Fabrication of cylindrical neural probes with integrated conductor wiring

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The function of a neuron depends on its microcircuitry – the inputs it receives from local and long-range connections and the outputs it sends to other neurons.[1] Mapping these connections is typically done by stimulating a population of neurons chemically, electrically, or optically,[2,3] and recording the induced extracellular action potentials with implanted probes with 1 or more conducting electrodes. These probes may be cylindrical needles or thin planar blades. The needles have an advantage for probing deep structures and creating arrays, as their circular cross section minimizes insertion force, while the flat structure of planar probes allows low cost design flexibility and denser electrode patterns. In this paper, we explore the possibility of manufacturing cylindrical probes with dense thin film electrode patterns on fine optical fibers, thus, providing the design flexibility of planar probes in the cylindrical format required for deep brain studies and probe arrays.

Our objective is to fabricate probes on optical fiber substrates for optogenetic studies in the visual cortex of macaques. The design calls for 4 panels of staggered electrodes, each on a different side of a cylindrical substrate, as shown in figure 1. The electrode pattern, Fig. 2, spans the depth of the visual cortex (about 2 mm); each of the 4 panels will have ~14 pairs of staggered electrodes. The entire probe is coated with a crosslinked polymer except for *vias* where electrodes contact cerebro spinal fluid and the interconnect traces contact aluminum bands in the interface region of the probe, also seen in Fig. 2. Thus, 3 masks (metallization, *vias*, and Al bands) are required to fabricate the probe. Figures 3 a), b) show the jig used to expose the fibers.

The fabrication process relies on helium atom beam lithography to achieve the depth-of-field required to print micron-scale structures on optical fibers. A conformal coating of plasma polymerized styrene serves as a negative tone resist. An indirect alignment scheme is used which relies on the 2-sided alignment accuracy that can be achieved in registering the V-grooves with the stencil mask patterns and 2 mechanical fixtures, a stainless steel fiber stop and a cubic bead (see Fig.3). The errors involved with this technique will be presented at the conference. Yield data based on 1 kHz electrode impedance in phosphate buffered saline of the finished probes will also be discussed.

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1 R. Douglas and K. Martin, *Annual Review of Neuroscience* **7**, 419-451 (2004).

2 K. Deisseroth, *Nat Methods* **8,** 1, 26-29 (2011).

3 F. Zhang *et al*., *Nat Protoc* **5**, 439-456 (2010).

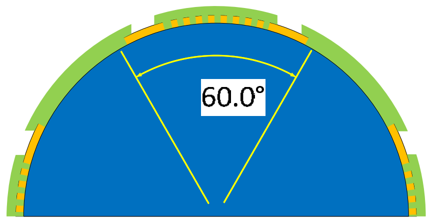


Figure 1: Wiring patterns are defined on 4 or more panels on the sides of an optical fiber.

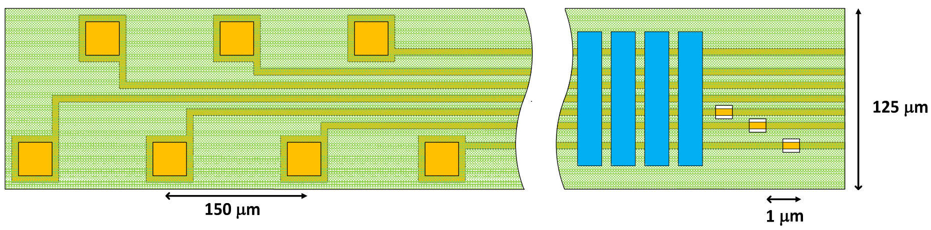
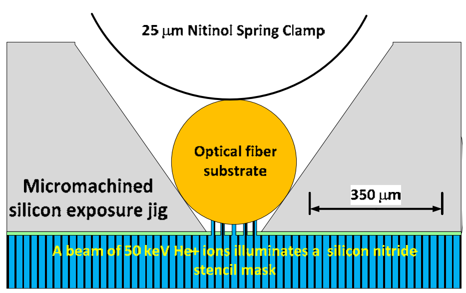
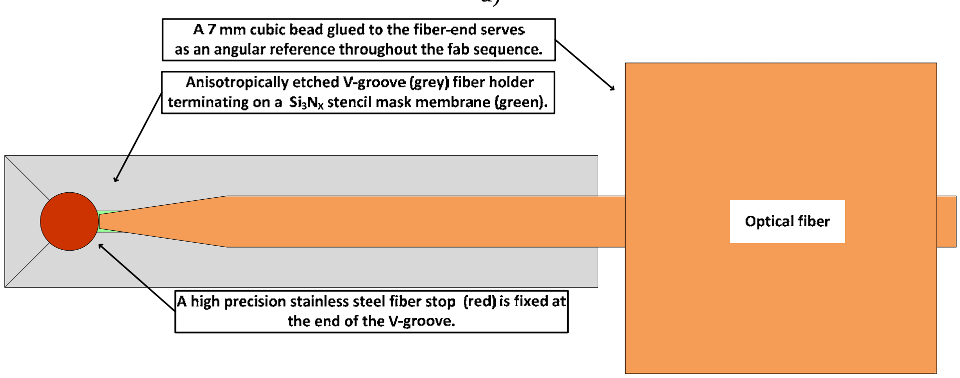


Figure 2-Electrode panel (not to scale): The left hand side of the electrode panel is implanted in the brain; the right hand side provides the interface between the interconnect traces and signal processing electronics. The gold conductor layer has a greenish cast where it is covered by an insulating plasma-deposited film; it is a pure gold color in the *vias* where the probe contacts cerebro-spinal fluid and where transverse aluminum bands make contact with the interconnect wiring. A ribbon cable is bonded to the Al bands with conducting epoxy.



a)



b)

Figure 3-Lithography jigs: a) a fiber substrate is held by light wire springs in an anisotropically etched V-groove terminating on a Si_xN_y stencil mask. When illuminated by a broad beam of energetic helium atoms, transmitted beamlets transfer the mask pattern to the optical fiber, b) a precision stainless steel ball serves as a fiber stop, locating the tip of the fiber relative to the stencil mask pattern. A cubic bead glued to a temporary tail is used to ensure angular alignment of the metallization, *via*, and aluminum band masks.

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