## FABRICATION

A four mask fabrication process flow is developed to fabricate the microprobes, as shown in Fig. 2 schematically.

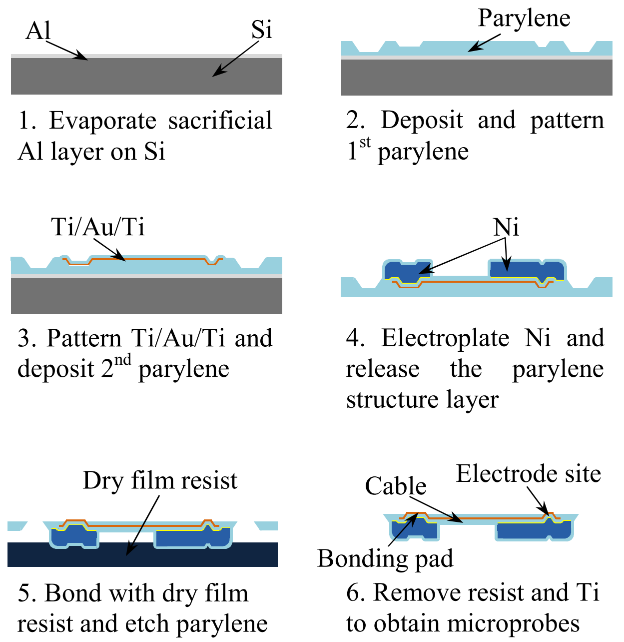


*Figure 2: Fabrication process flow for nickel microprobes*

First, a sacrificial layer of 1µm Al is evaporated on a double-side polished wafer (Fig. 2.1). Next, the wafer is treated with A-174 silane adhesion promoter. The first parylene layer of 16µm is deposited as insulator. This layer is then patterned by a two-step $O_2$ plasma etching (200W, 400mTorr, 53sccm) using RZJ-304-25 and AZ4620 photoresist mask separately: the first step etching depth is 3µm to define electrode sites and bonding pad openings, and then the second 9µm-deep parylene etching is performed to define the area of whole devices (Fig. 2.2). The sloped sidewall results in better step coverage than that of vertical one and final bump-shaped electrodes. More than 5µm-thick parylene remains to prevent the delamination of parylene during the following wet etching processes. The parameters of $O_2$ plasma etching are optimized to obtain a fast etch rate (~0.5µm/min) and good etch uniformity within the wafer. Subsequently, $O_2$ plasma treatment for 30s is performed to improve the adhesion between evaporated metal and parylene. The multi-layered film of 15nm-thick Ti, 300nm-thick Au and 15nm-thick Ti is evaporated successively and patterned by wet etching. Lift-off process is an alternative method to produce the metal layers. The second parylene layer of 3µm is deposited to encapsulate the metal film and thus the parylene-metal-parylene sandwich structure is accomplished (Fig. 2.3).

To construct the mechanical support layer, nickel electroplating technique is used. A film consisting of 15nm Ti and 100nm Cu is sputtered as the seed layer. A 36µm-thick electroplating mould is created using two-step coating of AZ4620 photoresist (800rpm for 61s). Then a hard bake at 120℃ for 30min is used. In order to obtain probes of sufficient mechanical strength, a 40µm-thick nickel structure is electroplated with a current density of 15mA/cm$^2$ at 58℃ for 4.5hr. A modified Watts bath is used to improve the strength of microprobes. The thick photoresist is removed with PRS-3000 photoresist stripper for 10min at 65℃ and the seed layer is flushed using wet etching. The third parylene film of 3µm is conformably deposited to encapsulate the Ni structure for biocompatibility (Fig. 2.4). In order to speed up the removal of the sacrificial layer, the wafer is manually sliced into chips. The chip is immersed in an Al etchant ($16H_3PO_4+2HAC+HNO_3$) at 40℃ for ten minutes and consequently parylene structure film is released from the substrate. The released parylene film is bonded with dry

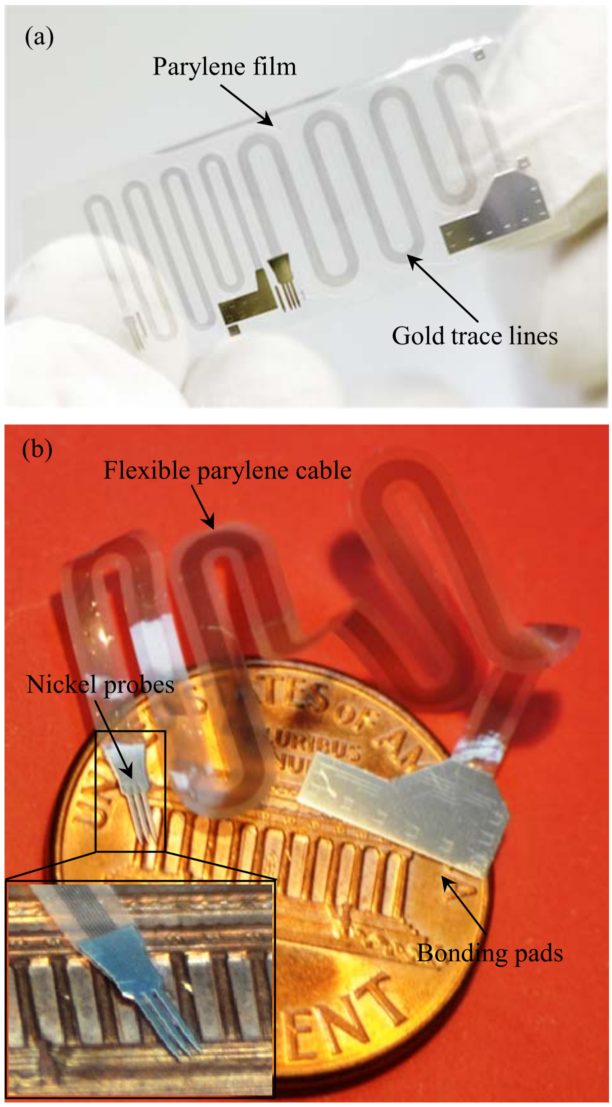


*Figure 3: (a) microprobes in parylene film before released; (b) whole device with close-up view of 3-shaft nickel microprobes.*

film resist using a laminator at 110℃ and mounted on a substrate using a twin adhesive. $O_2$ plasma etching is performed on parylene side until electrode sites and bonding pads are exposed, while devices are separated simultaneously (Fig. 2.5). The Ti layer on electrodes is removed to expose the Au layer and dry film resist is dissolved in acetone. Finally, the micro-probes with flexible parylene cable are achieved (Fig. 2.6).

Fig. 3a shows the microprobes within the parylene film before released using dry etching. The multilayer structure consisting of parylene film, gold interconnection lines and nickel layers is successfully fabricated. No delamination or adhesion problems are found between the two parylene layers and between the parylene layer and metal layers.

The shanks of the fabricated microprobes are 40µm thick. The flexible parylene cable have nine gold trace lines of 40µm wide and spaced 60µm. The S-shape is designed to utilize the wafer area effectively. The whole device is successfully released using parylene etching techniques, as shown in Fig. 3b.

The SEM picture of the tips of the fabricated microprobes with the 25µm×25µm electrodes is presented in Fig. 4. Parylene shows very good adhesion performance on electroplated nickel. It can be seen that the electrodes are bumped out of the surface, which can reduce the impedance value of the electrodes and allow a better contact with the neural tissue.

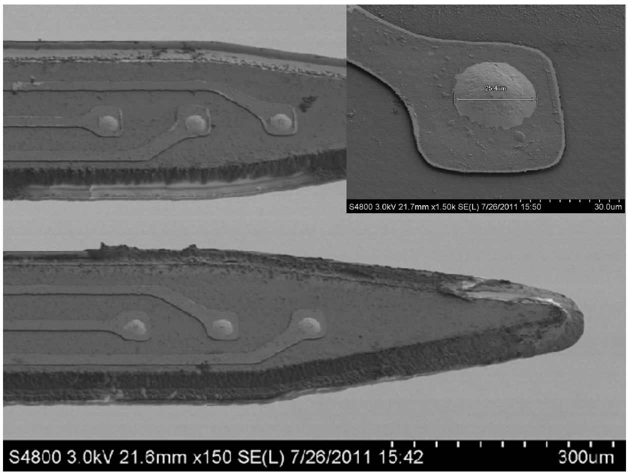


*Figure 4: SEM of the tips of microprobes*

# RESULTS
## Mechanical Test

The mechanical strength of electroplated nickel and single-crystal silicon are measured and compared using micro-hardness tester (MVK-H21). The applied load is 2.94N. The surface hardness of the fabricated microprobes is HV580 while the ones of nickel electroplated with sulfamate-base bath and single-crystal silicon are HV360 and HV950, respectively. The nickel electroplated with modified bath are less rigid than silicon, but more mechanically robust.

## Impedance Test

The electrical connections between the microprobes and a printed circuit board (PCB) are manually created using silver epoxy. The impedance of the fabricated electrodes is measured in 0.01M Phosphate buffered saline (PBS) solution using an impedance analyzer (Agilent 4294A, 40Hz~110MHz). A tri-electrode measurement setup consisting of an Ag/AgCl reference electrode and a Pt counter electrode is employed. Fig. 5 shows the measured impedance magnitude and phase of the electrodes over 40Hz~100kHz frequency range matching that of the neural signals of interest. Typically, the impedance magnitude at 1kHz is approximately 1.0MΩ.

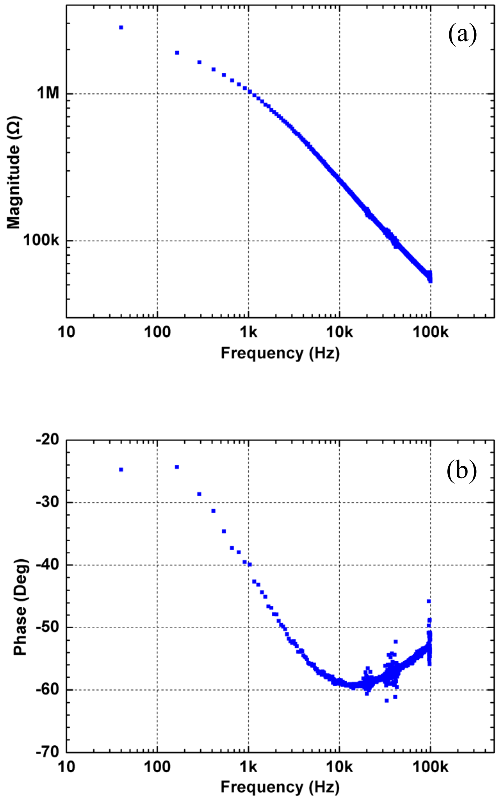


*Figure 5: (a) Impedance magnitude and (b) phase of 25µm×25µm electrode sites.*

## *In-vitro* Penetration Test

The *in-vitro* penetration test of the electroplated nickel microprobes is performed, as shown in Figure 6.

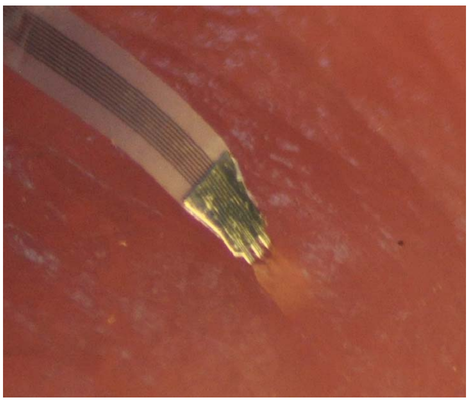

*Figure 6: In-vitro penetration test of the fabricated microprobes.*

The microprobes, simply pushed with tweezers, are easy to penetrate the muscle tissues of the pig. No mechanical deformation is observed when the microprobes are pulled out from the tissues.

## CONCLUSIONS

This study successfully exploits low-cost nickel electroplating and parylene etching techniques to fabricate nickel-based multi-electrode microprobes with flexible parylene cable, which are more mechanically robust than silicon-based ones. Parylene encapsulation ensures the biocompatibility. The microprobes offer nine electrode sites of 25μm×25μm located on three parallel 2mm-long, 160μm-wide and 40μm-thick shanks. The 80mm-long parylene cable facilitates the electrical connection and reduces the packaging requirements. The impedance magnitude and phase of the fabricated electrodes are measured using a tri-electrode setup over the frequency range from 40Hz to 100kHz. The *in-vitro* test of penetration into the muscle tissues is performed to validate the high mechanical performance of nickel microprobes. Due to the novel fabrication process, the bump-shaped electrodes are obtained, which allow a better contact with neural tissues and consequently improve the signal to noise ratio of recording signals.

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