Thermally efficient, ultrathin diamond-based µLED neural probes for versatile optogenetic protocols in vivo

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Optogenetics has revolutionised the study of biological neural networks by allowing genetically targeted, millisecond-timescale, localised optical stimulations of neurons. This presents a strong challenge for neural implant technology. Investigation of deep, layered brain structures in vivo may require structured light delivery covering a large volume of tissue, which can be achieved using independent implant-embedded emitters such as µLEDs, with simultaneous electrode recordings. However, monolithic optrodes show inherent limitations, notably for heat extraction, and current hybrid devices suffer from prohibitively invasive footprints.

With its superior thermal properties, excellent biocompatibility and increasing availability, diamond holds a strong potential for the next generation of hybrid bioimplants. Here we demonstrate the first minimally invasive, thermally efficient single-crystal diamond optrode prototype integrated with 8 transfer-printed AlInGaN µLEDs (50x50µm2, λ = 455nm) and 16 electrodes over two shanks. Specific techniques were developed for processing ultrathin diamond membranes, manufacturing efficient transfer-printing LEDs and for their advanced transfer-printing on highly textured substrates.

The probe dimensions (shank LxWxT = 5.5mm x 150µm x 25µm) and large irradiance range (up to ~300mW/mm2 per LED at 3mA) approach those of state-of-the-art monolithic Silicon-based optrodes, with a thermal performance improved by more than an order of magnitude, allowing a wide set of optogenetic protocols including extended/high-power optical pulses at high duty cycles with a predicted tissue temperature increase of <1°C. Process scalability on commercial wafers is demonstrated on a polycrystalline diamond membrane (20mm diameter, 50µm thickness), opening the way for novel, inexpensive diamond-based tools for neurophotonics and biomedical applications.