

Preface

Nanoscale materials enable unique opportunities at the interface between physical and life sciences. The interface between nanoelectronic devices and biological systems makes possible communication between these two diverse systems at the length scale relevant to biological functions. The development of a “bottom-up” paradigm allows nanoelectronic units to be synthesized and patterned on unconventional substrates. In this thesis, I will focus on the development of three-dimensional (3D) and flexible nanoelectronics, which mimics the physical and chemical properties of biomaterials in order to explore fundamentally new methods for the seamless integration of electronics with other systems, with a special focus on living biological tissue.

First, I introduce a mechanics-driven strategy that employs “bottom-up” approach for the fabrication of ultra-flexible 3D macroporous nanoelectronic networks, which have the porosity larger than 99%, hundreds of addressable nanodevices and feature sizes ranging from 10 μm to 10 nm. Second, I demonstrate that these nanoelectronics as nanoelectronic scaffolds (nanoES) that mimic the structure of natural extracellular matrix can be easily integrated with organic gels, polymers, and biomaterials without altering their physical/chemical properties. Notably, these devices, as functional embedded systems, can sense local optical, voltage, chemical, and strain signals in hybrid materials. Third, I present the culture of synthetic tissues within these nanoES to generate “cyborg” tissues, introducing a fundamentally new way to seamlessly integrate nanoelectronics with tissues in 3D to precisely interrogate the whole tissue activity at single cell and single spike level. The response of cyborg tissue to the external drug stimulation and microenvironment pH change can be monitored in real time by the embedded devices. Finally, I report a freestanding “mesh electronics” that can be delivered through syringe injection and self-restore their geometric configuration. This mesh electronics can be injected into *in vivo* systems for a chronic brain–machine interface at single neuron level in a minimally invasive way, representing the *state-of-the-art* brain–machine interface. Multiplexed recording of brain signals from nanosensors on the scaffold shows promise for the precise mapping of brain activity. The macroporous structure of the electronics allows reorganization of the neural tissue surround and within the

electronic network and promotes migration of adult neural stem cells from the subventricular zone to the electronic network. The ultra-flexibility and nanoscale feature size fully mimic the mechanical properties of the tissue, eliminating the immunoresponse from the brain tissue to the implanted electronics. Together, these results open up new directions in the design of nanoelectronics and integration of nanoelectronics with living cellular networks, tissues, and organs, bringing opportunities that we can explore to fundamentally revolutionize fields ranging from smart systems design and regenerative medicine to brain-machine interface.

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