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, Oxford 81, Oxford 82, Unaxis deep Si etcher, Oxford PECVD, Oxford ALD, Anatech, P7 profilometer, ZEISS Ultra and Supra scanning electron microscopes (SEMs)

ELECTRONICS

Abstract:

Recording neural activities in live animals is critical to advancing our understanding of the brain, with far-reaching consequences in healthcare as well as philosophy. Such neural recording can be broadly categorized into two groups — tethered and untethered. An example of tethered neural recording is an electrodes array that can be inserted into the brain, which is then connected to the outside world directly via a wire. Naturally, such a tethered approach is not only inconvenient, but also creates chronic damage due to the residual motion between neurons and electrodes as the brain moves. Hence, there has been much interest in developing tetherless neural recording units.

While RF Coil [1] and ultrasonic approaches [2] have shown promise, the physics of such transduction limits their scaling much below a millimeter. On the other hand, optical techniques, which are becoming increasingly powerful, are nonetheless 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 [3].

In this work, we combine the merits of electronics and optics to develop an extremely scaled, untethered electrode unit, where an AlGaAs micro-light emitting diode (μLED) is heterogeneously integrated on top of conventional CMOS. These micro-scale opto-electrically transduced electrodes (MOTEs) are powered by, and communicated through the microscale optical interface (μLED) while the CMOS provides low power amplification and signal encoding. Such MOTEs combine the benefits of optical techniques with high temporal-resolution recording of electrical signals, and are the smallest neural recording units to date (~ 60 μm × 30 μm × 330 μm).

Summary of Research:

Our fabrication starts with a 5 mm × 5 mm, conventional 180 nm CMOS die, which contains the electronics for signal amplification, encoding, and transmission [4]. The CMOS die is then integrated with an aluminum gallium arsenide (AlGaAs) diode, which acts as a photovoltaic (PV) as well as LED, hence 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 [5], 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 of the MOTE [6].

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. In the meantime, the substrate is flattened by Oxford 81 plasma etcher to promote the adhesion between the PVLEDs and the CMOS. Once the PMMA-coated AlGaAs diodes are transferred onto the CMOS die, high vacuum annealing leaves only the PVLEDs array on the CMOS die. To establish the electrical contact between the PVLED and CMOS, we have used ABM contact aligner for photolithography with AZ nLof2020 UV photoresist for efficient lift-off process that ensues after the metal deposition.

After the contact fabrication, the contacts of CMOS and PVLED are connected via similar photolithography process, and to maximize the conformality of the routing metal, we employ the CNF's AJA sputtering system. Following the routing step, each MOTE is etched using Oxford 100 etcher and Unaxis deep reactive ion etch (DRIE) to be separated from the array. Following the etch, each MOTE is encapsulated using Oxford ALD and PECVD for SiO_2, Si_3N_4, and Al_2O_3 deposition.

Finally, the substrate is turned upside down for backside thinning. Figure 2 summarizes 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 the Westbond 7400A Ultrasonic wire bonder for board-level testing. ZEISS Ultra and Supra scanning electron microscopes (SEMs) are also used to inspect the fabricated iMOTE for debugging purposes.

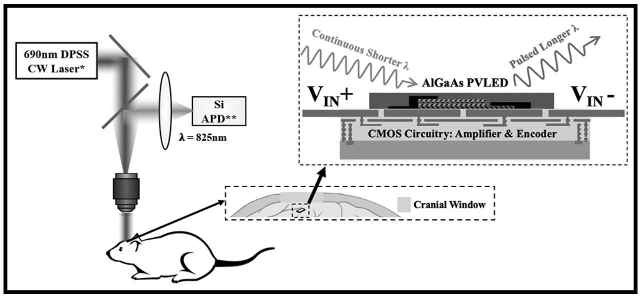

Figure 1: An envisioned employment of the MOTE for neural recording (see ref. [6]).

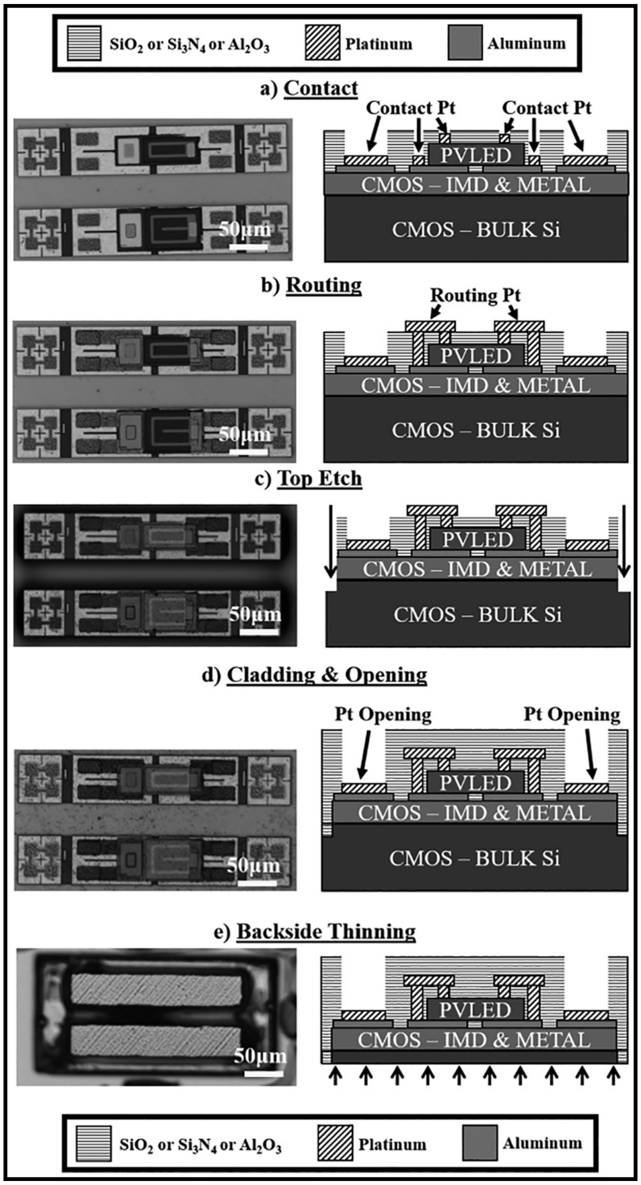

Figure 2: Fabrication flow of MOTE integration where AlGaAs PVLED is integrated on CMOS [6].

Conclusions and Future Steps:

We have demonstrated that such heterogenous integration fabrication is not only feasible but scalable with high yield (> 80%). The high-quality dielectric deposition tools available at CNF (ALD, PECVD, etc.) allow for excellent cladding that protects the MOTEs in a biological environment (> six months in phosphate buffered saline solution, and > two months in a mouse brain). We plan to continue optimizing the fabrication processes, CMOS circuitries and the PVLED efficiencies so that the MOTEs can be deployed deeper in the brain or to another biological environment. In parallel, we will continue our *in vivo* studies to demonstrate the neural recording based on MOTEs in a mouse brain.

References:

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