Carbon Nanotube Fiber Microelectrodes for Neural Recording and Stimulation

Flavia Vitale[1], Samantha R. Summerson[2], Caleb Kemere[2], and Matteo Pasquali[1]
[1]Department of Chemical and Biomolecular Engineering, [2]Department of Electrical and Computer Engineering
Rice University, Houston, TX, United States

INTRODUCTION

Implantable electrodes are the basic tool for the development of chronically implanted sensory, limb prostheses and deep brain stimulation (DBS) devices for treatment of neurological disorders.
Small surface area (< 4000 μm²), flexible microelectrodes allow for safe, high-resolution stimulation and recording of single unit activity, while reducing the damage at the electrode-tissue interface [1,2].
Current materials for microelectrodes (i.e. metal alloys, carbon fibers) require electroplating with noble metals or electroactive polymers to achieve the desired impedance, posing issues of tip degradation and electrode lifetime.
Carbon nanotubes fibers (CNTf) combine the specific electrical conductivity of metals, the typical specific strength of carbon fibers [3]. CNTf have great potential for neuroengineering applications because of these exceptional properties and the subcellular size.

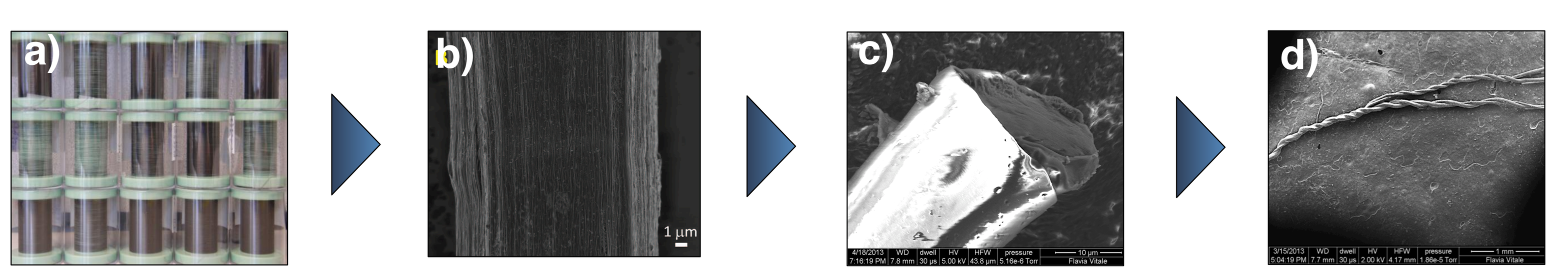
OBJECTIVES

This work explores the potentials of CNT fibers as flexible, small area microelectrodes for neural stimulation and recording applications

- Development of a fabrication method
- Characterization of electrochemical properties
- Comparison with current materials for microelectrodes
- Evaluation of CNTf electrodes *in vivo* and stability analysis

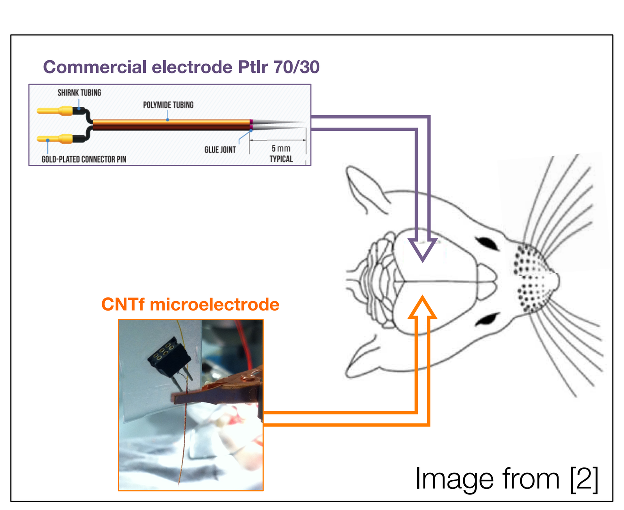
MATERIALS AND METHODS

Electrode fabrication



(a,b) CNT fibers are fabricated by wet spinning of high concentration solution of CNTs [1]. (c) A continuous dip-coating process is used to coat the fibers with 2 μm layer of an insulating elastomer. (d) Coated CNTf are shaped into microelectrodes with the desired configuration (i.e. stereotrodes, tetrodes)

Characterization



In vitro

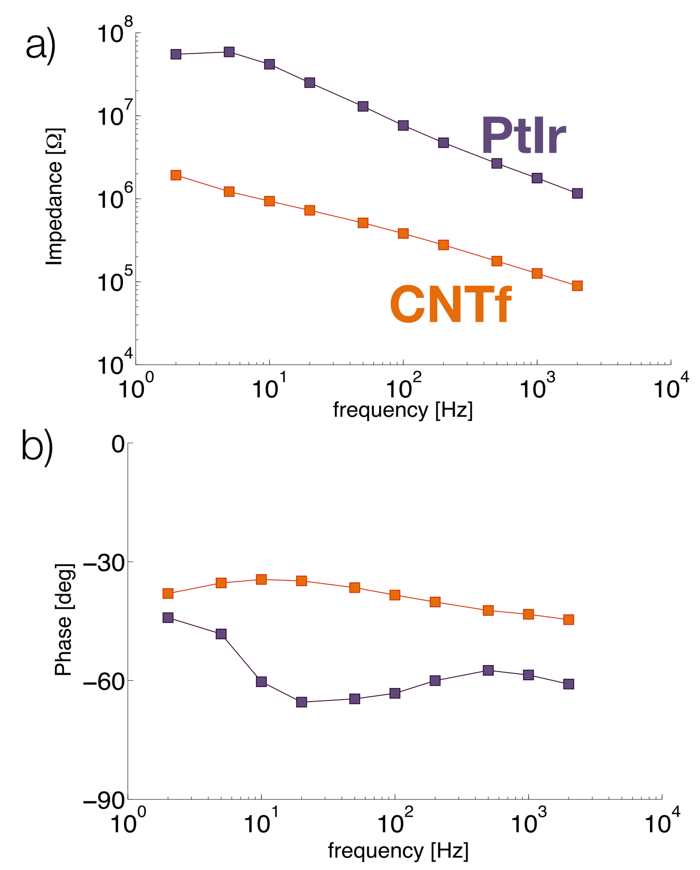
- Characterization of electrochemical properties in an electrolytic cell

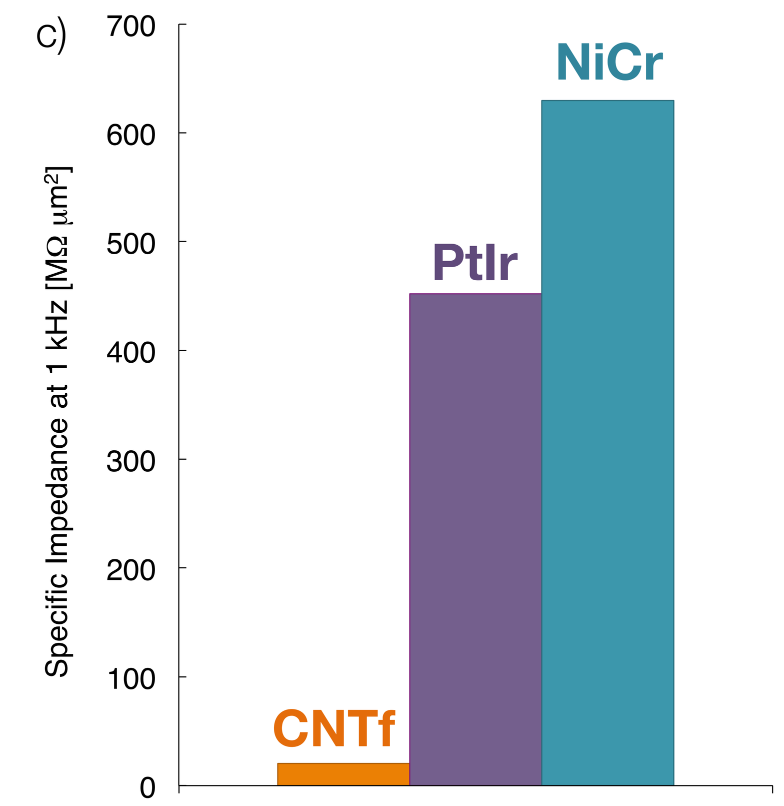
In vivo

- Implant of CNTf microelectrodes in GPi of Long Evans rats (n = 4)
- Voltage transient and stability analysis

RESULTS

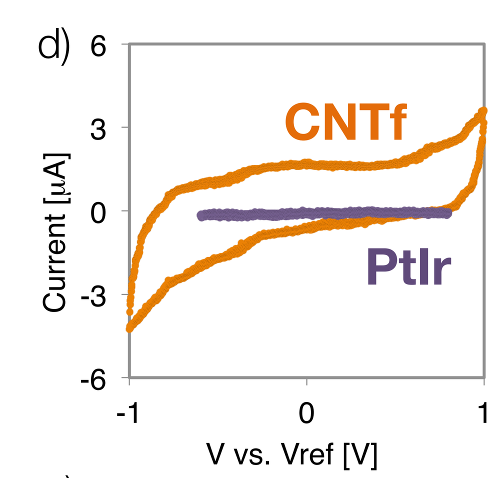
In vitro



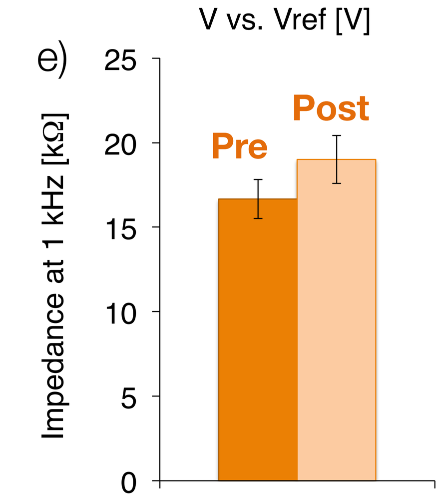


Impedance spectroscopy of 18 μm CNTf and same size PtIr wire; a) modulus, b) phase. CNTf show 15-20 times lower impedance in the entire range of frequencies tested. Impedance at 1 kHz is in the range suitable for neural recording applications (~100 kΩ), without need of electroplating as required when using standard metal electrodes (c)

Cyclic voltammetry shows that CNTf possess much larger cathodic charge storage capacity (715 mC/cm²) when compared to PtIr electrodes (6 mC/cm²)



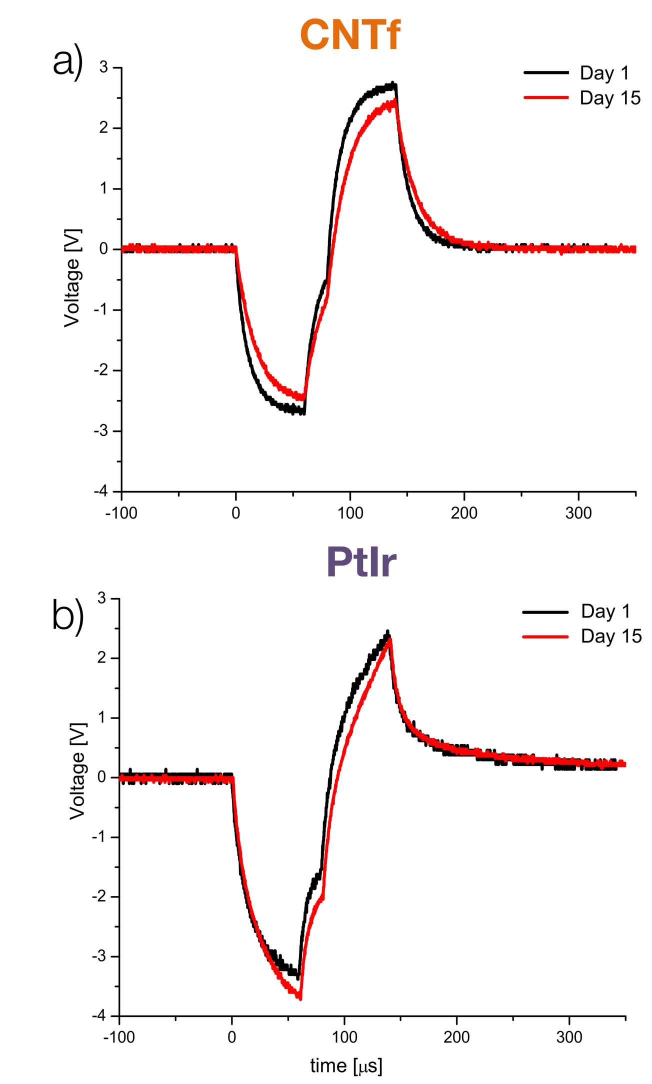
e) CNTf stereotrodes are stable after 1 week of continuous pulsing with a train of charge balanced, biphasic 60 μs/phase, 250 μA pulses at 130 Hz (fiber diameter: 42 μm)

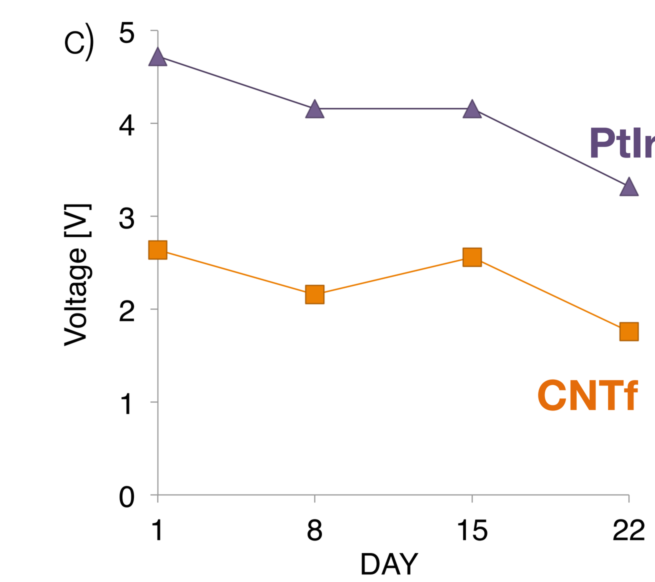


Summary of properties of the microelectrodes used for the *in vivo* study

	CNTf	PtIr
Surface area [μm²]	1385	30000
Impedance @ 1 kHz [kΩ]	15	10
Water window [V]	-1.5 - 1.5	-0.6 - 0.8
Charge injection capacity [mC/cm²]	7	0.08

In vivo





In vivo voltage transient immediately after and 15 days following the implant (biphasic stimulation pulse, 60 μs/phase, 20 μs interpulse, 250 μA at 130 Hz). CNT fibers (a) are stable and functional and show lower voltage transient when compared to PtIr (b).
The stability is confirmed by maximum negative voltage excursions over a period of three weeks (c).

CONCLUSIONS

CNTf hold great promise as a new material for small-scale, flexible, neural electrodes for recording and stimulation.

Results of this work show:

- CNTf can be easily processed to fabricate microelectrodes
- CNTf are intrinsically multifunctional for recording and stimulation, thanks to the low impedance and high charge accumulation capacity
- CNTf electrodes implanted in model animals show very good stability and functionality over time

REFERENCES

[1] Cogan, S.F. "Neural Stimulation and Recording Electrodes". Annu. Rev. Biomed. Eng. 10:275-309 (2008).
[2] Venkatraman, S. "*In vitro* and *In Vivo* Evaluation of PEDOT Microelectrodes for Neural Stimulation and Recording" IEEE Trans. Neural Syst. Rehabil. Eng. 19:307-316 (2011).
[3] Behabtu, N. "Strong, Light, Multifunctional Fibers of Carbon Nanotubes with Ultrahigh Conductivity" Science 339:182-185 (2013).