Development of antistatic wire insulator by dispersing electroconductive nanoparticles: from the laboratory material to the prototype

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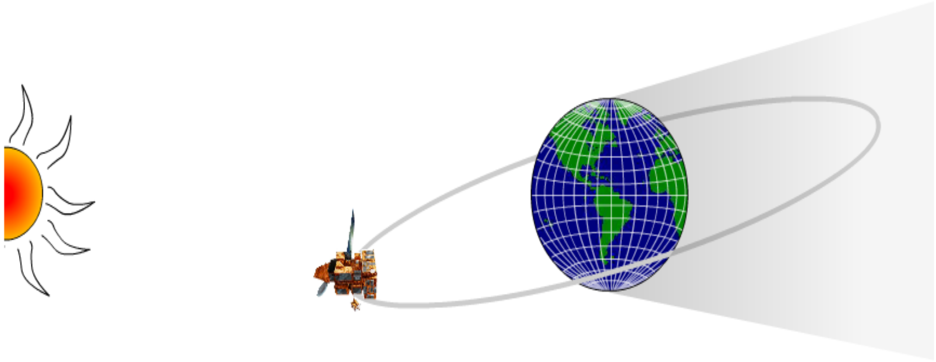
Space Passive Component Days, ESA-ESTEC, 9-12 October 2018

MATERIALS SUBJECTED TO SPACE HAZARDS

Low earth orbit (LEO): known hazards



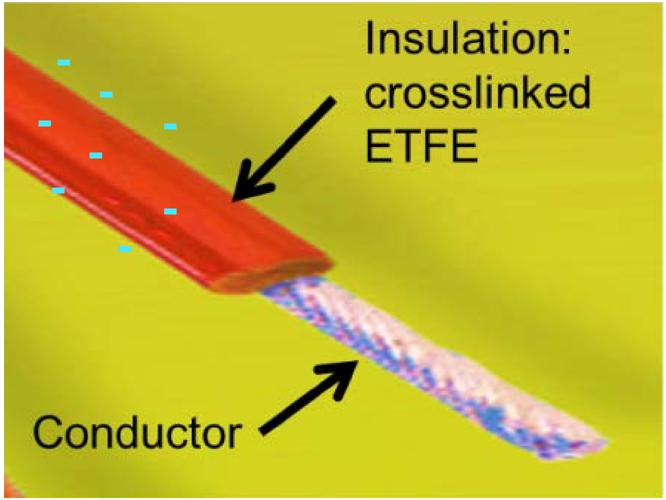
Thermal: -180° to 160°
Charging: eV to >100keV
Ultraviolet: equivalent sun hour
Atomic oxygen: atom/cm^2
Particle radiation: 200 Mrad

Jupiter mission: unknown threats

ESA plan to send explorer satellite to study Jupiter moons in 2022

(JUICE project, 350 Millions €)

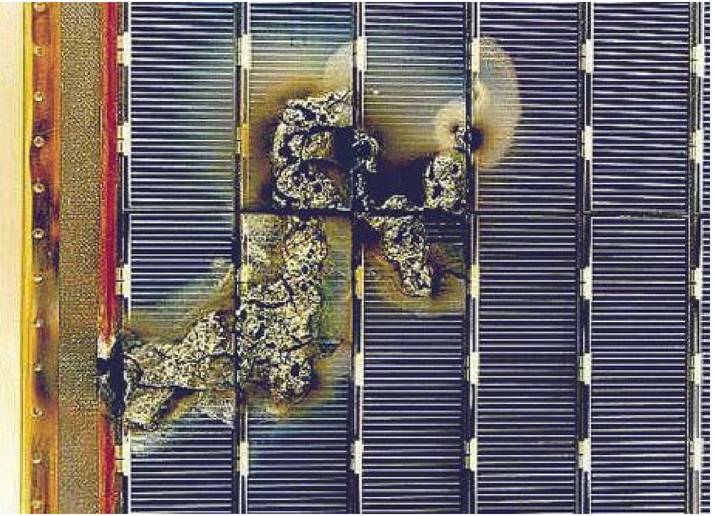
SURFACE CHARGING EFFECT ON SATELLITE ARRAYS



SUNLIGHT POSITION:
Positive charging of solar panels (photoelectric current)

SHADOW POSITION:
Negative charging of the wire connected to the solar panel (plasma current)

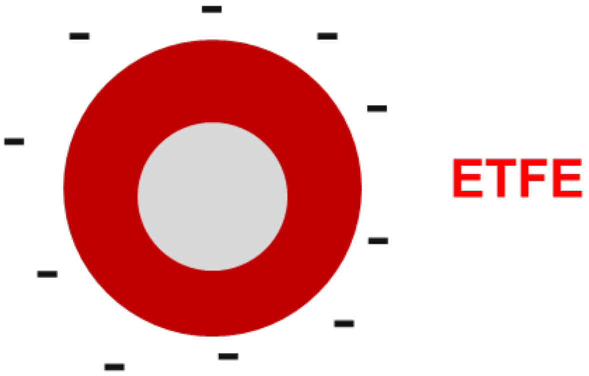
SURFACE CHARGING EFFECT ON SATELLITE ARRAYS

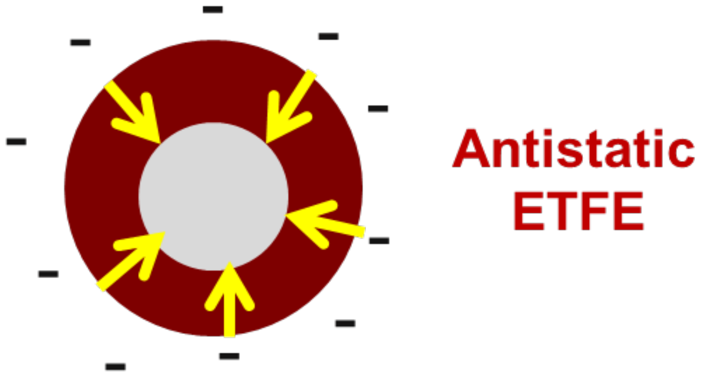


From ESA

Surface arcing effect or electrostatic discharges
→ damage of satellite arrays / onboard electronics

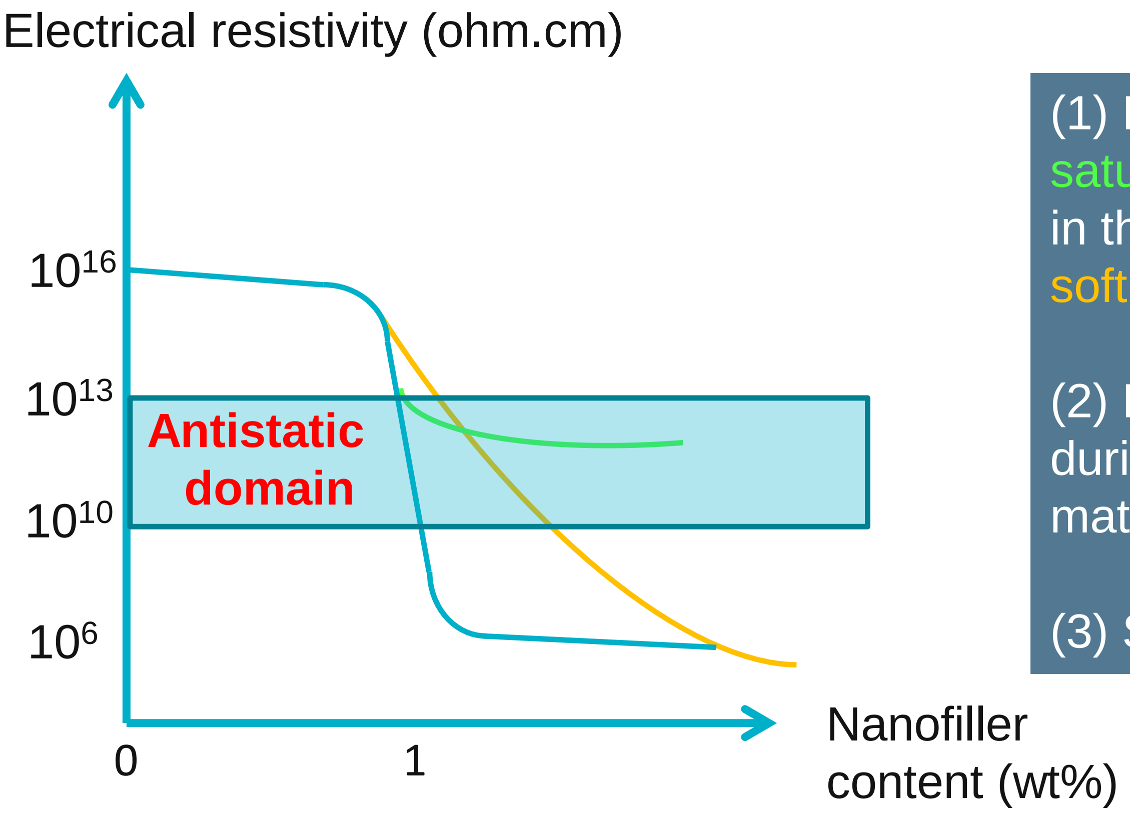
PROJECT OBJECTIVES





Modification of ETFE formulation by adding conductive nanoparticles (carbon nanotube, carbon black…) to decrease bulk resistivity → dissipation of surface charging

TECHNICAL CHALLENGES



(1) Developing formulations with saturation of resistivity in the antistatic domain or with a soft percolation threshold

(2) Retaining antistatic properties during the scale-up from lab materials to wire prototyping

(3) Space durability ?

esa

Request for quotation (RFQ)
Project ended 09/2018

Material development & testing

LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY | LIST

Prototype manufacturing & testing

axon' cable & interconnect

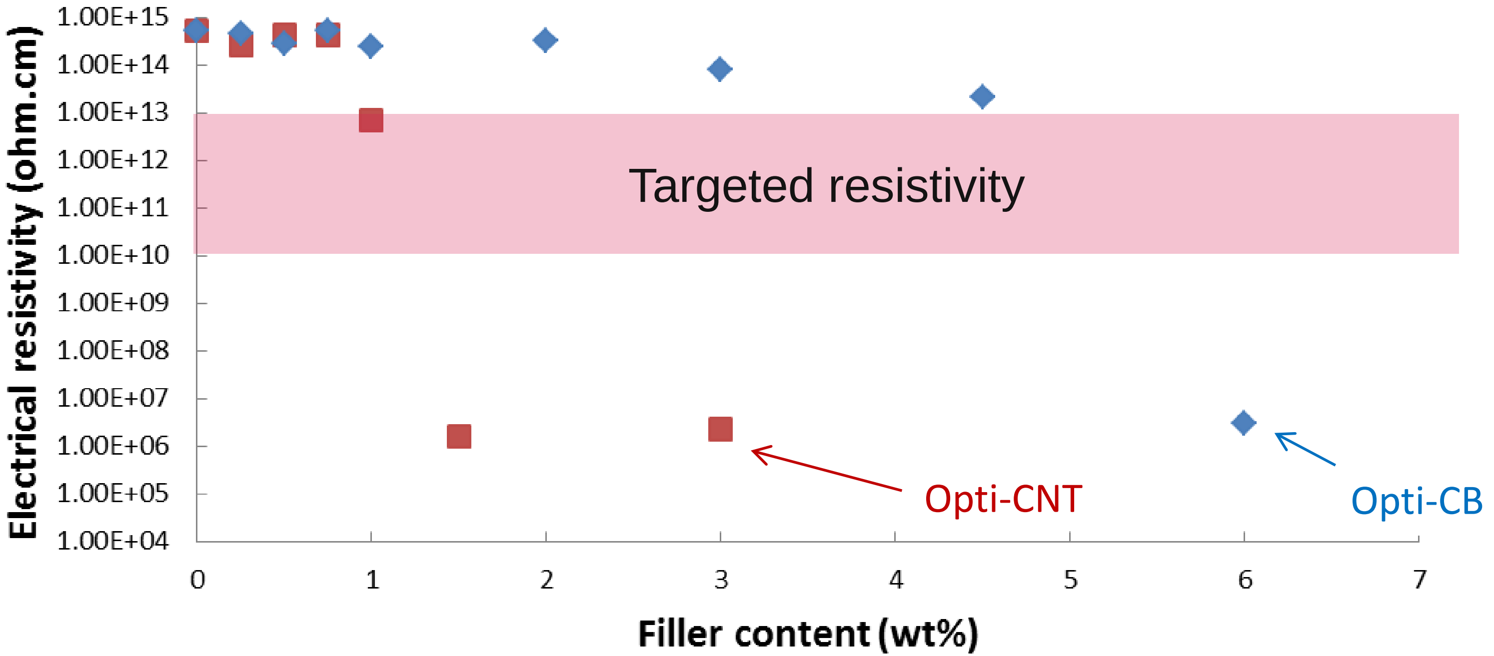
Nanocomposite processing:

Micro-extruder (10g/batch), mini-extruder 1 kg/h…

Characterization:

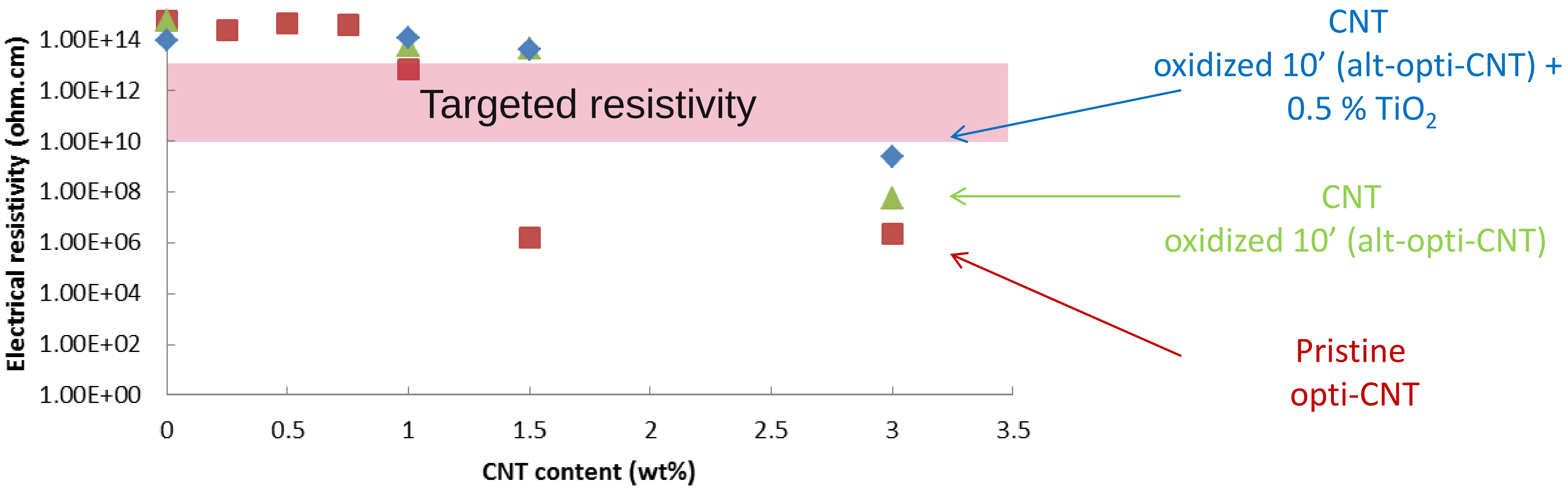
SEM, AFM, µCT, DSC, DMA, TGA, NMR, FTIR, NMR, nanoSIMS, SAXS/WAXS, tensile testing….

Comparison between CB and CNT on the on ETFE nanocomposite resistivity



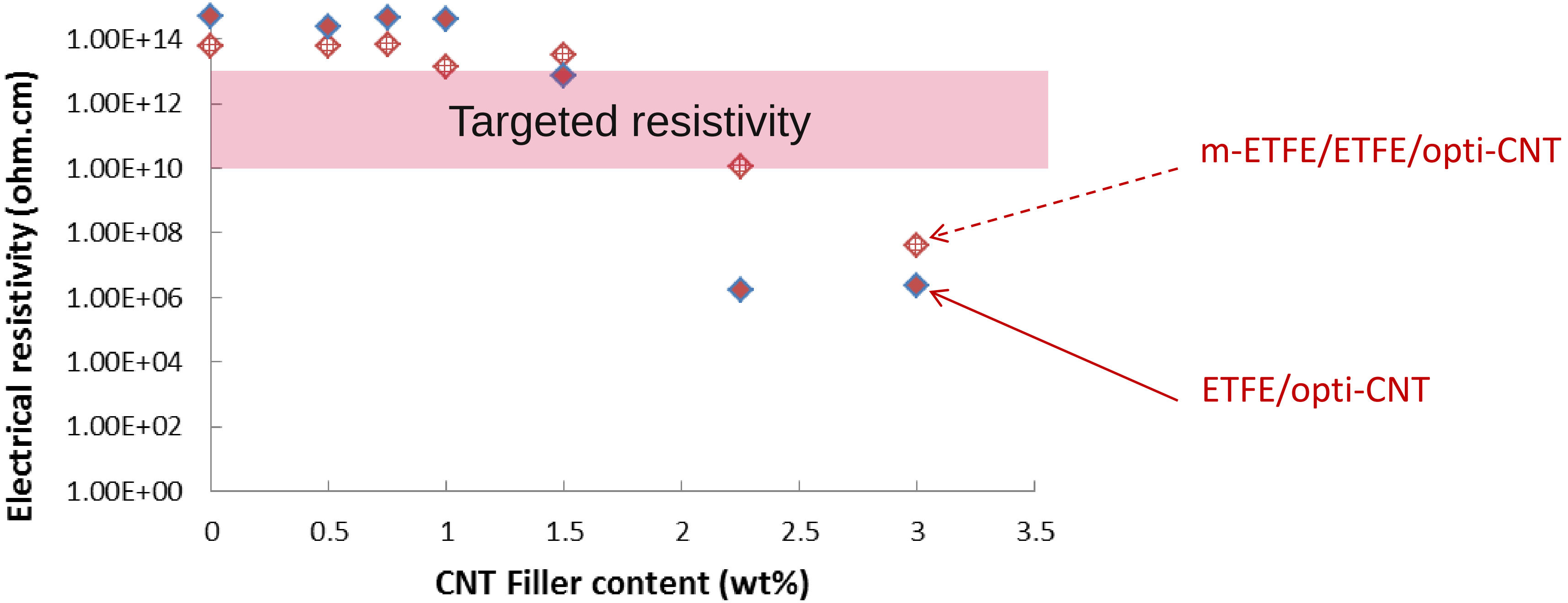
CB provides a softer percolation threshold compared to CNT
→ ETFE/opti-CB 100/5.125 selected

Effect of the CNT treatment and addition of non-conductive particles on ETFE nanocomposite resistivity



Percolation threshold can be tailored with oxidation of CNT and adding TiO_2
→ ETFE/alt-opti-CNT 100/2 selected

Effect of mixing ETFE with a chemically modified ETFE (m-ETFE) on ETFE nanocomposite resistivity

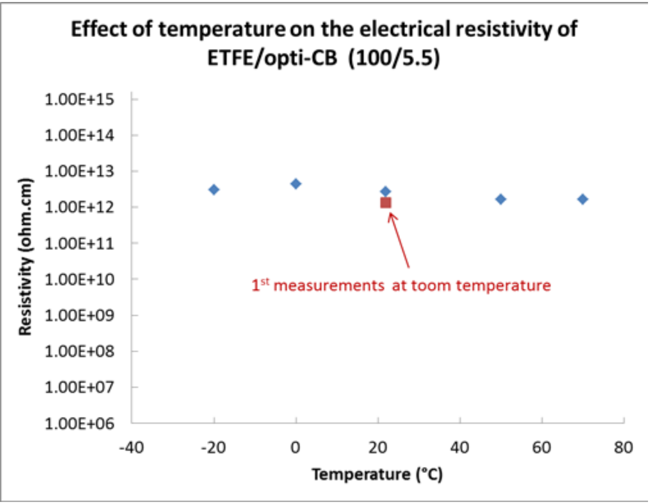


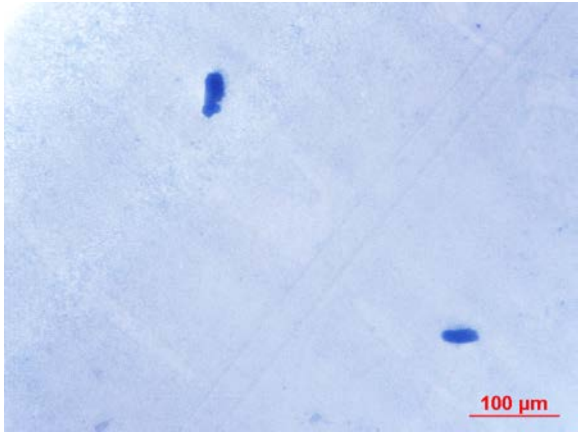
Percolation threshold can be tailored by mixing ETFE with a chemically modified ETFE → ETFE/m-ETFE/opti-CNT (50/50/1.875) selected

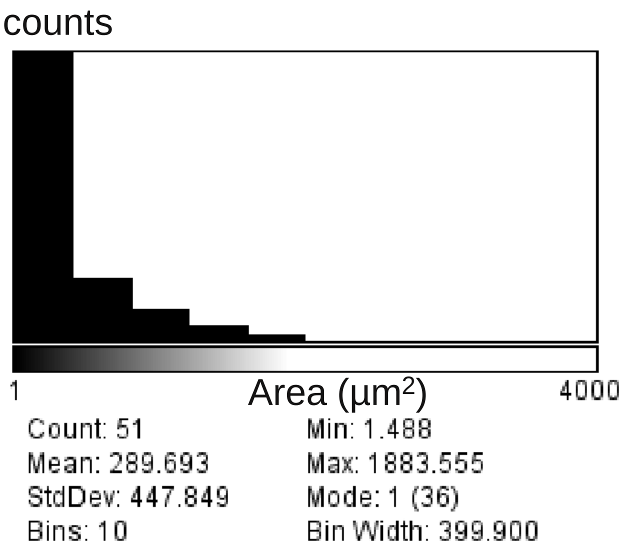
In-depth characterization of the selected formulations

Formulations	Electrical resistivity in the antistatic range	Electrical resistivity repeatability	Electrical resistivity stability from -20°C to 70°c	Electrical resistivity after annealing	Agglomerate size	Nanoparticle dispersion	Thermal expansion	Tensile testing	Thermogravimetric testing
ETFE/alt-opti-CNT (100/2) ✗	FAILED	Not tested	Not tested	Not tested	Not tested	Not tested	Not tested	Not tested	Not tested
ETFE/alt-opti-CNT (100/2.5) ✗	FAILED	Not tested	Not tested	Not tested	Not tested	Local agglomerates with single particle dispersion	Not tested	Not tested	Not tested
m-ETFE/ETFE/opti-CNT (50/50/1.875) ✓	PASSED	PASSED	STABLE	STABLE	1 µm² to 400 µm², average 105 µm²	Local agglomerates with single particle dispersion	Max 2% from 22°C to 180°C	Elongation < 50% / ETFE	Effective fraction of opti-CNT: 4.5%
ETFE/opti-CB (100/5.125) ✗	FAILED	Not tested	Not tested	Not tested	Not tested	Not tested	Not tested	Not tested	Not tested
ETFE/opti-CB (100/5.5) ✓	PASSED	PASSED	STABLE	DECREASED	1 µm² to 400 µm², average 290 µm²	Local aggregates, hard to see single particle	Max 2% from 22°C to 180°C	Elongation > 50 % / ETFE	Effective fraction of opti-CB: 6.2%

Some typical characterization results: ETFE/opti-CB (100/5.5)



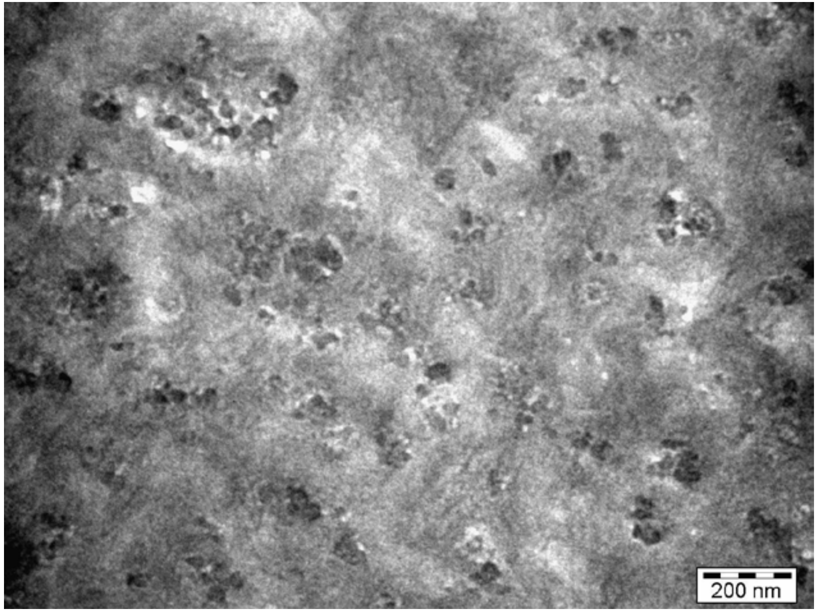


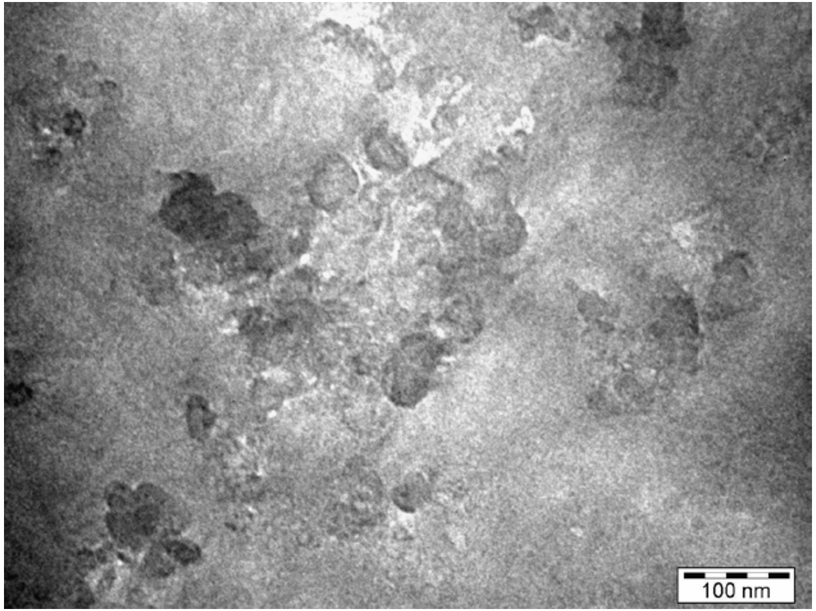


Electrical resistivity
→ Stable from -20° to 70° C

Optical microscopy
→ calculation of average aggregate size as an indicator of dispersion, here 300 µm²

Some typical characterization results: ETFE/opti-CB (100/5.5)



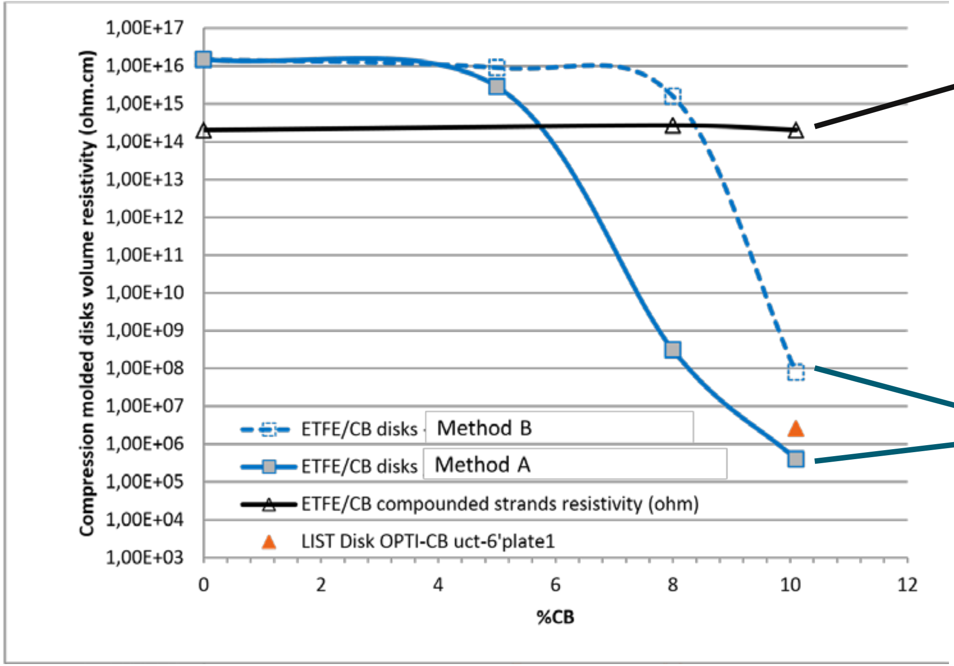


Transmission electron microscopy
→ no single particle, organization into aggregates of diameter comprised between 100 nm and 200 nm

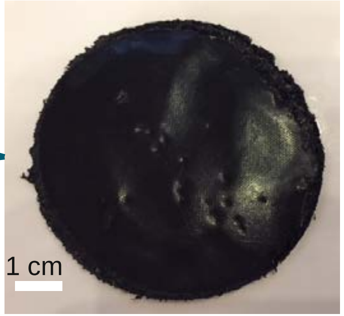
Scale-up at AXON requires masterbatches that will be diluted at different concentrations

3 x 10 kg of masterbatch:
ETFE/opti-CB, c-ETFE/opti-CB, and m-ETFE/-ETFE/opti-CNT
processed at LIST

AXON compounding stage (dilution), case ETFE/CB



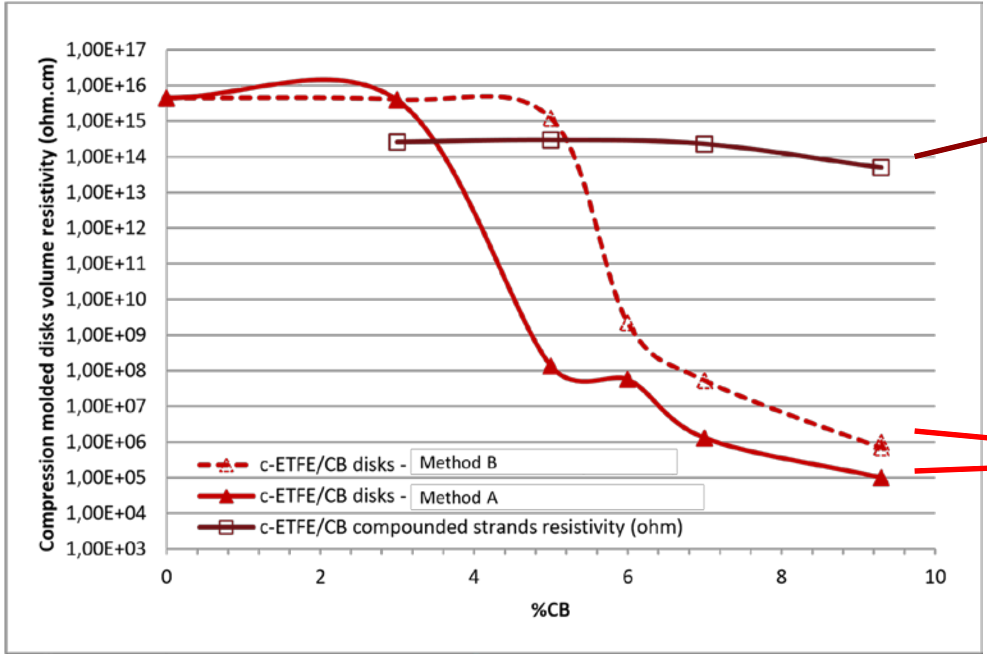
Compounded strands



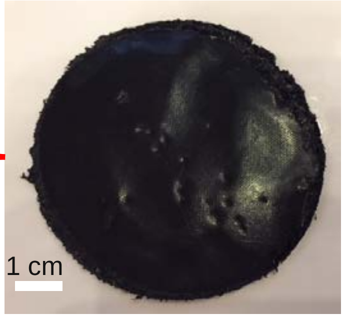
Compression-molded disk

Percolation curve determined for the disks, important effect of processing methods (conditions), but compounded strands non conductive

AXON compounding stage (dilution), case c-ETFE/CB



Compounded strands



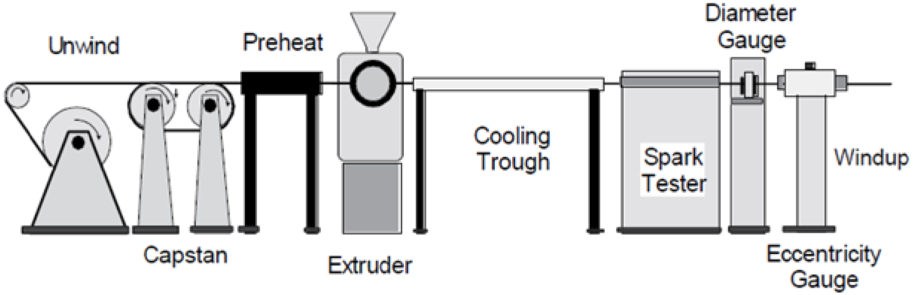
Compression-molded disk

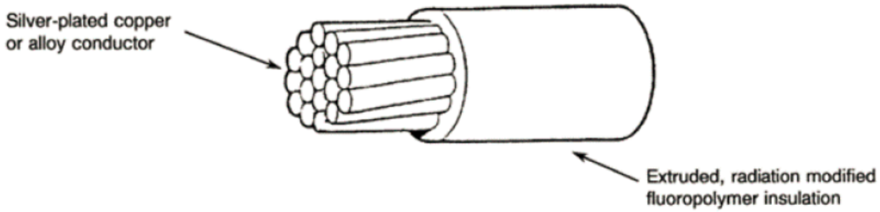
Percolation curve determined for the disks, important effect of processing methods (conditions), but compounded strands non conductive

AXON compounding stage (dilution), case m-ETFE/ETFE/opti-CB

m-ETFE/ETFE/opti-CNT impossible to dilute during the compounding stage
→ formulation too viscous, abandoned

AXON wire manufacturing

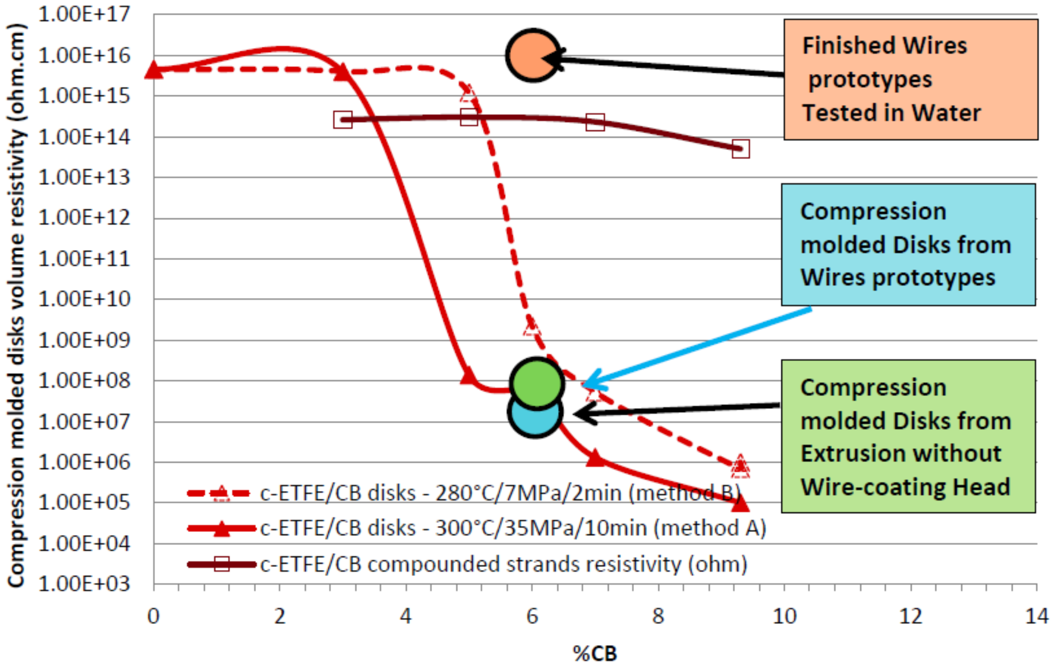




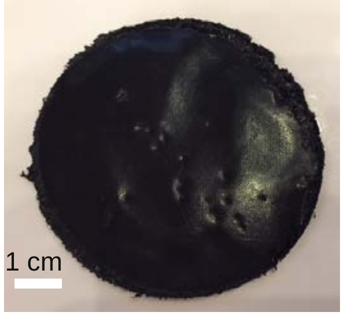
Variant No.	Shielded	Un-Shielded	No. of Cores	ISO 2635 Wire Code	Stranding No. of Strands × Diameter (mm)	Conductor Characteristics			Shield Strand Ø (mm)	Core Max Ø (mm)	Finished Wire or Cable Characteristics	
						Max Ø (mm)	Nom Section (mm^2)	Max Ohmic Resistance (Ω/km)			Max Ø (mm)	Max Weight (kg/km)
01		X	1	-	7×0.1 (1)	0.3	0.06	385.1	-	-	0.64	0.98
02		X	1	-	7×0.12 (1)	0.38	0.08	244	-	-	0.7	1.35
03		X	1	001	19×0.1 (1)	0.53	0.15	149	-	-	0.86	2.11
04		X	1	002	19×0.12 (1)	0.66	0.25	106.2	-	-	0.99	2.97

ESCC3901/012 Type ETFE-based wire variant table extract- variant 4

AXON extrusion stage (wire production), case c-ETFE/CB



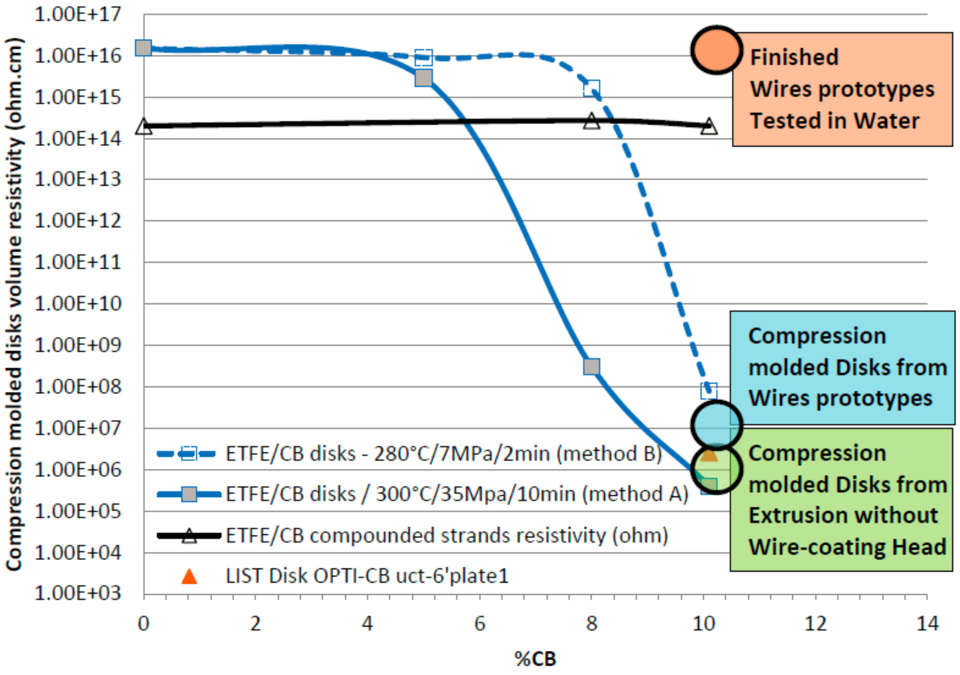
Extruded wire



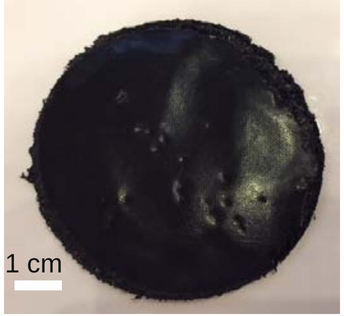
Compression-molded disk

Loss of electrical conductivity in the case of the extruded wire insulator, conductivity recovered when the insulator is transformed into compression-molded disks

AXON extrusion stage (wire production), case ETFE/CB



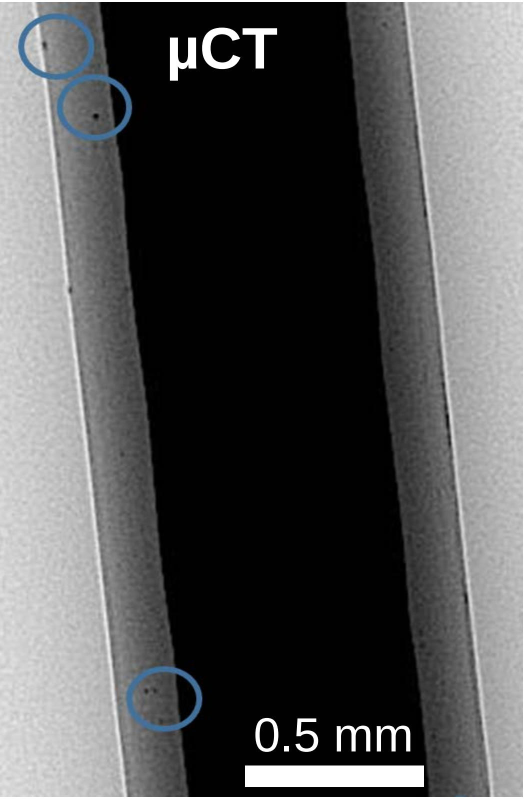
Extruded wire

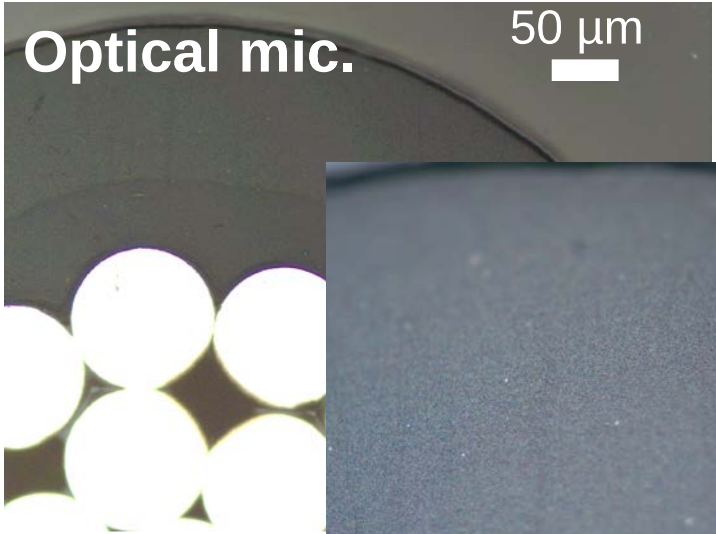


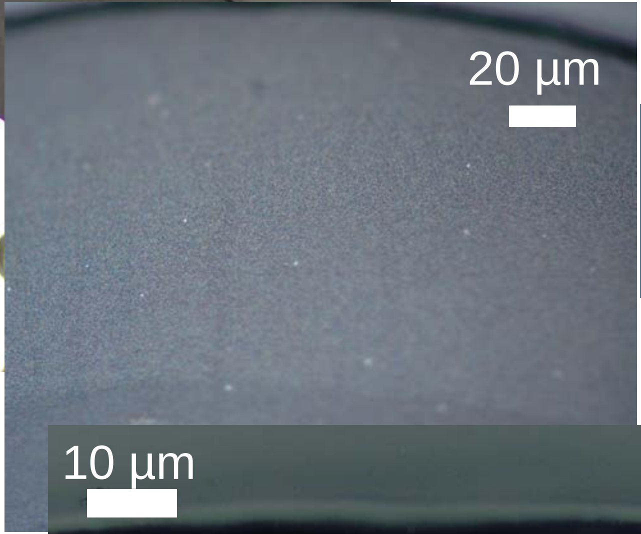
Compression-molded disk

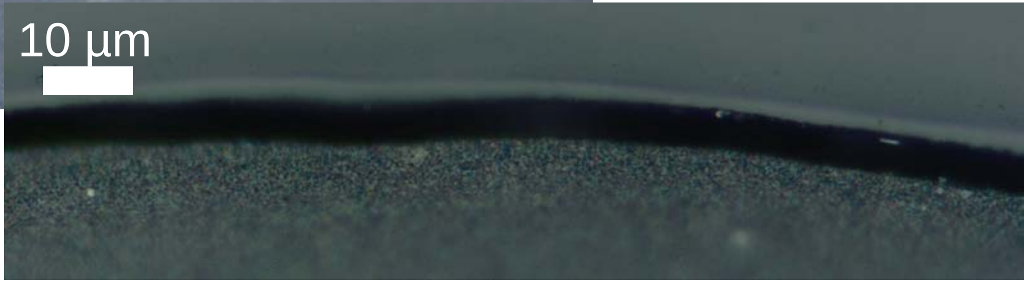
Loss of electrical conductivity in the case of the extruded wire insulator, conductivity recovered when the insulator is transformed into compression-molded disks

Loss of conductivity in the case ETFE/CB wire insulator? Particles distribution?





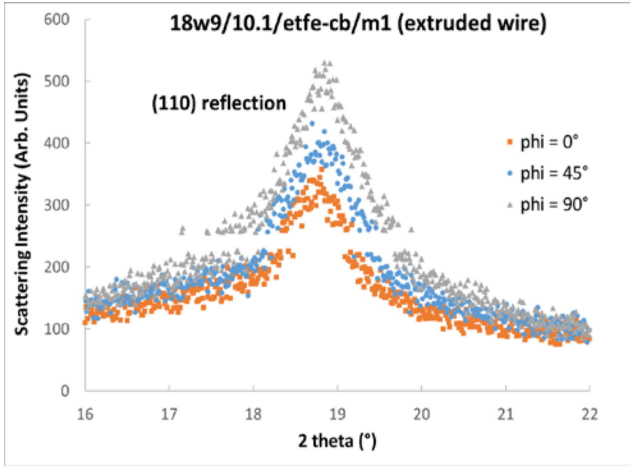




Homogeneous aggregate distribution

Loss of conductivity in the case of ETFE/CB wire insulator? Wire design?

Effect of extrusion

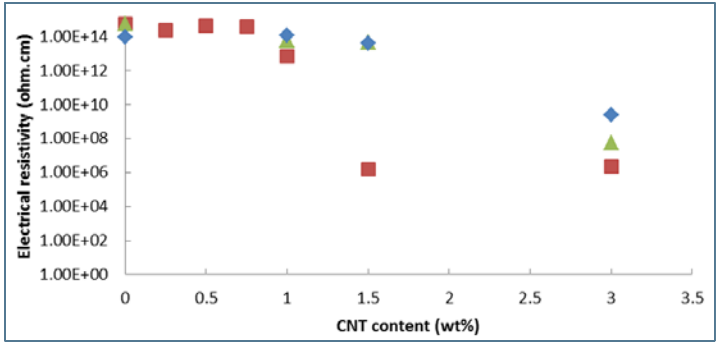


Orientation of the polymer chain possibly deconnecting conduction paths

Effect of wire insulator thickness

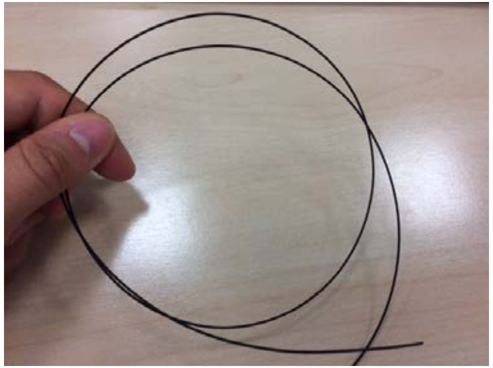
Case	Electrical resistivity (ohm.cm)
Wire with insulator made of **ETFE/opti-CB 90/10 (insulator thickness 0.2 mm)**	4.99E+16
Wire with insulator made of **ETFE/opti-CB 90/10 (insulator thickness 0.475 mm)**	7.05E+15

Possible existence of a critical thickness



Percolation threshold of ETFE nanocomposite can be tailored at the lab scale

- Oxidizing conductive particles
- Mixing conductive with non conductive particles
- Chemically modifying the matrix



But the electrical properties are not retained during the wire insulator extrusion

- process-induced chain orientation induced a potential disconnection between electrical paths
- Possible existence of a coating critical thickness

New wire design with shaping reflecting the compression-molding process
Space durability of the nanocomposites unknown