

Semiconducting Polymer Nanoparticles: Enabling A New Frontier in Bioelectronic Neural Interfacing

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Implantable neurostimulation devices provide a direct therapeutic link to the nervous system that could enable brain stimulation for treatment of Parkinson's disease, nerve regeneration to remedy spinal cord injury, and retinal prosthetic devices that could cure blindness. To achieve such goals, new bioelectronic systems that can deliver electrical stimulation to nerve cells are required. Although silicon microelectronics and metal electrodes have been the historic gold standard for bioelectronic interfaces, their use in clinical practice is limited. The main obstacles to further translation of these devices include a low biocompatibility that reduces *in vivo* lifetimes, a mechanical rigidity that is poorly matched with soft tissue, causing inflammation and ineffective electrical contact, and a requirement for costly external power supplies to deliver current.[1] These issues result in indiscriminate tissue activation, with a consequent lack of spatial selectivity.

In this work, we report our group's recent efforts to simultaneously address these issues by combining soft carbon-based organic semiconductors and nanoscale science to build new bioelectrodes that allow optical neurostimulation without external power. Our approach creates bioelectronic interfaces from conducting polymers that can be formed into customized nanoparticles with established solution-based chemistry methodologies. This approach enables the stimulating electrodes to be combined with targeted pharmaceutical factors in the fabrication procedure, which subsequently optimize connections to the neural network when released *in-vivo*. [2] We will discuss how we tuned the optoelectronic properties of the polymer nanoparticles to cover standard red, green, and blue spectral regions, allowing spectrally selective platforms for neurostimulation. These materials are then turned into electroactive inks, and subsequently fabricated into pixelated arrays using inkjet printing that demonstrate both anatomical and functional biocompatibility via immunolabelling with neuronal marker MAP2 and visualisation with epifluorescence microscopy. We demonstrate the controlled release of drugs from the organic semiconducting nanoparticles via electrical stimulation, aiding in precise spatial delivery of pharmaceutical factors. Finally, we employ whole-cell patch clamp electrophysiology recordings to demonstrate an exciting result; purely optical neurostimulation of dorsal root ganglion nerve cells. We demonstrate that the organic semiconductors can trigger changes in the nerve cell membrane potentials via a capacitive coupling mechanism, the efficacy of which can be improved by judicious selection of the device architecture.[5]

[1] T. Someya, Z. Bao, G. G. Malliaras, *Nature*, 540, 379, (2016).

[2] R. Crovador, H. Heim, S. Cottam, ..., M. J. Griffith; *ACS Appl. Bio Mater.*, 4, 6338, (2021).

[3] C. P. Sherwood, ..., M. J. Griffith; *IEEE J. Selected Topics Quant. Electron.*, 27, 1, (2021).