Fabrication and Manipulation of Micro-Scale Opto-Electrically Transduced Electrodes (MOTEs)

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Primary CNF Tools Used: ABM Contact Aligner, AJA Sputter, Westbond 7400A Ultrasonic Wire Bonder, Oxford 81/82/100, Unaxis Deep Si Etcher, Oxford PECVD, Oxford ALD, Anatech, P7 Profilometer, Zeiss Ultra and Supra Scanning Electron Microscopes

Abstract:

Recording neural activity in live animals *in vivo* is critical in elucidating how the brain functions. However, such recording 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 suffer from the residual motions between electrodes and neurons as the brain moves, limiting 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 potent, are 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 an untethered opto-electrical system on chip (SoC), Micro-scale Opto-electrically Transduced Electrodes (MOTEs), which are powered by, and communicating through, a microscale optical interface, combining many benefits of optical techniques with high temporal-resolution of electrical recording.

Summary of Research:

Our fabrication starts with about 5 mm × 5 mm, 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 photovoltaic (PV) as well as light emitting diode (LED), hence the diode is abbreviated as PVLED. The PVLED provides an optical link which 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 system description of such MOTE [3].

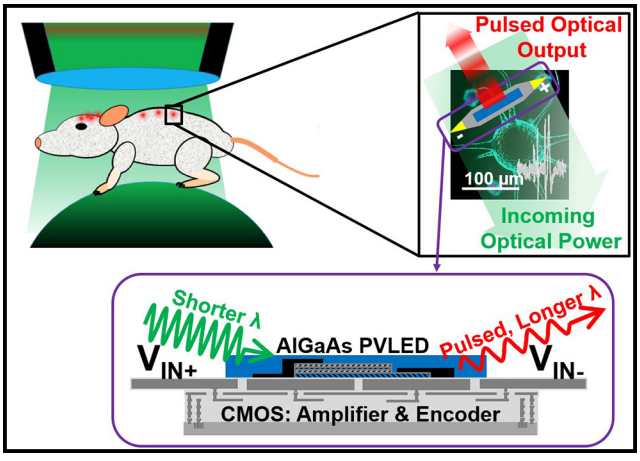

Figure 1: An exemplary implementation and system level description of the MOTEs in a mouse animal model [3].

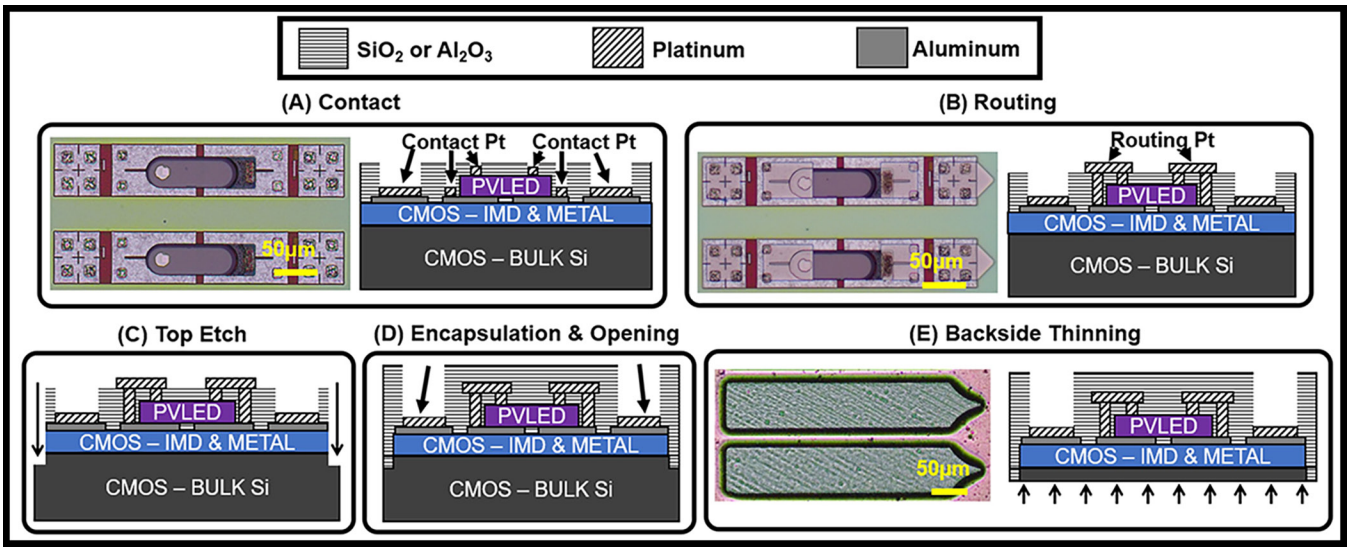

Figure 2: MOTE Fabrication Process. (A) An AlGaAs μLED (bullet-shaped) array is transferred on top of a CMOS chip containing an array of unit MOTE circuitry, and Pt is deposited over contact areas. (B) Routing Pt electrically connects each μLED with an underlying CMOS. (C) Each MOTE is segregated and (D) encapsulated with SiO_2 and Al_2O_3 except for the measurement electrodes area. (E) The backside Si is thinned so that total thickness is < 30 μm. Adapted from [4].

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, 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. Following the routing step, each MOTE 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 embarking on the nano/micro-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 MOTE for debugging purposes.

Conclusions and Future Steps:

MOTEs are the smallest electrophysiological sensor of its kind, and we are currently testing the MOTEs *in vivo* in mouse animal models. As we accumulate more data on our ongoing *in vivo* efforts, we plan to improve fabrication processes as well as surgical procedures for inserting the MOTEs into the mouse cortex. Moreover, we are aiming to design MOTEs for electrochemical applications.

References:

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