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Soft, flexible and transparent graphene-based active spinal cord implants for optogenetic studies

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Patients affected by spinal cord injuries (SCI) are usually unable to perform trivial motor activities and thus, for therapeutic purposes, epidural spinal cord stimulation (ESCS) is currently used. Moreover, more exploratory research, using optogenetics, is being conducted in rodents for a better understanding of the mechanisms that occur while delivering specific therapies. However, the availability of tailored neurotechnologies for such experiments is limited.

This work reports the development and characterization of flexible, active spinal cord implants with optogenetic compatibility[1,2] (Fig.1). A scalable and reproducible microfabrication process has been developed, using graphene[3], a transparent, flexible and conductive material, to form the electrodes and interconnects of the implant. Small and thin[4] electronic chips were assembled via flip-chip bonding processes either on graphene or on metal-on-graphene layers. Soft, polymeric encapsulation was employed to sustain the high flexibility and transparency of the implant. The result is an active prototype consisting of a multi-layered graphene structure between two polymeric-based encapsulation layers, with thin chips integrated on the implant and test pads for interconnection to the outside world.

Raman spectroscopy and optical transmittance were employed for the characterization of the graphene layer while cyclic voltammetry and electrochemical impedance spectroscopy were performed to benchmark the electrical properties of the device. The assembly process of the chips was evaluated using four-point electrical measurements.

In this work, the first transparent, graphene-based active implants have been developed (Fig. 2 and Fig. 3). The prototypes were extensively characterized and the results showed a transparency of ~80 % as well as no deterioration over time when soaked in saline solution or when bent under various angles. The graphene electrodes showed an impedance of ~8 kΩ at 1 kHz frequencies and the resistance after the bonding process ranged from 10 mΩ up to 16 Ω for individual connections, depending on the substrate used.

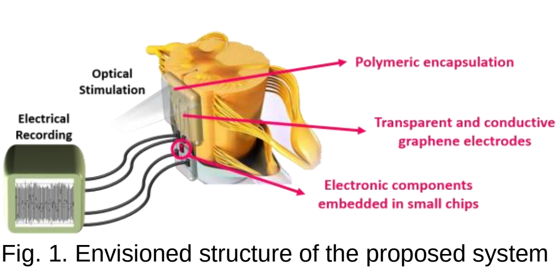

Fig. 1. Envisioned structure of the proposed system

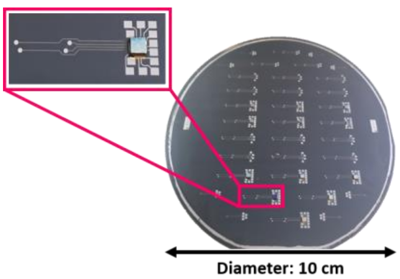

Fig. 2. Active prototypes developed on a silicon wafer

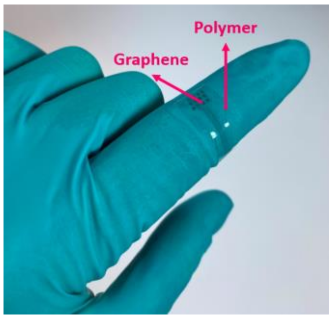

Fig. 3. Soft, flexible, graphene-based implants

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