Mechanical Behavior/Performance of Implantable Silver-Cored Conducting Cables

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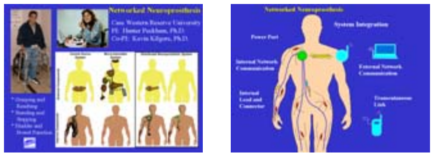
ABSTRACT

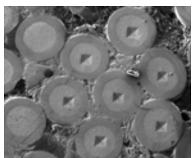
A team of materials scientists is supporting the development of Networked Implantable Neuroprostheses (NNPS) Systems on an NIH-Bioengineering Research Partnership project led by PI, Professor Hunter Peckham. The Materials Group is leading the material and structural evaluation, analysis, and testing of implantable leadwires and interconnects that form part of the NNPS. Leadwire and cable assemblies are being developed using Drawn Filled Tube (DFT) technology, i.e. silver-cored conductors. The leadwire is formed into cables that are used for the Network Cabling functions of the NNPS system. Two areas of particular interest are summarized in the poster: (a) Response of the leadwire and cable systems to the mechanical stresses imposed during long-term implantation. The Materials Group will design, construct, and analyze a series of tests to evaluate leadwire and cable designs. Long-term tests are ongoing to evaluate the performance of leadwires and cables intended for human application. (b) Corrosion and electrochemical behavior of the DFT material when implanted and exposed to the human body environment. The Materials Group will design, conduct, and analyze a series of experiments for the suitability of using DFT safely in the body.

SCHEMATIC OF NNPS CONCEPT

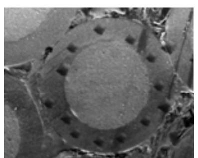


STRENGTH OF DFT ELECTRODES: MICROHARDNESS TESTS

- •Microhardnesses determined in Ag core and MP35N.
- •Ag core exhibits lower hardness (I.e. larger indent size) than MP35N.

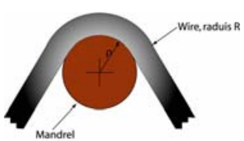


Microhardness indentations in Ag core



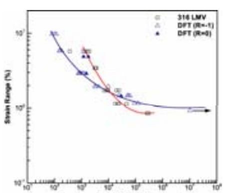
Microhardness indentations in MP35N

FATIGUE PERFORMANCE OF DFT AND 316L ELECTRODES



Electrodes are tested in cyclic fatigue via bending over a mandrel. Mandrel radius controls stress and strain experienced by electrodes/wires.

Flex tester used to conduct cyclic fatigue tests on electrodes/wires. Cyclic frequency < 5 Hz. Break detector automatically detects failure and stops cycle counter.



Initial results comparing fatigue behavior of 1x7 316L Stainless Steel electrodes/wires to 7X7 DFT electrodes/wires. Data obtained using flex tester with different sized mandrels to vary strain range. Individual data points indicate number of cycles to failure for each strain range (I.e. mandrel size) tested. Arrow indicates sample that did not fail.

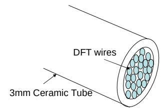
MECHANICAL PERFORMANCE RESEARCH OBJECTIVES

Quantify the mechanical behavior of implantable electrode materials

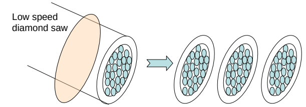
- **•Investigate the effects of materials selection and electrode architecture on strength and cyclic (i.e. fatigue) performance under biomedically relevant test conditions.**
- **•Determine the microstructures present in the electrodes.**
- **•Conduct fractographic analyses on electrodes fatigued to failure.**

MICROSTRUCTURE OF DFT ELECTRODES: TEM INVESTIGATION

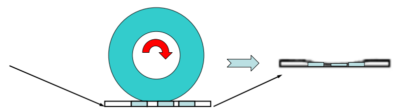
Sample preparation method - Standard Cross-Section Method



Mounting the DFT wires into a ceramic tube with M bond 610 adhesive epoxy.

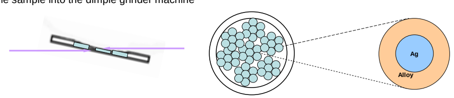


Slice the tube from cross-section direction of the wires

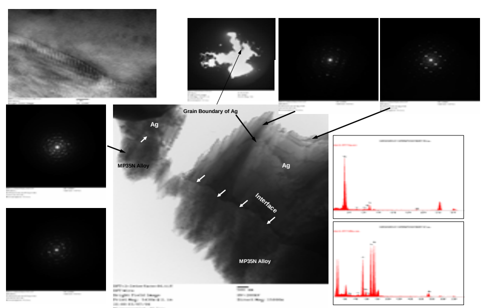


Put the sample into the dimple grinder machine

Dimpling at the center of the sample



Ion-beam milling until a hole generated near the center. The edge of the hole is thin enough for electron to transmit.



- •TEM shows the interface between Ag/MP35N alloy is well bonded; no precipitates present.
- •The Ag core exhibits a large grain size, as indicated by single crystal diffraction pattern.
- •The MP35N exhibits a fine grain size and polycrystalline diffraction pattern.

CORROSION RESEARCH OBJECTIVES

Determine the amount and rate of Silver-Cored conducting cables.

- **To investigate corrosion behavior of single components (Ag & MP35N).**
- **To quantify the corrosion of Silver-Cored conducting cables.**

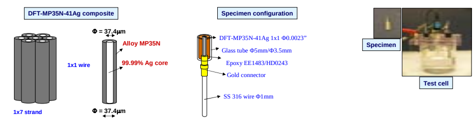
Parameters

- Materials: DFT-MP35N-Ag, pure Ag wires, alloy MP35N
- Environments: 0.9w/o NaCl, Ringer solution, in vivo environment.
- Conditions: freely exposed, imposed FES signal.

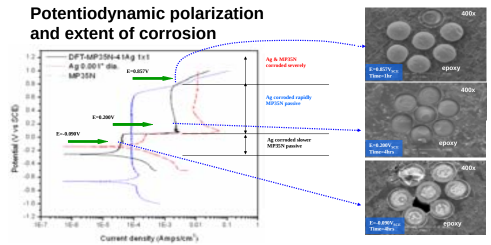
Methods

- Electrochemical: potentiodynamics, potentiostatic, cyclic voltammogram, linear polarization…
- Controlled exposures
- SEM/EDS, surface analysis
- 3-D characterization of damage
- Modeling: E-pH, corrosion damage model

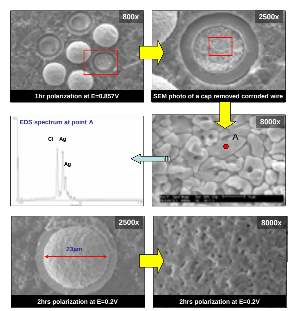
Materials and experiment



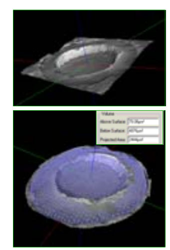
Potentiodynamic polarization and extent of corrosion



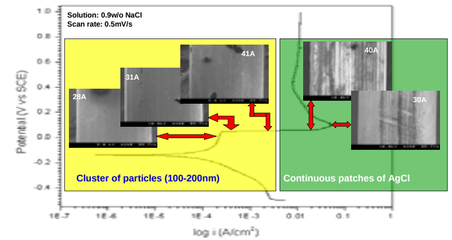
SEM/EDS Analysis



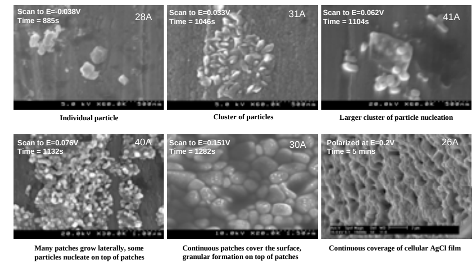
3D reconstruction



Transition formation from cluster of particles to continuous patches of AgCl film

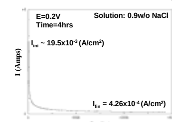


Stages of AgCl formation



- Early corrosion forms AgCl nano particles on surface.
- Later, patches of AgCl film grow laterally on surface.
- Once continuous AgCl later forms corrosion rate decreases rapidly with time.

Corrosion behavior of DFT-MP35N-41Ag during long exposure time



- -Total coulomb passed = 12.3 Cb/cm^2
- - Total Ag dissolved amount = 1.27x10^{-4} mol/cm^2
- - Calculated dissolve depth = 33 μm
- - Rate of Ag dissolution after 4hrs of exposure: r = 4.41x10^{-9} mol/cm^2.s = 39 μm/day

Summary

- The corrosion behavior of Ag was investigated. Ag core exhibit a transition from a slow corrosion process to a severe corrosion behavior when exposed to anodic polarization.
- The transition potential region is at about 40mV to 70mV vs SCE.
- The abrupt increase of corrosion current has a strong relation with the formation of a AgCl film on the surface of Ag substrate.
- Once AgCl film forms, corrosion current decreases as time goes on.

Acknowledgements

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