HOOK AND LOOP MICROFASTENER: FLEXIBLE MICROELECTRODES TIED TO A NERVE

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ABSTRACT

Neural recording from a nerve is a way to offer safer brain-machine interface (BMI) technology, compare to that from a brain tissue. However, because a nerve is soft and small diameter geometry, attachment of an electrode device to the nerve is still problematic, resulting in unstable recording and damage to the nerve. Here we propose a highly-flexible and -biocompatible parylene–based microelectrode array with a hook and loop microfastener, which realizes the electrode stably tied to a nerve (~1 mm in diameter). We fabricate microscale-hook and -loop fasteners using 10-µm-thick parylene film, while an array of Pt-microelectrodes is integrated for multisite nerve recording applications. Attachment and recording capabilities of the device are demonstrated using a mouse's peripheral nerve, offering the device advantages of i) tunable tie position, ii) numerous diameters of 'cuff' of the film device, and iii) reattachable features. Such flexible microelectrode device is also applicable to numerous biological samples, including not only any nerves, but also tissues and organs.

INTRODUCTION

Electrical recording of neuronal signals from a brain tissue is an important technology in fundamental neuroscience, medical applications, and BMI technology (e.g., control prosthetic limb and arm)[1]. On the other hand, recording of a peripheral nerve is a way to offer safer BMI technology, compared to that from brain tissue. To realize the peripheral nerve recording, microfabricated flexible 'cuff' electrode devices have been proposed [2] [3]. However, attachment of these electrodes to a nerve, which is soft and has a small diameter (~1 mm), is still problematic, resulting in unstable recording and damage to the nerve. These device issues should be solved for use in *in vivo* applications, particularly in chronic device implantations.

To overcome these device issues, the approach reported here is to improve the device attachment by using a concept of 'hook-and-loop fastener'. Figure 1 shows a photograph of a conventional hook-and-loop fastener, which consists of two components: tinny hooks and loops on each fastener. These hooks and loops are attached each other, resulting in the two pieces fastened. We use the hook-and-loop in nerve recording device, in order to offer the advantages of i) tunable tie position, ii) tunable diameter of cuff for numerous diameters of nerve, and iii) re-attachable, even thought the nerve is in wet environment (Fig. 1).

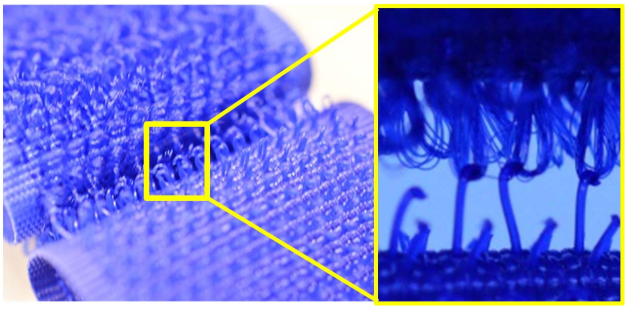

Figure 1: Photograph of a conventional hook-and-loop fastener.

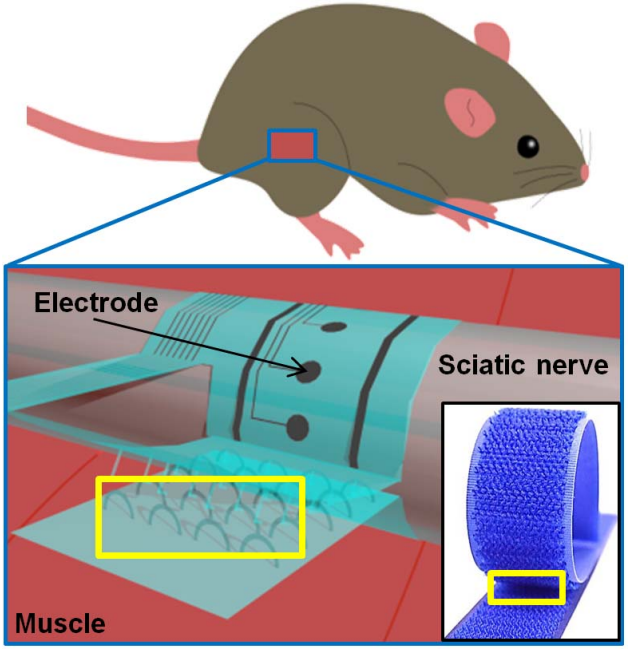

Figure 2: Schematic of a flexible microelectrode array device, which is tied to a mouse's nerve with the hook and loop microfastener.

EXPERIMENTAL RESULTS

Hook and Loop structure

We fabricate the microscale hooks and loops by using a highly biocompatible parylene film. Before the device fabrication, we calculate the holding force of a pair of hook and loop of parylene by finite element method (FEM)(Fig. 3). The thickness and width of the hook/loop used in the model are 10 µm and 70 µm, respectively. Figure 3a shows the layout of microscale hook and loop, which are modeled in FEM (prior to the pulling the hook, Fig. 3b). Figures 3c-1 and c-2 show displacements of the both hook and loop before and after the pilling of the hook,

respectively. We also confirmed that these parylene–based hook and loop have enough strengths to bond and separate each other. The simulation also indicates that the maximum holding force of a pair of hook and loop ranges from 10 mN to 20 mN. In actual device, the holding force can be increased by increasing the number of hook and loop pairs in the film.

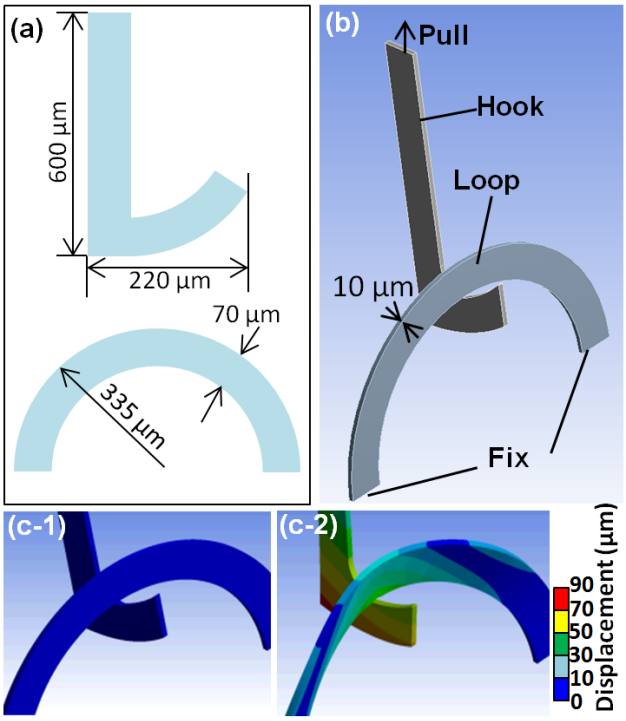

Figure 3: FEM model of a pair of hook and loop. (a) Layouts for hook and loop. (b) FEM model. (c) Displacements of the hook and loop before (c-1) and after (c-2) the pulling the hook.

Parylene-film based microelectrode array

Based on the preliminary studies, a parylene-film–based electrode device with hook/loop fastener was fabricated (Fig. 4). We start the device process with a 5-µm-thick parylene film, which is deposited on a Si substrate. A Pt layer as the electrode-site and interconnection was formed on the parylene by sputtering and etching (CF_4 plasma). The Pt layer was then covered with another parylene (5 µm), followed by parylene patterning by O_2 plasma with a mask (Ti). Finally, the parylene-film is released from the substrate using acetone [4-6].

To form vertically aligned loop and hook structures, a parylene film, which consists of loops (or hooks) (Fig. 5a), is rolled with and bent with a wire (~ 0.5 mm diameter stainless) (Fig. 5b). Because the loop structure does not completely follow the film, the loop slightly stands up (Fig. 5c). The 'out-of-plane' loop is immediately rubbed against a plate (sponge) and stand up completely (Fig. 5d). With the continuous process of the wire rolling, the vertically aligned loop (or hook) arrays are formed (Figs. 5e-f)

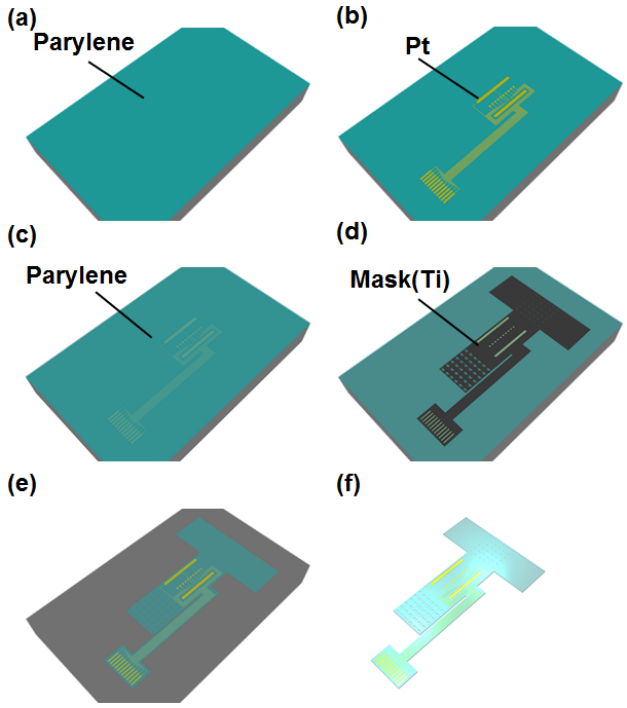

Figure 4: Fabrication process for parylene-based flexible microelectrode array device with a hook and loop fastener design.

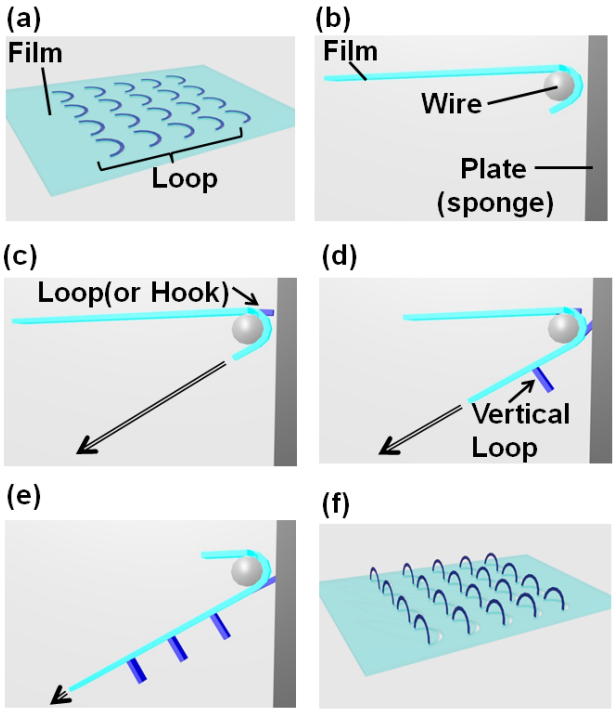

Figure 5: Planar loops stood up vertically by rolling the film into a wire and rubbing to a plate. (a) 2D loops embedded in a film (parylene). (b) The film rolled and bent with a wire. (c, d) Loop stood up by rubbing the film to a plate. (e, f) Vertical 3D loop array formed.

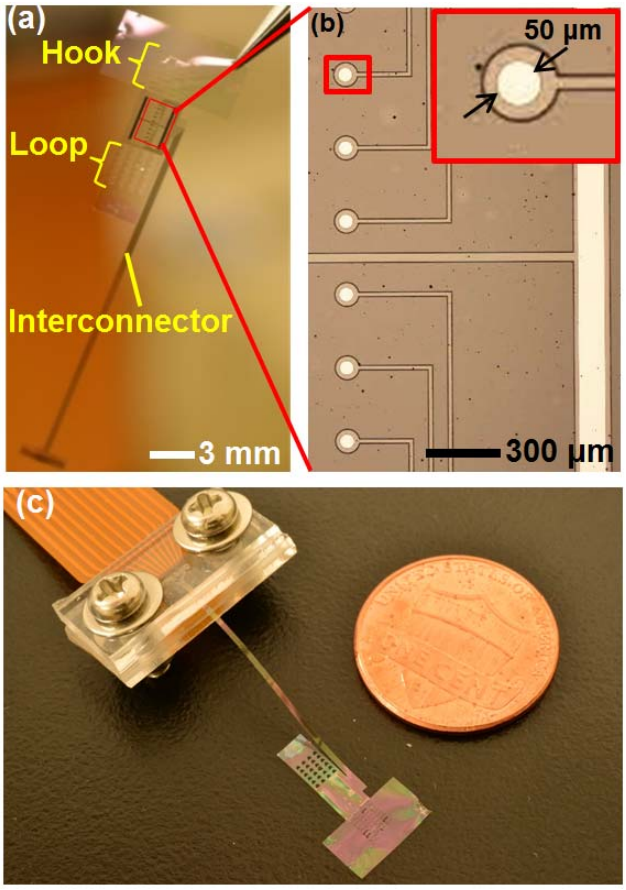

Figure 6: Fabricated parylene–based microelectrode array for nerve recording. (a) Photograph of the device overview. (b) Pt-microelectrode in the device. (c) Photograph showing the device package with FPC. US penny is shown for comparison.

Figure 6a shows the photograph of a fabricated device, which consists of hooks, loops, and microelectrode arrays. Diameter of the Pt-electrode (exposed area from the upper parylene layer) is 50 µm. These electrodes are designed as a 10 channel linear array with the gap of 200 µm (Fig. 6b). The film also consists of two reference electrodes of Pt at the film edges. Figure 6c shows a packaged parylene film device with polyimide–based flexible printed circuit (FPC) using an anisotropic conductive sheet. Impedance of the Pt-microelectrode measured in room temperature phosphate-buffered saline at 1 kHz is ~ 200 kΩ, which value is low enough to measure neuronal signals.

The fabricated device can make a loop as 'cuff' by folding the film and bonding the hooks with the loops (Figs. 7a and 7b). Forming the cuff structure is easy by tweezers within < 1 sec. We also confirmed that these hook and loop have enough strengths for the bonding and separating each other, as demonstrated in the cycle tests more than ten times. Figure 7c is a photograph, showing that a fabricated device is tied to a 1-mm-diameter cable (red cable, Fig. 7c), which diameter is similar to that of a mouse's nerve.

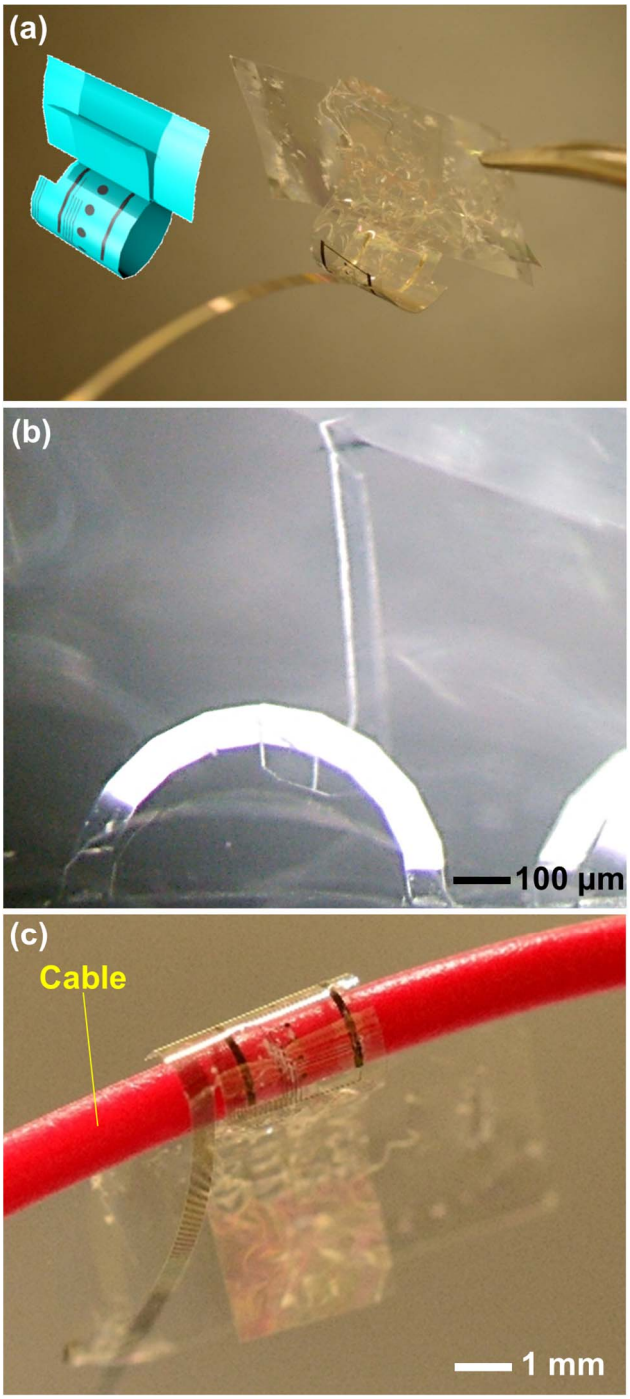

Figure 7: A 'cuff' parylene film device by hook and loop microfastener. (a) Photograph of a fabricated device, showing a 'cuff' by folding the film and bonding the hooks with the loops. (b) Enlarged image of a pair of hook and loop, which are bonded each other. (c) Photograph showing film electrodes tied to a 1-mm-diameter cable (red cable).

In vivo neural signal recording

In vivo recording capability of the fabricated device was demonstrated using mouse's peripheral nerves (~ 1 mm in diameter). Herein, the fabricated device, which is connected to a recording system, is tied to a mouse's sciatic nerve, while the tibial nerve is stimulated with a bipolar tungsten electrode (bottom photograph in Fig. 8a). We used the stimulation currents ranged from -30 µA to +30

μA (100 μs duration, a train of 5 pulses, 1 s inter-stimulus interval). Neural responses to the stimuli were observed at the stimulation currents of -20 and -30 μA (Fig. 8b). Figure 8c shows the multisite recording of the nerve via ten channel microelectrodes, which surround the sciatic nerve, while the tibial nerve is stimulated at -30 μA.

CONCLUSIONS

Although we demonstrated the hook and loop microfastener for tying the flexible microelectrodes to a ~ 1-mm-diameter mouse's nerve, the device is also applicable to not only nerve but also numerous biological samples, including larger (or smaller) diameter nerves, tissues, and organs, offering the device advantages of tunable tie position, tunable film diameter, and reattachable features for *in vivo* applications.

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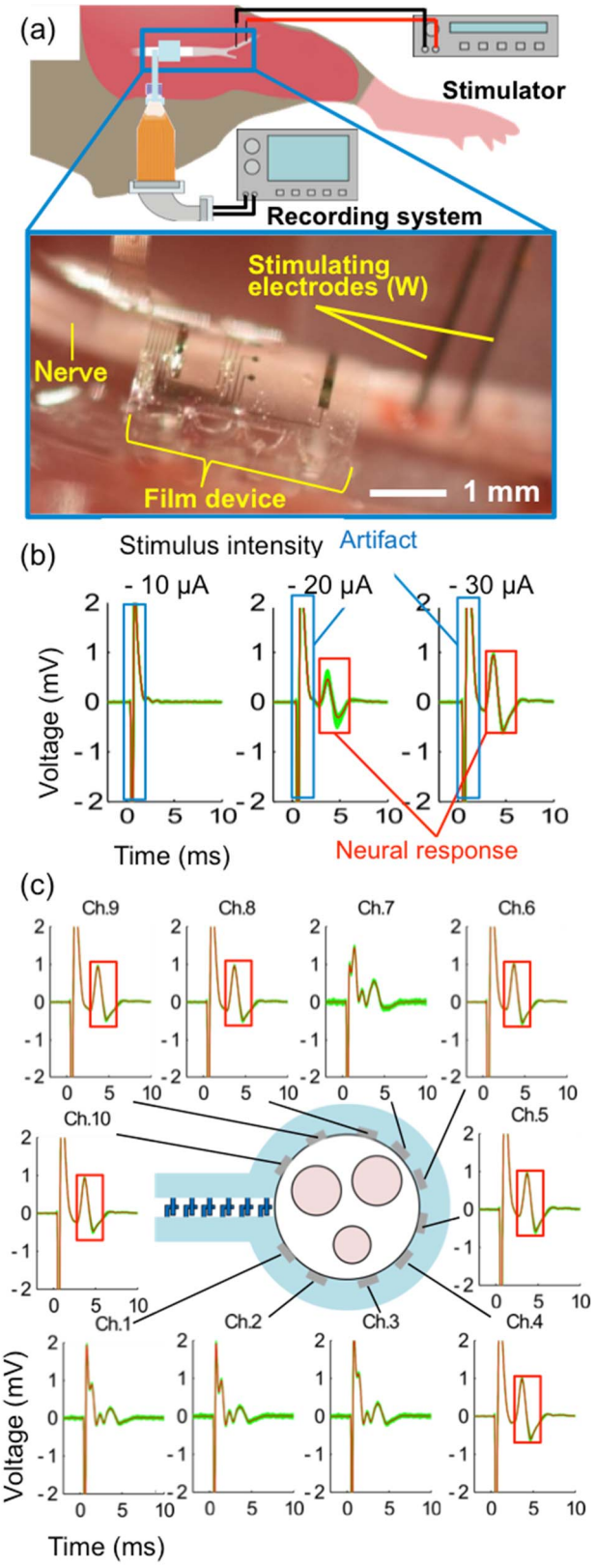

Figure 8: In vivo recordings of a mouse's sciatic nerve. (a) Schematic and photograph of the experiment setup. The parylene-film device is tied to the nerve, while the nerve is stimulated with tungsten electrodes. (b) Stimulation current dependent neuronal responses. (c) Multisite nerve recording via ten channel microelectrodes (stimulation current = -30 μA).