# A Parylene Cuff Electrode for Peripheral Nerve Recording and Stimulation

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**Topic Area:** Peripheral Nerve Interfaces

**Introduction:** The creation of a versatile, noninvasive brain-computer interface is key to the development of new medical technologies including advanced prostheses, however achieving a stable electrophysiological connection to peripheral nerves is challenged by the presence of the epineurium sheath which limits access to individual nerve fibers. Intraneural devices, which physically penetrate this sheath, achieve strong signal fidelity but are overly invasive. To overcome these hurdles, we developed a non-invasive Lyse-and-Attract Cuff Electrode (LACE) with integrated direct-to-nerve drug delivery system as a means to chemically disrupt the epineurium and then promote axonal sprouting towards electrodes within the microchannels.

**Methods:** The Parylene C cuff incorporates 4 microfluidic channels (250 µm W × 20 µm H), each containing a pair of platinum electrodes (300 µm W × 1500 µm L). The cuff wraps around a nerve with the microfluidic outlets in contact around the circumference of the epineurium, and is held in position by an adjustable locking mechanism. During benchtop testing devices were wrapped and unwrapped around simulated agarose nerve phantoms to evaluate holding strength ($n > 10$). Microfluidic channels were evaluated by infusing dye with a syringe pump at variable flow rates while imaging dye progression. Baseline electrochemical measurements were obtained through cyclic voltammetry in a 0.05M $H_2SO_4$ and electrochemical impedance spectroscopy in 1X PBS.

**Results:** The locking mechanism was simple to implement and robust. No leakage was observed up to a flow rate of 2000 µL/min, with uniform flow through all fluidic outlet ports in the flat configuration ($n = 4$). In the curled configuration, flow was achieved in 3 out of 4 channels which is sufficient for the *in vivo* application. Localized drug delivery on a nerve phantom was demonstrated. A safe flow rate of 900 nL/min was achieved by the cuff when wrapped around a nerve phantom. Cuff electrodes yielded an electrical impedance of 1.8 kΩ, a phase of -56.4° at 1 kHz, and a charge storage capacity of 1.06 mC/cm$^2$ ($n = 6$), demonstrating suitable electrode properties for peripheral nerve recordings and stimulation.

**Conclusion:** We developed a peripheral nerve interface that combines electrodes and microfluidic channels in an adjustable cuff sized to interface with rat sciatic nerve. The LACE device uses a robust and simple locking mechanism that is adjustable for close contact with nerves of varying diameters. We demonstrated fully functional cuffs having low electrode impedances, microfluidic infusion at < µL/min flow rates, and localized drug delivery.

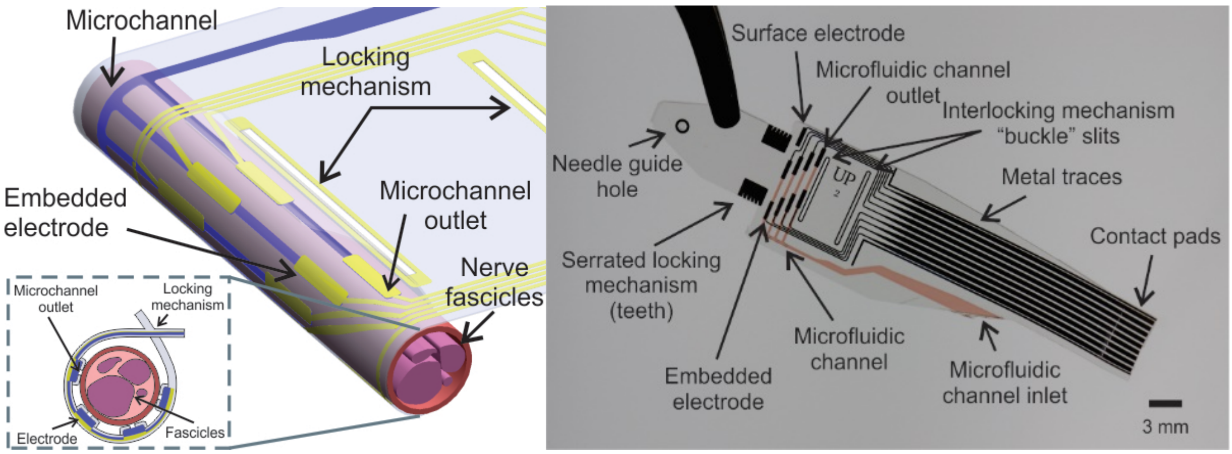


***Figure 1.*** *(a) Schematic of LACE for targeting individual fascicles within a nerve. Insert shows the cross-sectional view. (b) Fabricated LACE in which microfluidic channels are highlighted by the presence of photoresist.*

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**References:**
[1] X. Navarro, T. B. Krueger, N. Lago, S. Micera, T. Stieglitz, and P. Dario, "A critical review of interfaces with the peripheral nervous system for the control of neuroprostheses and hybrid bionic systems," *Journal of the Peripheral Nervous System,* vol. 10, pp. 229-258, 2005.
[2] T. Stieglitz, M. Schuetter, and K. P. Koch, "Implantable biomedical microsystems for neural prostheses," *Engineering in Medicine and Biology Magazine, IEEE,* vol. 24, pp. 58-65, 2005.
[3] S. Micera, M. C. Carrozza, L. Beccai, F. Vecchi, and P. Dario, "Hybrid bionic systems for the replacement of hand function," *Proceedings of the IEEE,* vol. 94, pp. 1752-1762, 2006.
[4] P. M. Rossini, S. Micera, A. Benvenuto, J. Carpaneto, G. Cavallo, L. Citi*, et al.*, "Double nerve intraneural interface implant on a human amputee for robotic hand control," *Clinical neurophysiology,* vol. 121, pp. 777-783, 2010.