Electronic Supplementary Material (ESI) for Soft Matter.

Supplemental Materials

Experimental

Formulation and extrusion of Silicone/Aedotron™ C3 blends to form elastic conducting wires

MED6607 is a one-part poly(dimethylsiloxane) (PDMS) room temperature vulcanizing (RTV) silicone in naptha (70% wt.) containing 15% wt. of PDMS pre-polymer, 10% wt. of methyltris(methylethylketoxime)silane tri-functional cross-linker, and 5% wt. treated amorphous silica. MED6607 is approved for long-term implant applications of 30 days or more in humans. Aedotron™ C3 was used as a gel in ACN containing 5-8% wt. of the conducting block copolymer (shown in Figure 1) and 95-92% wt. of solvents. MED6655 is a suspension of 100% FS particles in tert-butyl acetate and is approved for long-term implant applications of 30 days or more.

Characterization of coated and uncoated wires

The bulk conductivity of the uncoated wires was then calculated from the linear resistance and the known geometry of the wires:

$$C = \sigma \frac{A}{l} \qquad [1]$$

where C is the conductance, σ is the conductivity, A is the cross-sectional area, and l is the length of the wire.

Fabrication of electrodes for in vivo functional studies

For the *in vivo* studies, electrodes with the following characteristics were fabricated (Supplemental Figure 1):

- Core: The core of the wire was made by extruding a blend of 8.5% wt. Aedotron™ C3 in MED6607 through a 29G needle bore to give cured wires of 130 ± 20 μm in diameter.
- Tip: The tip of the wire was cut at a bias angle to decrease the active area of the electrode for recording applications. Wires were embedded in Norland #61 Optical Adhesive (Edmund Optics) and glued to a polyester cutting block. The wire axis and ends were aligned on the block during gluing with alignment guides and visual inspection such that the wire was biased at a 3^o offset angle from the cutting wheel. The mounted/embedded wire was clamped in the cutting jig of a LECO Corp. Vari/Cut™ VC-50 diamond saw, outfitted with a 5 in. diameter diamond wafering blade, and the wire was cut through the embedding optical adhesive. This bias-cut end was then released in a mixture of 4:1 dichloromethane:1-methyl-2-pyrrolidinone which efficiently swells the optical adhesive for easy removal of the wire.
- Gold coating: Bias cut wire ends were masked with tape to cover ~2 mm of the wire and the unmasked portions were sputter-coated with ~10 nm of gold.
- Insulating layer: The gold-lined, tip-trimmed wires were then dip-coated in an insulating layer of FS using three coatings of MED6655 (diluted 2:1 with n-butyl-acetate) for 10 minutes drying time between coatings; final coatings were dried overnight.
- Trimming: After curing the FS coating, the soft wire tip-end and the back-end were trimmed to expose the electrically conducting core. The active area of the tip was determined to be 3900 μm^2 as determined by optical microscope metrology. The back-end was glued to either copper tape or a gold pin with silver adhesive and used for connection with the hardware. The electrical connection from the copper tape to the tip was confirmed using a DMM and a saturated salt brine solution for immersion of the tip.

Results and Discussion

Electrical properties of uncoated wires

In theory, the bulk conductivity is an intrinsic property of the material and should be independent from the wire diameter for each given loading of Aedotron™ C3. However, the results demonstrate that the bulk conductivity of the 4.5% wt. blend slightly increases as wire diameter decreases (i.e., bulk conductivity increases with the shear force applied during extrusion which is higher for smaller diameters; Supplemental Table 2). This suggests that there is a limited shear-induced alignment of the conducting domains within the blend during extrusion, a well-known phenomenon in composite materials. At higher loadings this phenomenon is not visible. Such shear-induced alignment is fairly limited and the average bulk conductivity calculated by averaging the values obtained from different wire diameters has a small standard deviation (last row, Supplemental Table 2).

Mechanical properties of uncoated and insulated wires

All recorded stress-strain curves had the expected shape with a linear region corresponding to reversible elastic deformation (from which the Young's modulus was calculated) and a second region corresponding to irreversible deformation. The stress-strain curve of the unfilled PDMS (MED6607) shows a good signal-to-noise ratio (Supplemental Figure 2A), but all specimens slipped out of the grips prior to mechanical failure and elongation at break could not be determined. In contrast to the unfilled elastomers, the stress–strain curves of small diameter conducting wires are noisy; small dimensions (168-208 µm) translate to a small load for elongation (at the sensitivity limit of the instrument). In general, the noise associated with the curves increases as the diameter of the wires decreases and as the loading of Aedotron™ C3 increases; the stress-strain curve of a 7%-filled 29G (130 µm) uncoated wire is shown in Supplemental Figure 2B as an example. Formulations with a loading of Aedotron™ C3 of 12, 13 and 15% broke during specimen mounting and could not be tested for mechanical properties suggesting that these materials were too brittle to be used as neural electrodes.

The stress-strain curve of the Parylene C coated wire (Supplemental Figure 2, C and D) indicates an extremely sharp transition between the linear region of elastic deformation (characterized by a high modulus) and the irreversible deformation (characterized by a much lower modulus).

Needle Gauge Size	Needle Bore Diameter (μm)	Cured Wire Diameter ± SD (μm)
22 G	442	285 ± 30
26 G	271	179 ± 25
29 G	205	131 ± 20
30 G	176	121
31 G	144	92.6

Supplemental Table 1. Relationship between needle gauge size, needle bore diameter, and cured wire diameter.

Fill (%)	4.5%	5.5%	7.1%	8.5%	10.0%	12.0%	13.0%	15.0%
Wire size	**Bulk Conductivity ± SD (S/cm)**							
22G	0.10±0.03	0.44±0.01	0.87±0.08	2.34±0.11	2.53±0.40	2.27±0.13	4.36±0.88	6.27±0.50
26G	0.07±0.01	0.44±0.02	0.85±0.05			1.81±0.18	2.65±0.11	
29G	0.11±0.01	0.52±0.03	0.98±0.07			1.95±0.16	2.32±0.10	
30G			0.59±0.01					
AVG	0.09±0.02	0.46±0.05	0.82±0.16	2.34±0.11	2.53±0.40	2.01±0.24	3.11±1.09	6.27±0.50

Supplemental Table 2. Bulk conductivity (± SD) in S/cm of elastomers versus Aedotron™ C3 loading calculated from linear resistance measurements on wires of different diameters. The last row is the average conductivity of each composition over all wire sizes.