Injectable Micro-Scale Opto-Electrically Transduced Electrodes (iMOTEs)

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Primary CNF Tools Used: ABM contact aligner, AJA sputter, Westbond 7400A ultrasonic wire bonder, Oxford 100 / 81 / 82, Unaxis deep Si etcher, Oxford PECVD, Oxford ALD, Anatech, P7 profilometer, ZEISS Ultra and Supra SEMs

Abstract:

Recording neural activity in live animals *in vivo* poses several challenges. Electrical techniques typically require electrodes to be tethered to the outside world directly via a wire, or indirectly via an RF Coil [1], which is much larger than the electrodes themselves. Tethered implants result in residual motion between neurons and electrodes as the brain moves, and limits our ability to measure from peripheral nerves in moving animals, especially in smaller organisms such as zebra fish or fruit flies. On the other hand, optical techniques, which are becoming increasingly powerful, are nonetheless often limited to subsets of neurons in any given organism, impeded by scattering of the excitation light and emitted fluorescence, and limited to low temporal resolution [2]. Here we present the electronics for an untethered electrode unit, powered by, and communicating through a microscale optical interface, combining many benefits of optical techniques with high temporal-resolution recording of electrical signals, named Injectable Micro-scale Opto-electrically Transduced Electrodes (iMOTEs).

Summary of Research:

Our fabrication starts with a 5mm × 5mm, conventional 180 nm CMOS die, which contains the electronics for signal amplification, encoding, and transmission. The CMOS die is then integrated with AlGaAs diode, which acts as a photo-voltaic (PV) as well as light emitting diode (LED), hence the diode is abbreviated as PVLED. The PVLED provides an optical link that powers the electronics and transmits encoded signals in optical pulses. The MOTE utilizes pulse position modulation (PPM) for signal encoding for its high information-per-photon efficiency, where the spacing between the output pulses is proportional to the measured electric field of neuronal signals across the measurement electrodes.

Figure 1 depicts a conceptual deployment and simplified schematic of described iMOTE [3].

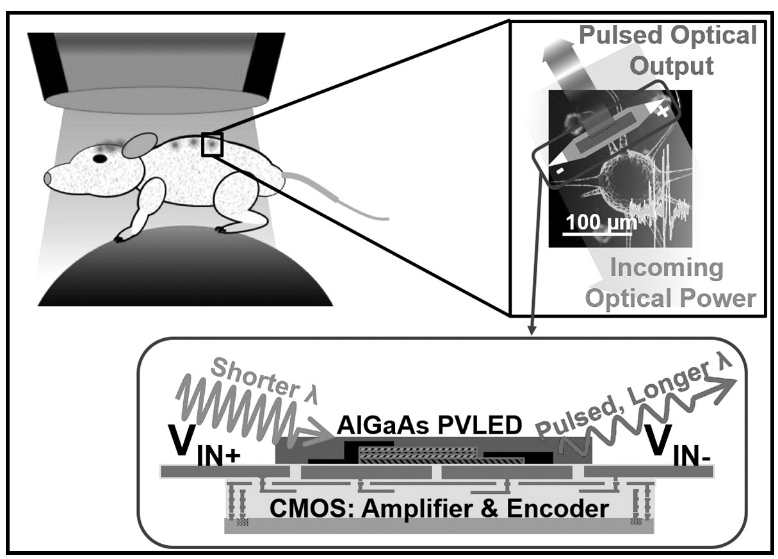

Figure 1: An envisioned implementation of the iMOTE along with a simplified system description.

The AlGaAs diodes are first fabricated on a sapphire wafer, to be later released from the sapphire substrate with a sacrificial poly(methyl methacrylate) (PMMA) polymer. Once the PMMA-coated AlGaAs diodes are transferred onto the CMOS die, the Oxford 81 plasma etcher is used to remove the sacrificial PMMA, leaving only the diodes array intact on the CMOS die. To establish the electrical contact between the PVLED and CMOS, we have used the CNF ABM contact aligner for photolithography with AZ nLof2020 UV photoresist for efficient lift-off process that ensues after metal deposition. After the contact fabrication, the contacts of CMOS and PVLED are connected via similar photo-lithography process, and to maximize the conformality of the metal routing, we employ AJA sputter.

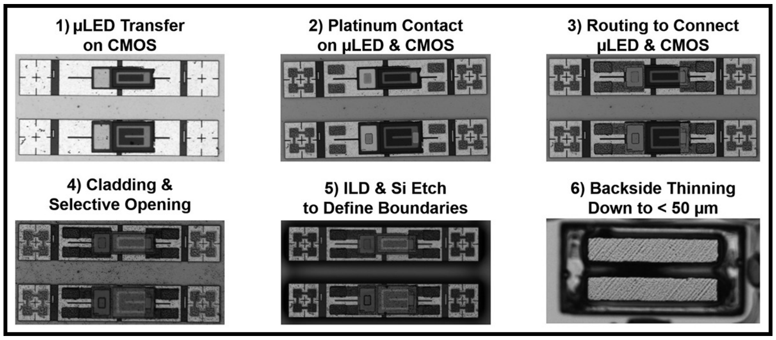

Figure 2: Fabrication flow of iMOTE integration where AlGaAs PVLED is integrated on CMOS. 1) Micro-scale PVLED is transferred on CMOS, 2) platinum contacts fabricated on both PVLED and CMOS, 3) platinum routing is added to connect the contacts made in 2), 4) iMOTEs are passivated with SiO_2 and Si_3N_4 except for its input electrodes openings, 5) using dielectric etching and deep silicon etching, iMOTEs are 'cookie-cut', 6) backside etching allows thinning-down below 50 µm.

Following the routing step, each iMOTE is encapsulated using Oxford ALD and PECVD for SiO_2 and Si_3N_4 deposition, followed by dielectric etching using Oxford 100 and Unaxis deep reactive ion etch (DRIE) for release. Figure 2 described the fabrication sequence described herein.

It should be noted that before making much changes are made in fabrication flow, to confirm the functionality of each module (CMOS and the diode), we use Westbond 7400A ultrasonic wire bonder for board-level test. ZEISS Ultra and Supra scanning electron microscopes (SEMs) are also used to inspect the fabricated iMOTE for debugging purposes.

References:

[1] R. R. Harrison, et al., "A Low-Power Integrated Circuit for a Wireless 100-Electrode Neural Recording System," in IEEE J. Solid-State Circuits, vol. 42, no.1, pp. 123-133, Jan. 2007.

[2] W. Yang and R. Yuste, "*In vivo* imaging of neural activity," Nature Methods, vol. 14, no. 4, pp. 349-359, April 2017.

[3] S. Lee, et al., "A 250 µm × 57 µm Microscale Opto-electronically Transduced Electrodes (MOTEs) for Neural Recording," IEEE Transactions on Biomedical Circuits and Systems, vol. 12, no. 6, pp. 1256-1266, December 2018.