Fabrication of Implantable Microcoils for Ultra-Focal Stimulation of Neurons with Selectable Orientation

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Technologies that can stimulate neurons at specific orientations are highly desired in therapeutic applications (e.g., to mitigate potential side effects of unintentional neuronal modulation) and neuroscience research (e.g., to elucidate neural circuitry with increased resolution). As an emergent neuronal stimulation strategy, microscopic magnetic stimulation (μMS) is gaining increasing attraction for its advantages in allowing selective and directional neuronal activation compared to electrode-based electrical stimulation (EES). Moreover, μMS stands out with distinct merits. Firstly, unlike EES, it does not require charge balance for input stimuli; instead, it utilizes a time-varying magnetic field to induce the stimulating current, thus avoiding charge buildup issues that may lead to undesired stimulation in EES. Secondly, through configuration design, μMS stimulation can be confined to an ultra-focal region on neural elements along a specific direction, which, on the contrary, is very challenging for EES. Another key benefit of μMS relates to its contactless stimulation mode that, when packaged with a biocompatible material, may mitigate inflammation responses for chronic stimulation. Contactless stimulation may also enhance compatibility with medical imaging by minimizing heat accumulated in tissues.

We designed and fabricated figure-8 micro-coil array devices with a high aspect ratio and densely arranged traces on a micro-scale footprint (Figure 1). The micro-coil array devices were built on a flexible substrate compatible with tissue implantation and consisted of multiple function layers (coil/via/lead). The fabrication of the micro-coil chip includes photolithography, electroplating, reactive ion etching, parylene coating, and other nanofabrication techniques and processes. The fabricated micro-coils can tolerate >5 A pulse electric current input required for the μMS stimulation.

We preliminarily tested a micro-coil prototype in an anesthetized rat for sciatic nerve stimulation as proof of concept. As shown in Figure 2, we could observe the unilateral electromyographic (EMG) response signal from the hindlimb of the rat upon imposing a brief micro-magnetic stimulation pulse on its sciatic nerve. Moreover, we captured distinct EMG response signals throughout the stimulation, coming from different neural circuits, thus suggesting the high focality of the proposed μMS system.

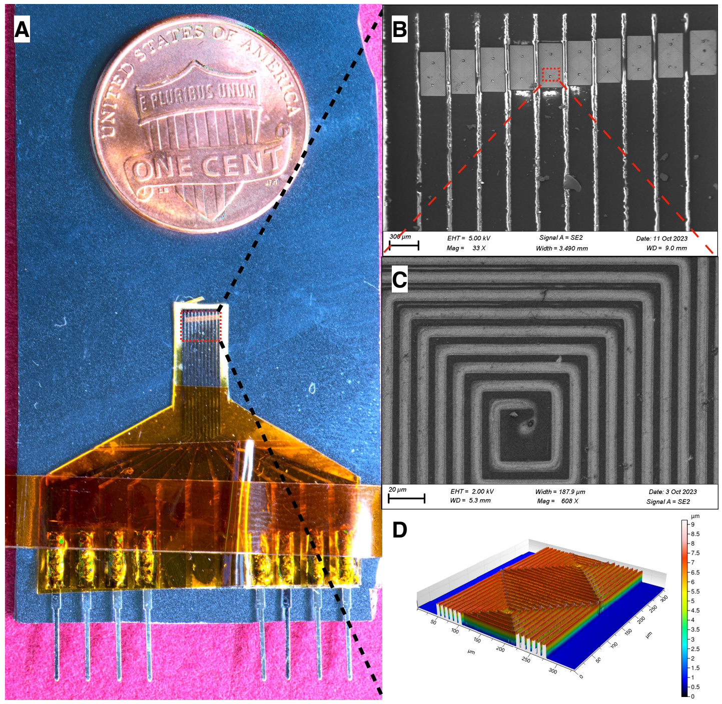

Figure 1: The prototype of the flexible figure-8 micro-coil array: (A) Photograph of the whole chip. (B, C) Scanning Electron Microscope (SEM) images of the micro-coil array. (D) Optical profile of the micro-coil.

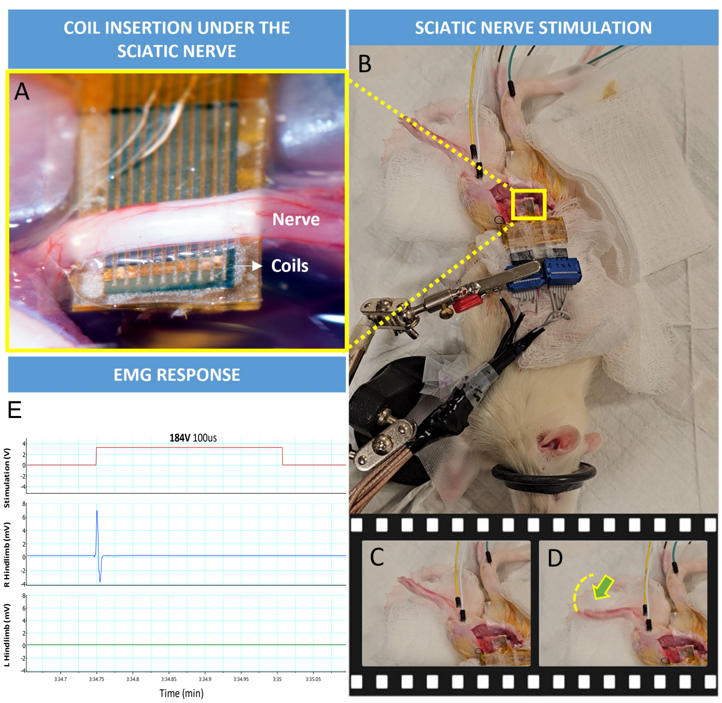

Figure 2: Sciatic nerve stimulation using the prototype chip. (A, B) Micro-coil insertion under the sciatic nerve of the rat. (C, D) Electrodes recording the EMG response from rat hindlimbs. (E) EMG signal measured in the hindlimbs after a brief stimulation pulse was applied to the sciatic nerve (blue line) compared to the control electrode signal (green line).