

Solid Rocket Motor Insulation Testing



Dr. Rusty Blanski

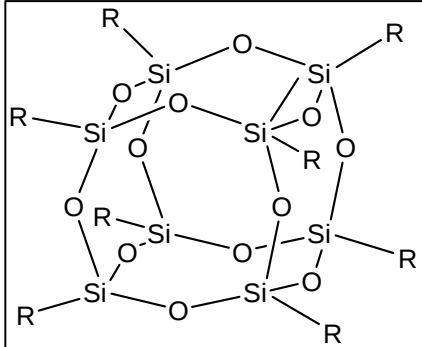
AFRL/PRSM

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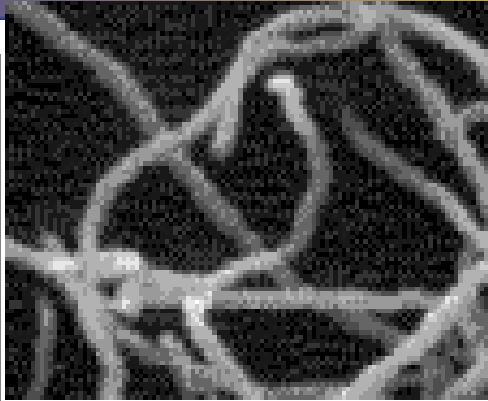
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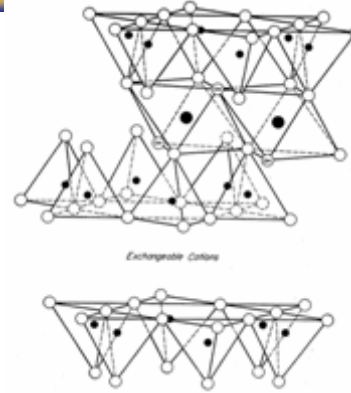
Nanomaterials for Insulation



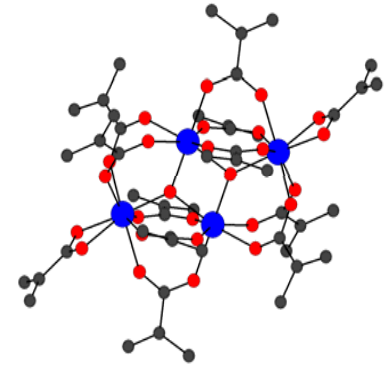
POSS



Carbon Nanofibers

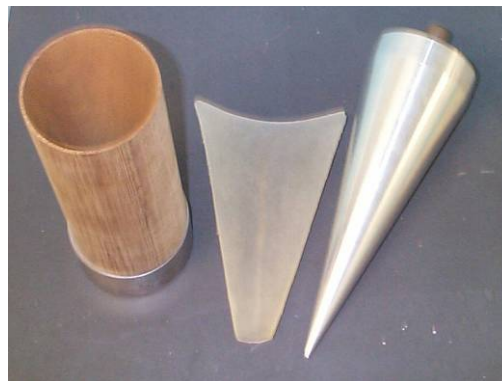
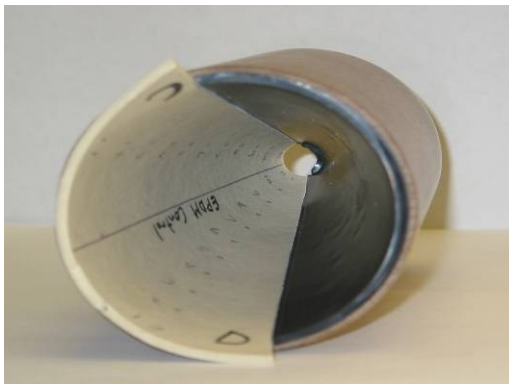


Clays



Zr/Hf nanoclusters

Goal: 50% Lower Erosion of Insulation (44% weight reduction, 7.4% booster payload increase)–Phase III IHP RPT (Phase II, 25%)
Objective: Development of Ceramic Forming Polymer and/or Structurally Reinforced Char Layer



Case Insulation





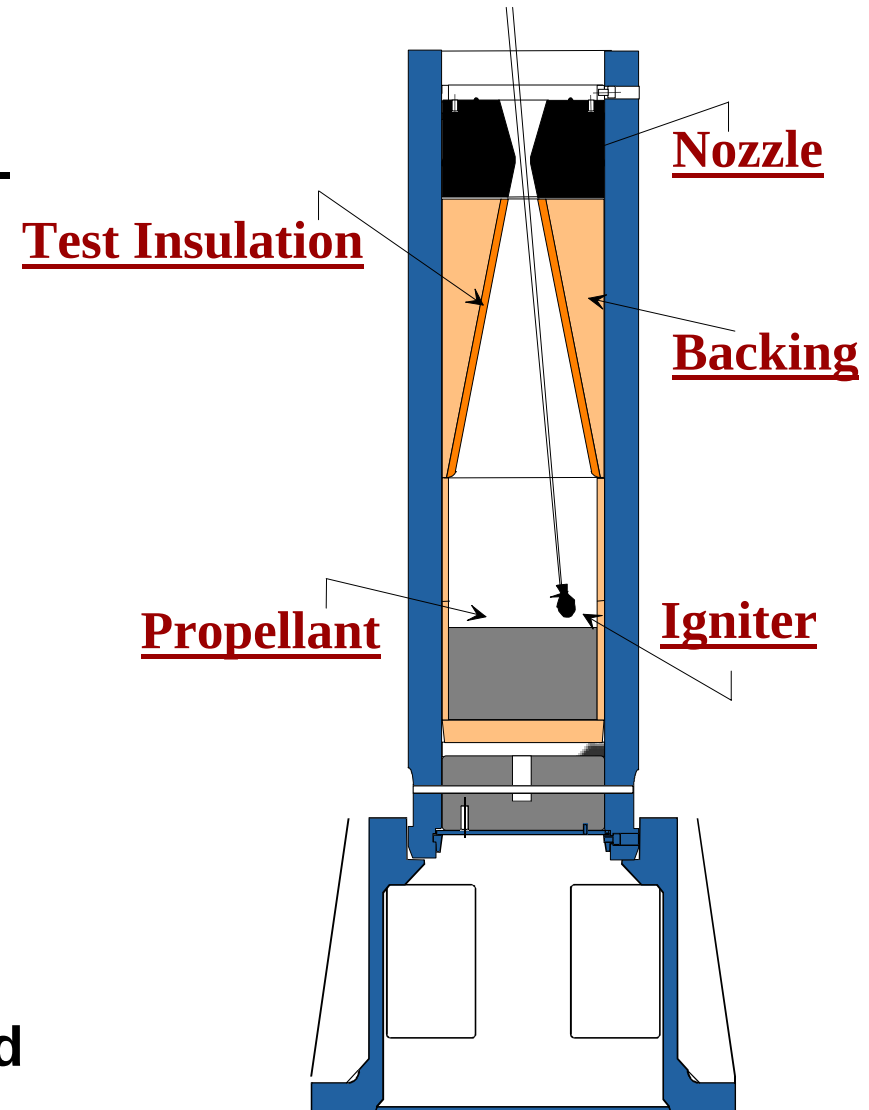
Solid Propellant Insulation Program

In-House Low Cost Screening of New Materials



Present Capabilities:

- Test facilities developed at AFRL-Edwards (4" Pi-K motor) with various propellants (Shuttle, Titan IV, Sidewinder)
- Only 100 g of material needed
- Cost (synthesis, part fabrication, ablation test, analysis): \$2K
- Rapid testing of 5-6 samples per day (or more)
- Nozzle materials can also be tested



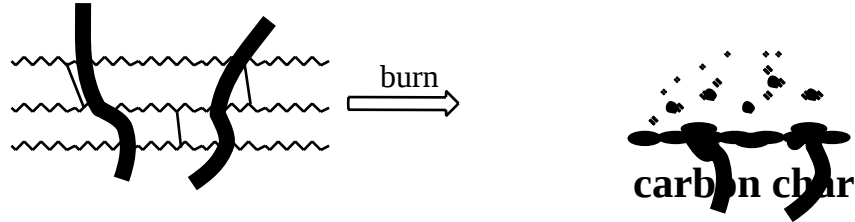


Nanofilled EPDM as Improved Ablative Potential Pathway to Increase Performance

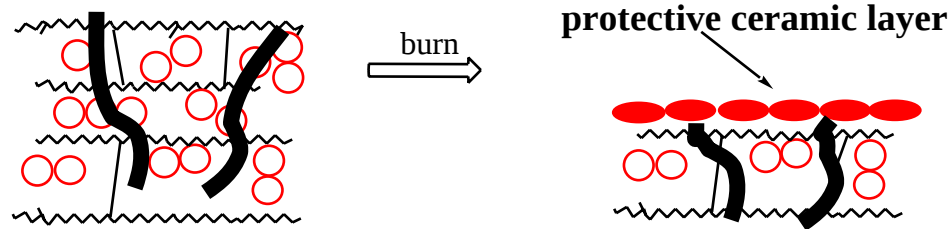


Microfibers

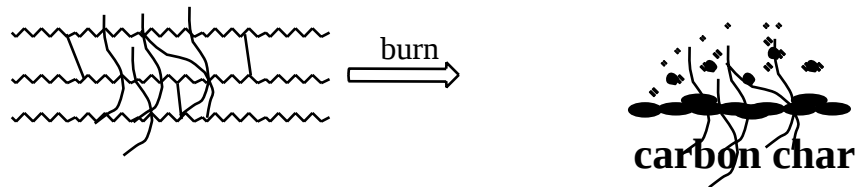
SOTA EPDM Rubber



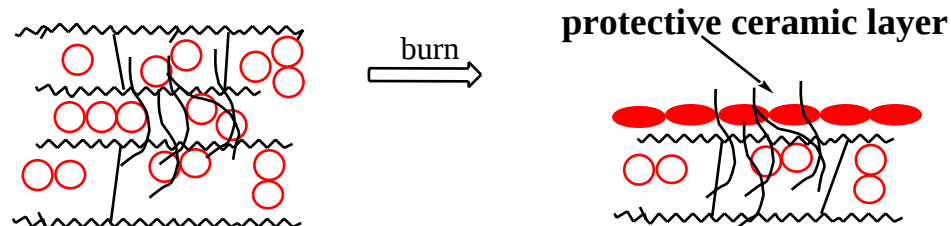
NANO EPDM Rubber



SOTA EPDM Rubber



NANO EPDM Rubber



Nanofibers



Public Release.
Distribution Unlimited

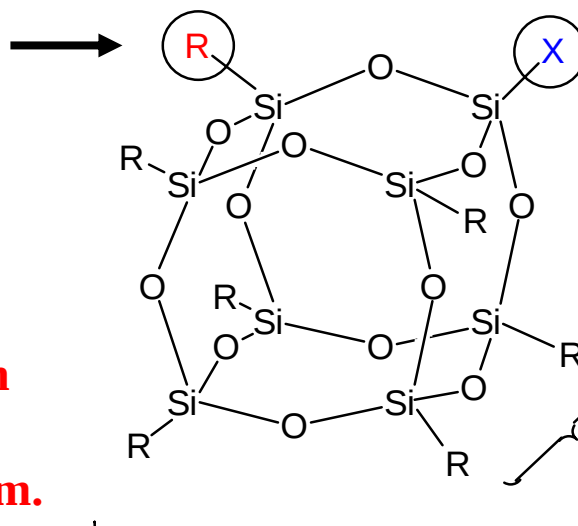
Pi-K Motor Firing



Anatomy of a Polyhedral Oligomeric Silsesquioxane (POSS) Molecule



Nonreactive organic (R) groups for solubilization and compatibilization.



May possess one or more functional groups suitable for polymerization or grafting.

Nanoscopic in size with an Si-Si distance of 0.5 nm and a R-R distance of 1.5 nm.

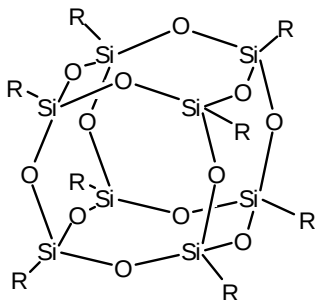
Thermally and chemically robust hybrid (organic-inorganic) framework.

Precise three-dimensional structure for molecular level reinforcement of polymer segments and coils.

The maximization of property enhancements in polymers results from interaction at the **nano-level (Edwards AFRL/PRSM ---> POSS monomers)**

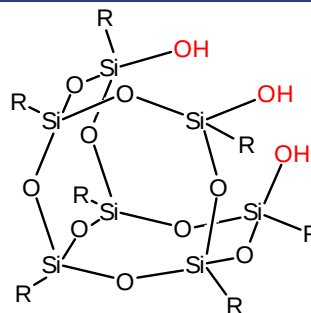


POSS Diversity: An Incredible Assortment of Cage Sizes and R groups

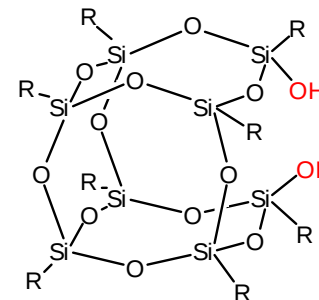


R = Methyl
Isobutyl
Cyclopentyl
Cyclohexyl

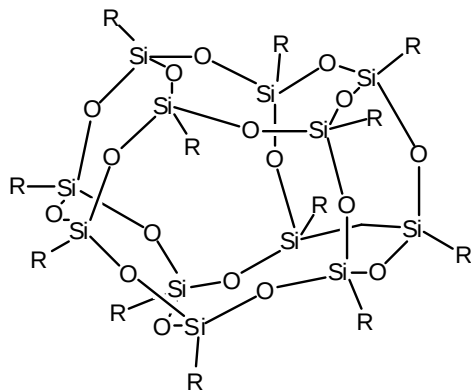
Phenyl
Phenethyl
Octadecyl
Vinyl



R = Isobutyl
Cyclopentyl
Cyclohexyl
Isooctyl
Ethyl
Phenyl



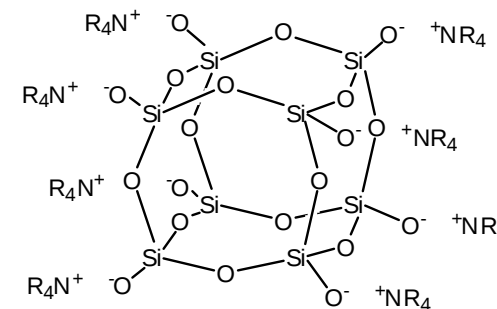
R = Isobutyl
Cyclopentyl
Cyclohexyl
Isooctyl



R = Phenyl
Trifluoromethylpropyl

Cage Mixtures
(T₈, T₁₀, T₁₂)

R = Vinyl
Phenethyl
Isooctyl



R = Methyl

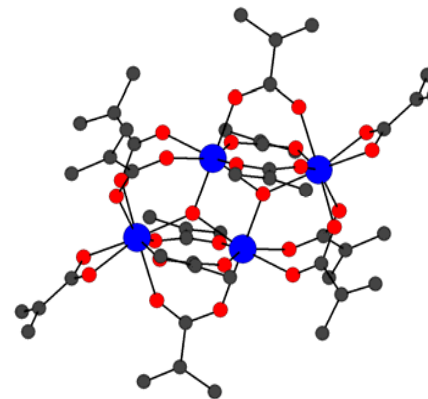
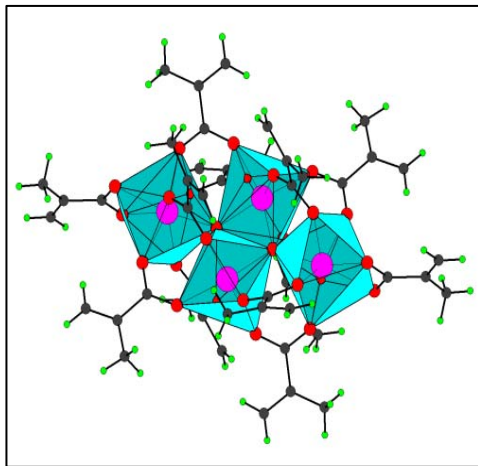
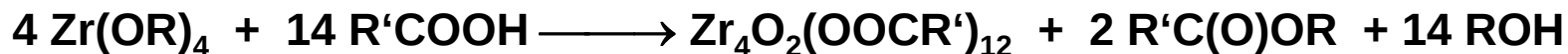


Synthesis of Zirconium Nanoclusters

Prof Ulrich Schubert TU Wien - WOS



In-situ Method



200 grams of Zr nanocluster Delivered to AFRL/PRSM
50 grams of Hf nanocluster also delivered

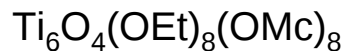
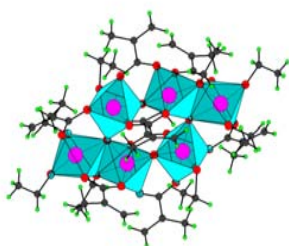
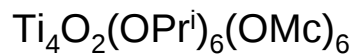
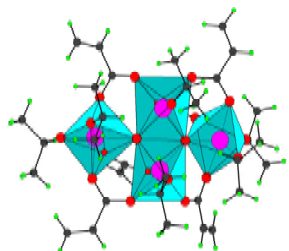


Wide Variety of Metal Nanoclusters

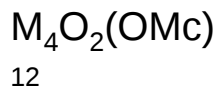
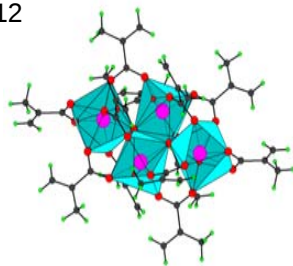
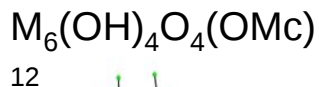
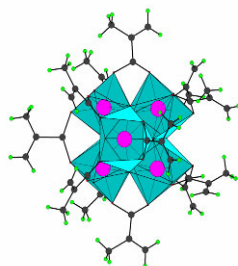
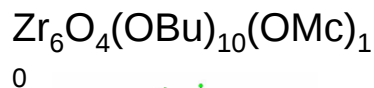
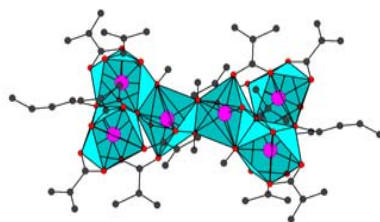
Prof Ulrich Schubert TU Wien - WOS



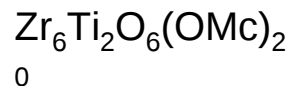
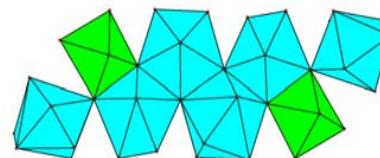
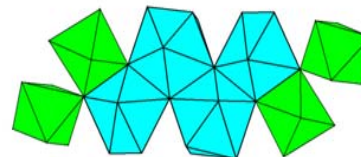
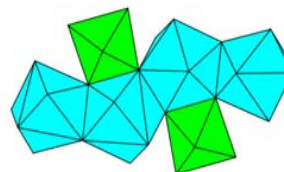
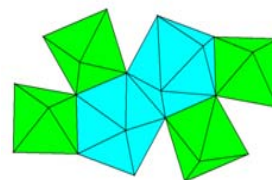
Ti



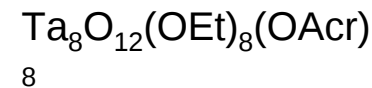
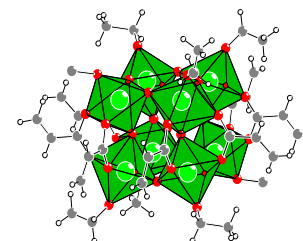
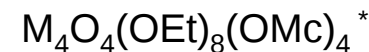
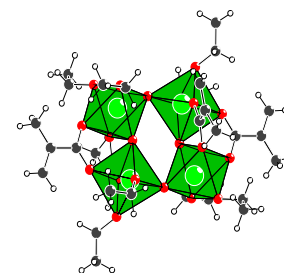
Zr or Hf



Mixed Ti / Zr(Hf)



Nb or Ta

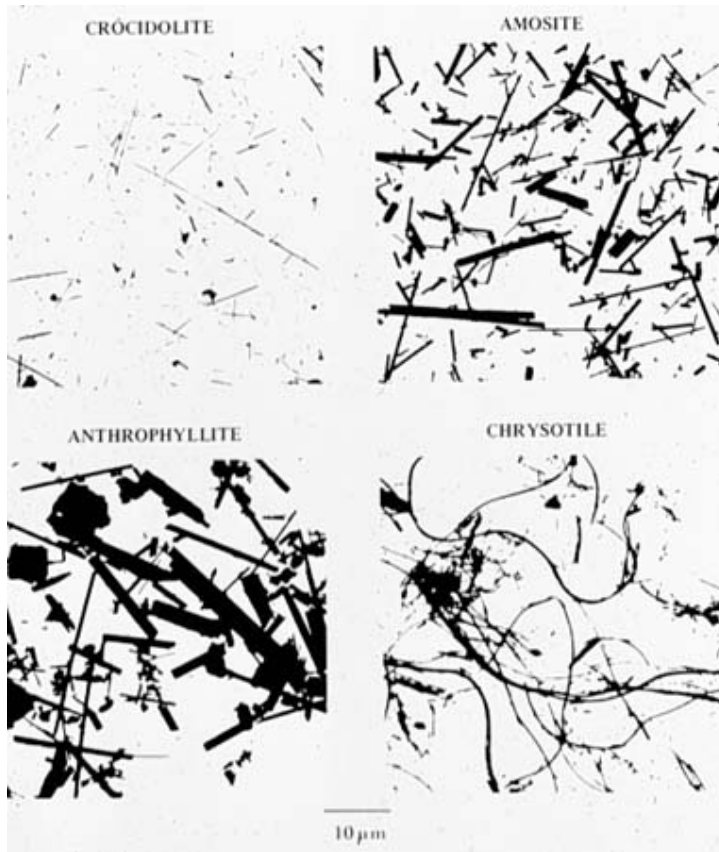


* M= Nb: L.Hubert-Pfalzgraf⁸ et al.



Other Fibers

- **Asbestos – the first and the best**



ASBESTOS FIBERS (SCANNING EM) - Amphibole fibers (crocidolite, amosite and anthrophyllite) are rectilinear while the serpentine (chrysotile) fibers are curved, twisted and of different diameters. The serpentine group is more prevalently used in industry however the amphiboles are more pathogenic in regards to induction of malignant mesotheliomas.

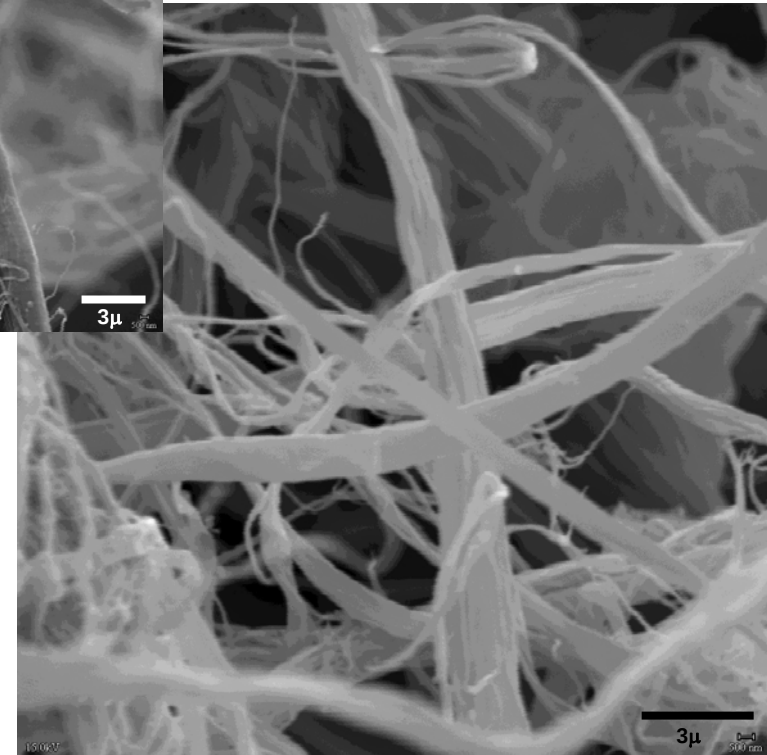
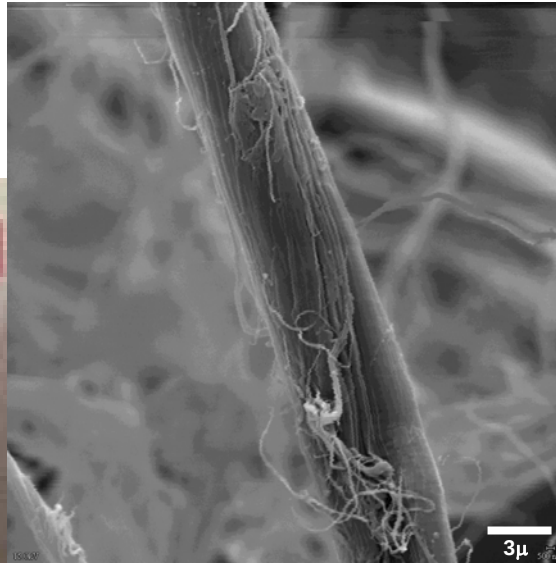
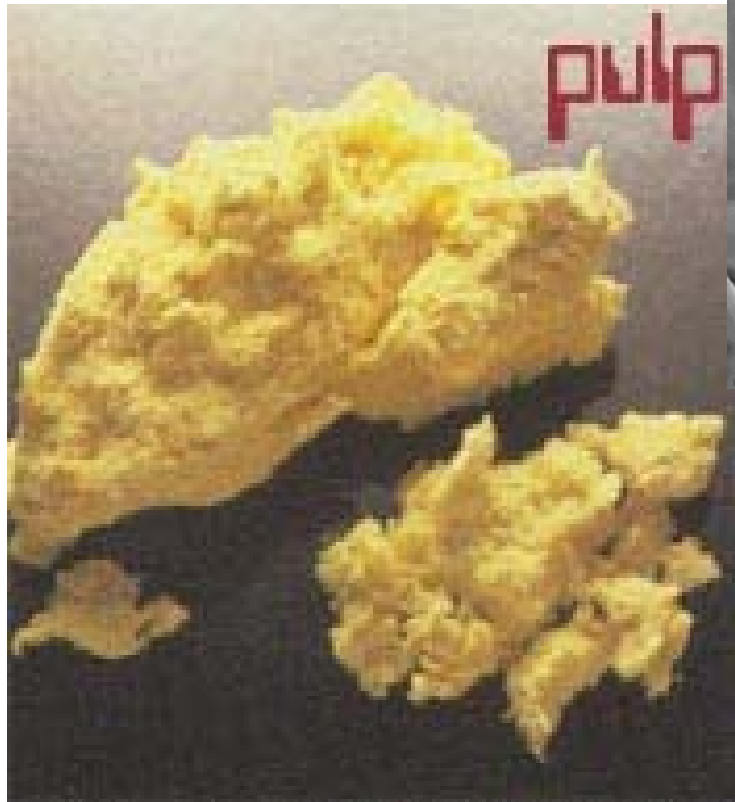
Source: [Tulane](#)

The most commonly used fiber is the Chrysotile fiber (pliable and nonfriable)



Other Fibers

Kevlar Fibers



Kevlar Pulp
Bulk Phase, 1/4" long

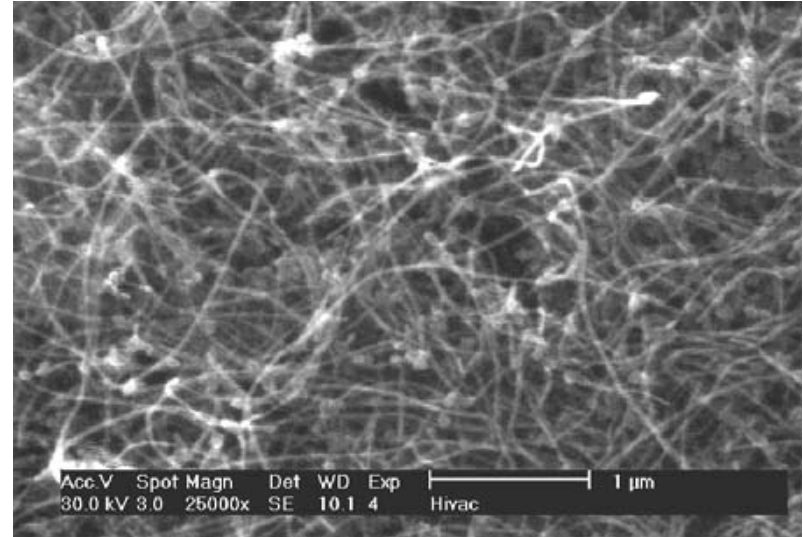
Kevlar Fibers
SEM



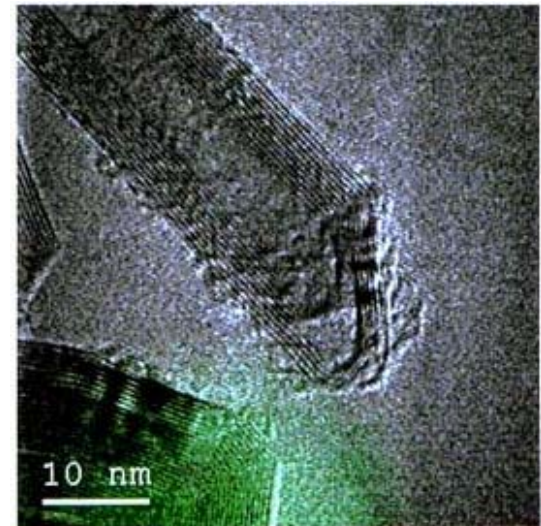
Carbon Nanofibers



- **Many Types**
 - **Single Wall Nanotubes**
 - 1.2-1.4 nm diameter
 - 2-5 μ long
 - \$370K/Kg as grown
 - \$950K/Kg purified
 - **Multiwall Nanotubes**
 - 2-20 nm diameter
 - 100 nm to $\sim 5 \mu$ long
 - 5-20 graphitic layers
 - \$110K/Kg as grown
 - \$170K/Kg purified



SWNT SEM from [SES Research](#)



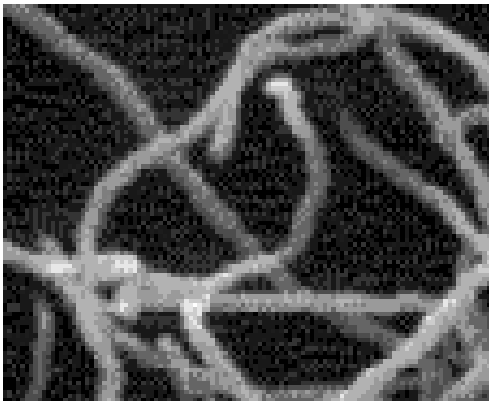
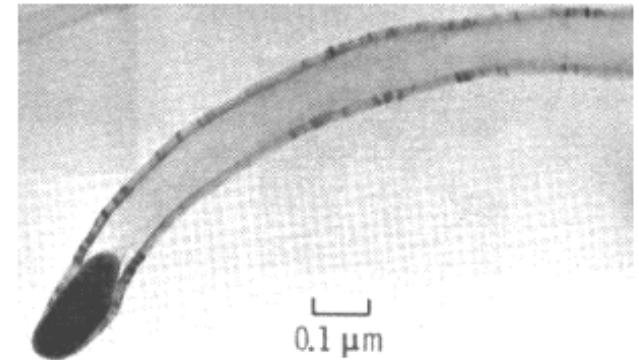
MWNT by STM



Vapor Grown Carbon Fiber



- ASI Price: < \$90/pound
- Thermally Stable
- Small size lends well for intimate mixing
- Shear considerations
- Grades Available: PR-19, PR-24 etc.
- Many surface treatments available



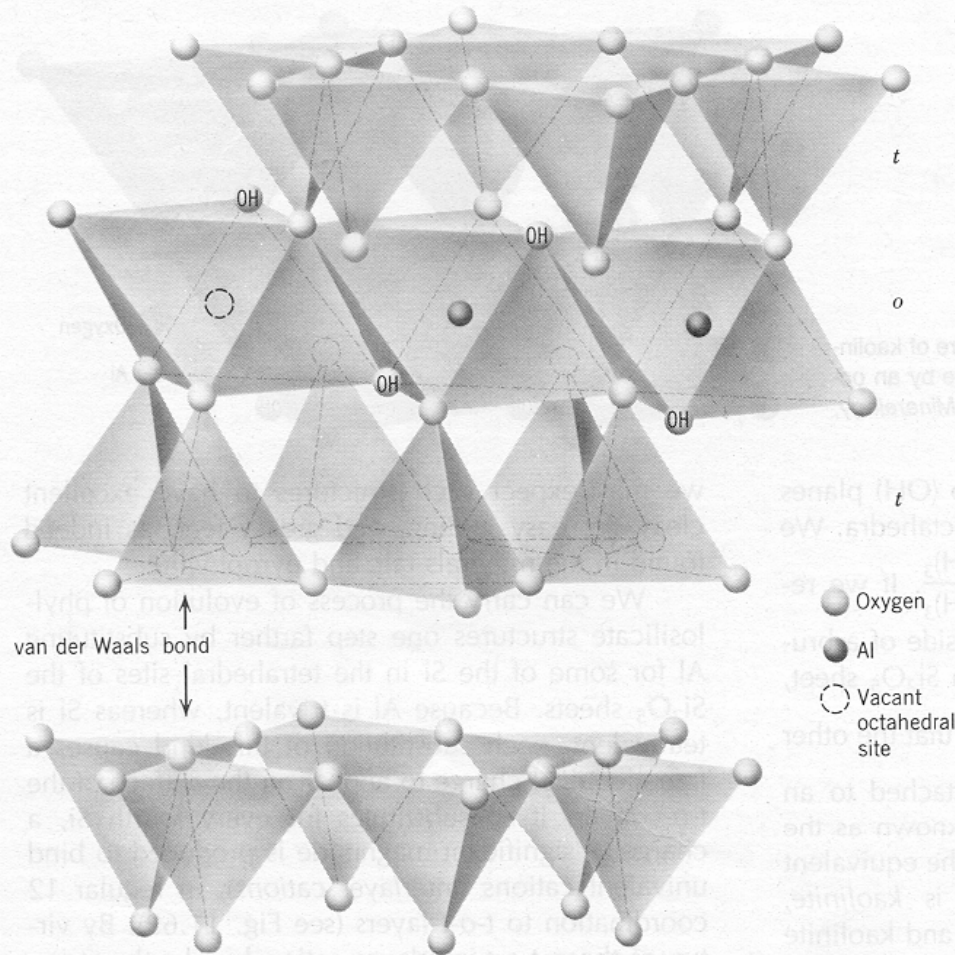
Carbon Nanofibers
Source: [ASI](#)

	PR-1	PR-11	PR-19	PR-24
Production	Lab scale	Bench scale	Full scale	Full scale
Diameter, nanometers	100 to 200	100 to 200	100 to 200	60 to 150
Length, nanometers	30,000 to 100,000	30,000 to 100,000	30,000 to 100,000	30,000 to 100,000
Comments	As grown material contains CVD carbon	As grown material contains CVD carbon	As grown material contains CVD carbon	As grown material essentially free of CVD carbon

AG, as grown fiber. PS, cleaned fiber. LHT, graphitized fiber. HHT, iron free graphitized fiber.



Modified Clays



- **Organically Modified** (generally with quaternary ammonium or phosphonium salts) to increase dispersion
- **Previous results show promise for SRM insulation (Vaia, Lichtenhan 1997)**

Montmorillonite nanoclay



Potential Transition Opportunities

Less Insulation Means More Propellant



Source: [Aerojet](http://www.aerojet.com)



**Atlas V test firing at Edwards (AFRL) AFB
May 2005**



In-House SRM Insulation Testing

Acknowledgements



- **Mr. Hieu Nguyen (Firing Engineer; Sample Analysis)**
- **Dr. Tom Hawkins and Del Jung (Motor Firings)**
- **Mr. Phil Counts (PRSM Master Machinist)**
- **Mr. Pat Ruth (Sample Preparation, measurement)**
- **Prof Joe Koo**
- **Prof Ulrich Schubert**
- **AFRL/PRS and AFOSR (\$\$\$)**