Micro-Scale Opto-Electrically Transduced Electrodes (MOTEs)

CNF Project Number: 2578-17

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Primary CNF Tools Used: ABM contact aligner, AJA sputter deposition, Westbond 7400A ultrasonic wire bonder

Abstract:

Recording neural activity in live animals *in vivo* poses several challenges. Electrical techniques often 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]. In our work, an untethered electrode unit capable of signal amplification and modulation is powered by, and communicates through a microscale optical interface, combining many benefits of optical techniques with high temporal-resolution recording of electrical signals [3]. To combine conventional complementary metal-oxide semiconductor (CMOS) for electronics and aluminum gallium arsenide (AlGaAs) light emitting didoes (LEDs) for optical functionalities, CNF has provided pivotal supports in fabricating the said hetero-integration.

Summary of Research:

We start our fabrication with a conventional 180 nm process CMOS die, which contains the electronics for signal amplification as well as signal modulation. In order to add an optical link, which powers the electronics by acting as a photo-voltaic (PV) as well as optical transmission by acting as a LED (hence the diode is abbreviated as PVLED), we need to integrate an AlGaAs diode onto the CMOS die. The AlGaAs diodes are first made on a sapphire wafer, then later released from the sapphire substrate with a sacrificial poly(methyl methacrylate) (PMMA) polymer that aids the release and the subsequent transfer processes.

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 diode intact with the CMOS die. To establish the electrical contact between the two, and because the CMOS die is often much smaller than conventional wafers (typically in the vicinity of 5 mm × 5 mm), we have used CNF's ABM contact aligner for photolithography with nLof2020 UV photoresist. To maximize the conformality of the metal coating for contacts, we have employed AJA sputter deposition.

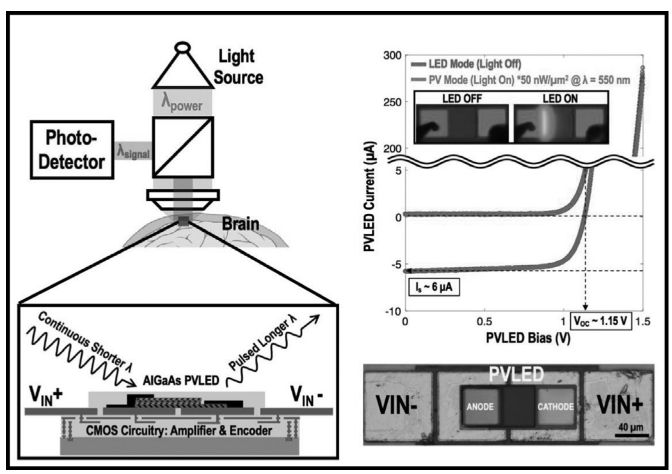

Figure 1: An envisioned implementation of the system. Top-right: characterization of a micro-scale AlGaAs diode device utilized as PV as well as LED. Bottom-right: a micrograph of an assembled system.

In addition, to confirm the functionality of each module (CMOS and the diode), we have relied on Westbond 7400A ultrasonic wire bonder for board-level integration efforts. We have also employed parylene deposition and the Oxford ALD FlexAL for passivation of the assembled heterostructure. Finally, ZEISS Ultra and Supra scanning electron microscopes (SEMs) are used to inspect the fabricated MOTE that is shown in Figure 1.

The assembled MOTE implements pulse position modulation (PPM) for signal encoding for its high information-per-photon efficiency and the diode, the PVLED delivers sharp (<100ns) current pulses, spacings of which are proportional to the measured electric field of neuronal signals across the measurement electrodes (two outer-most electrodes shown on the bottom right of Figure 1). Furthermore, it should be noted that the PVLEDs with different wavelengths can provide further disambiguation via wavelength multiplexing, providing a path towards many-MOTE probing of neural signals.

To demonstrate the system's capability to encode real neural signals, we have connected the input electrodes to the ventral nerve cord of an earthworm using probes, with a commercial neural amplifier connected in parallel to provide a reference baseline. Figure 2 clearly shows that the composite spikes have been accurately encoded in the output optical pulses, even when communication and power are purely optical.

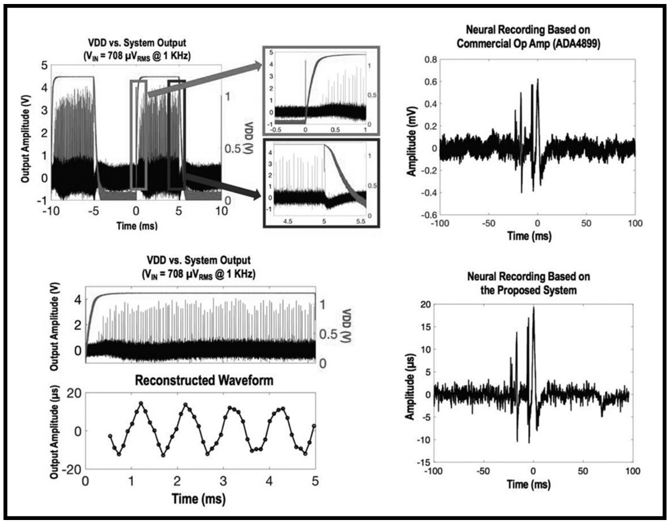

Figure 2: Left: start-up, showing optical pulses (top) and decoded signal (bottom). Right: neural recording on an earthworm ventral nerve using a commercial amplifier (top) and the presented system (bottom).

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 330.m.90.m opto-electronically integrated wireless system-on-chip for recording of neural activities," 2018 IEEE International Solid-State Circuits Conference (ISSCC), San Francisco, CA, 2018, pp. 292-294.