Ultraflexible electrodes for long-lasting, large-scale, bi-directional neural interface

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Neurons are densely packed and interconnected in the brain. Neurotechnology capable of detecting the faults and restoring normal functions must be able to interface with the brain at high spatiotemporal resolutions, with large scales, and over extended periods. Penetrating neural electrodes can tune into individual neurons and neural dynamics at sub-milliseconds resolution, but the desire for recording many neurons in a small volume and the desire to minimize the tissue damage by the electrodes compete with each other. In this talk, I will discuss our efforts on developing ultraflexible neural electrodes to realize extended functioning period at minimal tissue invasiveness, bi-directional communication, and scalability to thousands and more channels.

First, to mitigate tissue invasiveness, we focus on overcoming the mechanical mismatch between soft brain tissue and man-made devices. We engineered ultraflexible Nanoelectronic thread (NET) with a total thickness 1 μm while maintaining the long-term structural and electrical integrity. The ultrathin thickness results in a factor of 10^4 reduction in bending stiffness compared with other devices, enabling tight tissue-electrode integration without glial-scaring or neuronal degradation. Consistently, NETs reliably detect high-quality single unit for months, and maintain chronically stable impedance, noise level, and unit yield.

Additionally, NETs' intimate tissue integration benefits stimulation by reducing the separation between stimulating sites and neurons, lowering the activation threshold, and improving the stimulation selectivity and stability. We demonstrate in vivo that NETs enable glial-scar-free intracortical microstimulation, drive robust behavioral detection at one of the lowest current reported. The behavioral detection thresholds are stable over 290 days after an initial decay while neuronal activation thresholds remain stable. We hereby provide a path for a high-precision, bi-directional interface without risking tissue deterioration or exacerbating off-target side effect.

Lastly, I discuss two orthogonal efforts to overcome sampling scarcity. First, using nanofabrication we increase the packing density per device by 10 folds. Furthermore, the ultra-thin thickness of NETs and its excellent tissue compatibility make it feasible to implant many shanks at small separations, which significantly increases the volumetric density of neural recording. We demonstrated in vivo volumetric recordings at densities up to 1000 units per 1 mm^3, about 5 – 10% of all active neurons in the volume, as well as flexibly distributed recording of several thousand neurons across multiple cortical regions. These recordings warrant detection of structured patterns of strongly coupled neuron pairs suggestive of directional information flow. Recordings are stable over several months, enabling longitudinal measurements of network structure with millisecond dynamics. Notably, large-scale, high density mapping of local network significantly enhance decoding accuracy in a visual stimulation experiment, and large-scale recordings across multiple brain regions enables accurate decoding of complex behavior.