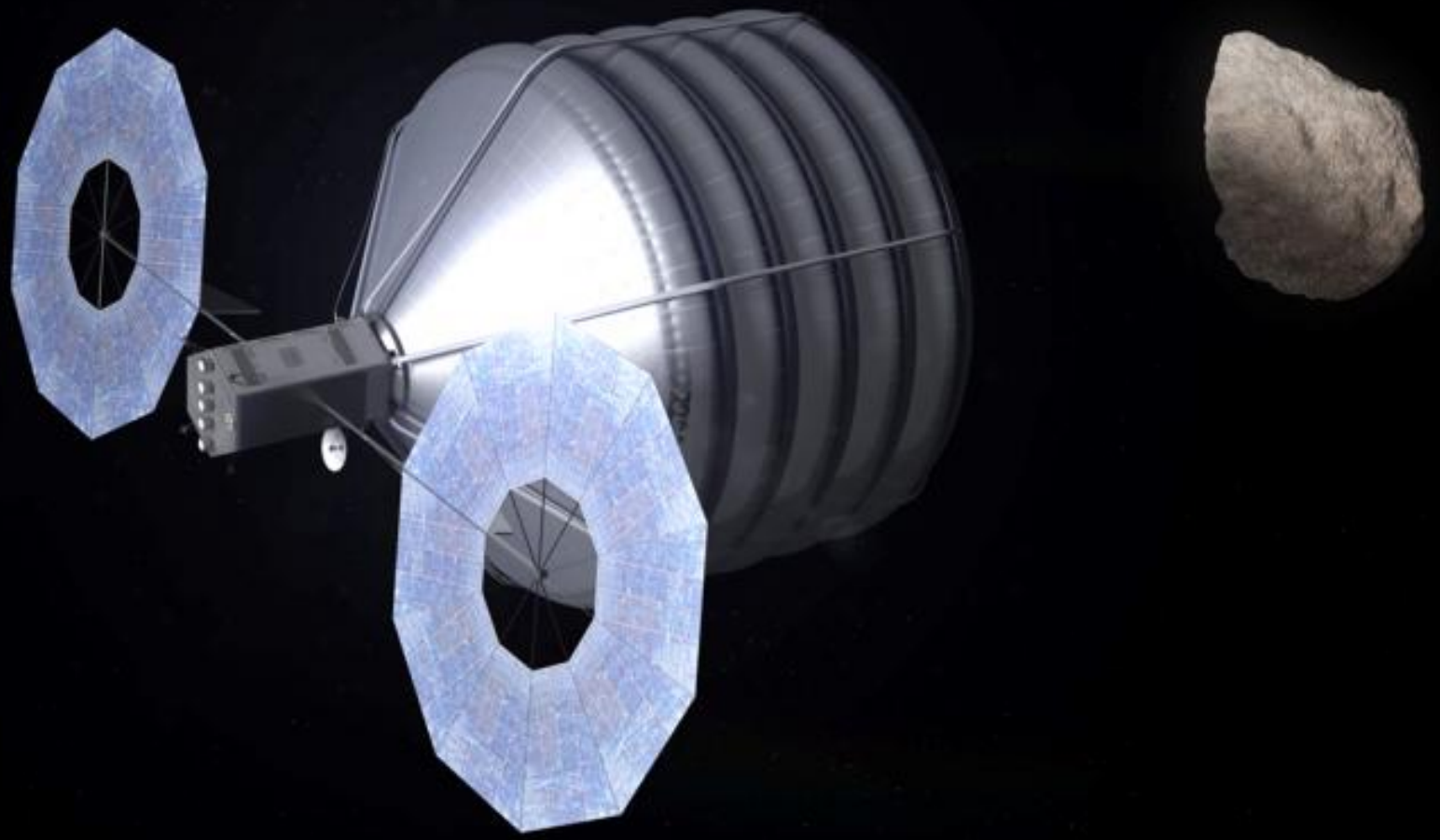
Flexible Graphene Composites for Human Space Flight Applications



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ERC Inc.

MRS Fall Meeting
December 05, 2013

Graphene Properties and Applications

- **Excellent Electrical Properties**
  - ↑ conductivity, ↑ carrier mobility, electron/hole carrier, zero gap
  - $\sigma \sim 10^6$ s/cm, $\mu \sim 200{,}000$ $cm^2 \cdot V^{-1} \cdot s^{-1}$
- **Exceptional Mechanical Properties**
  - predicted strengths as high as 1TPa
- **Outstanding Thermal Properties**
  - $\kappa \sim 5.0 \times 10^3$ $W \cdot m^{-1} \cdot K^{-1}$
- **Ideal Gas Barrier Properties**
  - practically impermeable
- **Potential NASA Applications**
  - Bladder materials in inflatable structures
  - Lightweight liners in COPVs
  - Food & drug packaging
  - Filtration devices

Impermeable Nanocomposites

- **Flexible Composite Structures**
  - elastomers: polyurethane, polyethylene, nylon, rubber, etc..
  - laminate composites with graphene embedded between plies
  - high transparency desirable
  - Inflatable bladders, food packing
- **Rigid Structural Materials**
  - carbon fiber composites: epoxy, polyethylene, cyanate ester
  - graphene embedded between laminates or dispersed within matrix
  - Pressure vessels, composite cabins
- **Methods of Graphene Deposition**
  - spray coating
  - spin coating
  - rolling
  - film transfer

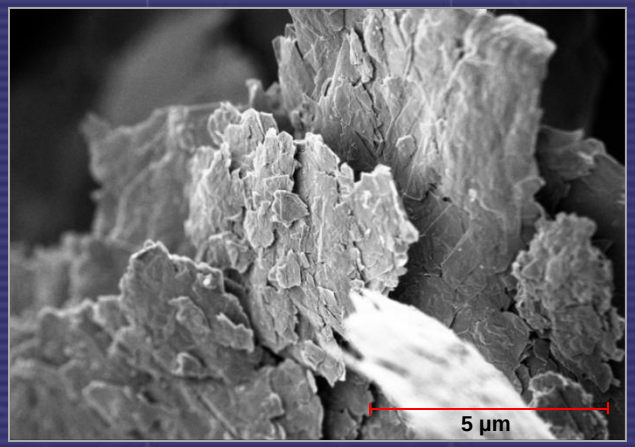
Graphene Dispersions

- **Raw Graphene Nanoplatelets**
  - Variety of organic solvents
  - Tip probe sonicator @ 30% of 500W
- **Graphene Oxide**
  - 2:1 ratio sulfuric to nitric acid mixture
  - 24 hour reflux in bath sonicator
  - vacuum filtered and rinsed
  - Dispersed in water
- **Stabilized Graphene Solutions**
  - Used a variety of organic pyrene derivatives as stabilizing agents
  - Bath sonicated 4 hours to form graphene suspensions

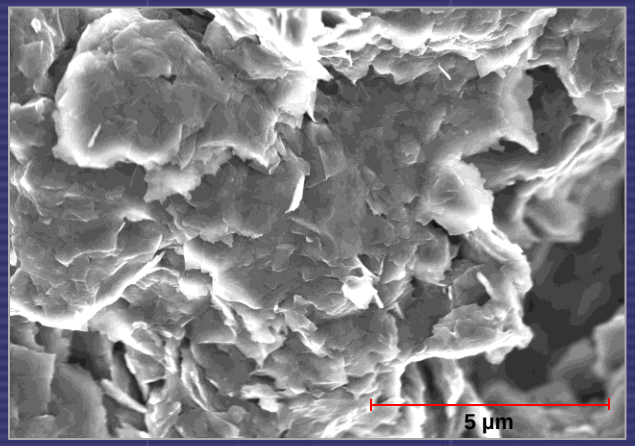
10 min sonication

after 3 weeks

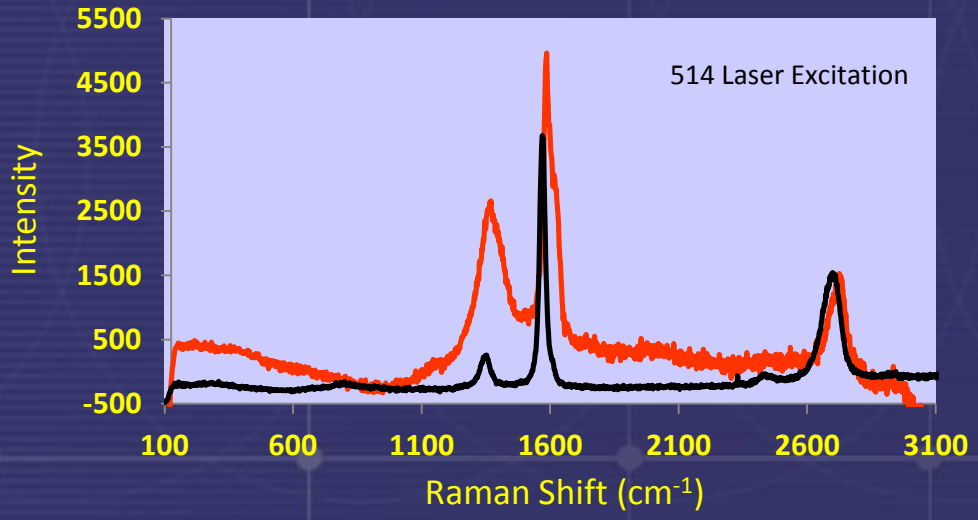
Graphene vs Graphene Oxide

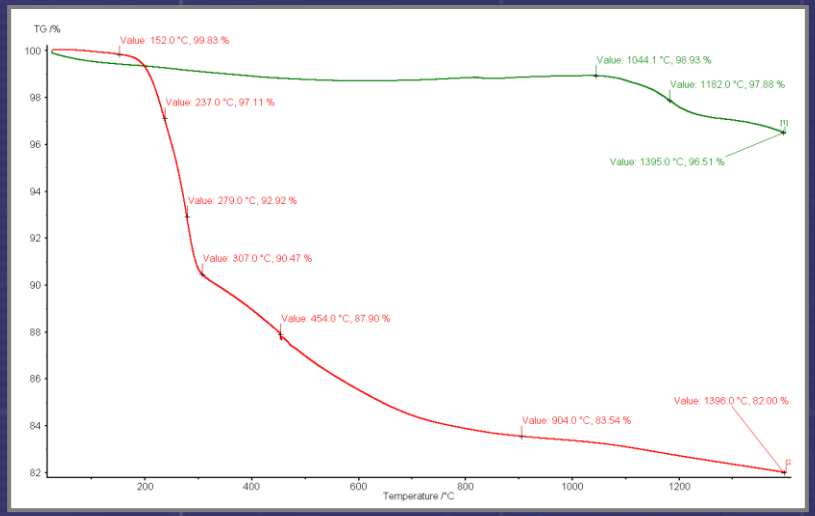


graphene

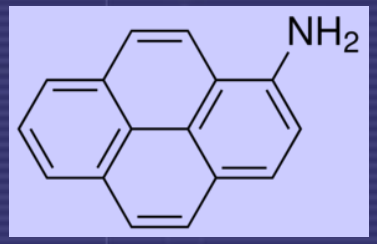


graphene oxide

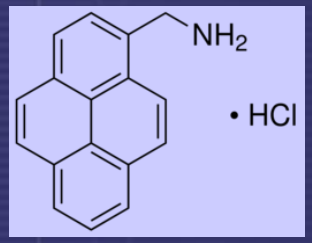




Graphene Stabilization

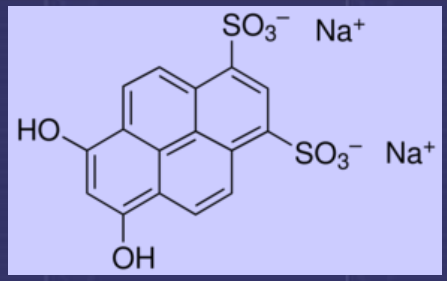


1



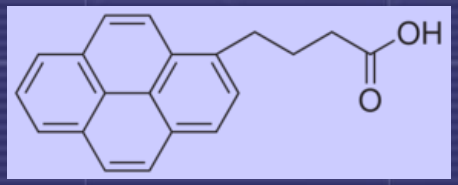
1-Pyrenemethylamine hydrochloride

2



6,8-Dihydroxy-1,3-pyrenedisulfonic acid disodium salt

3



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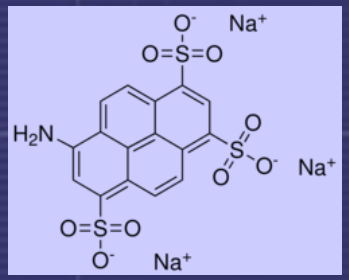
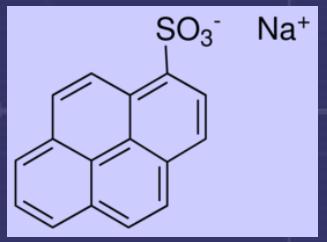


8-Aminopyrene-1,3,6-trisulfonic acid trisodium salt

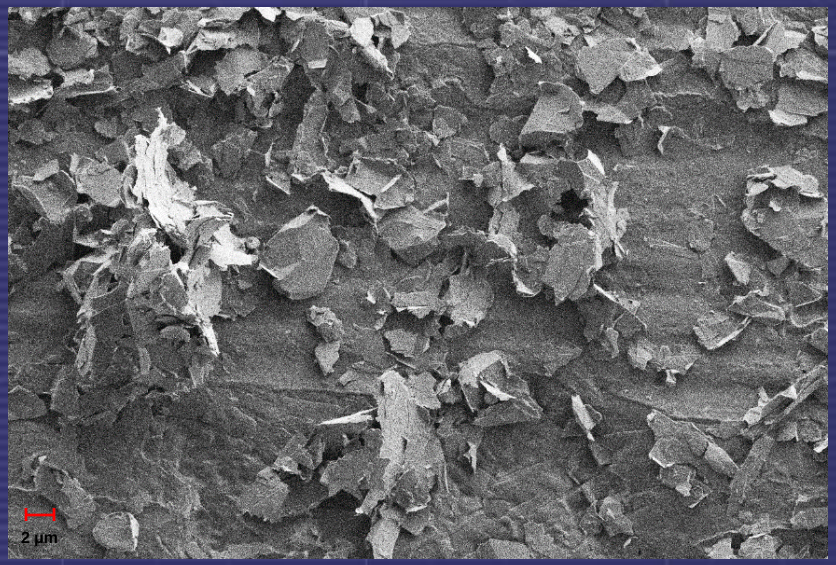
5

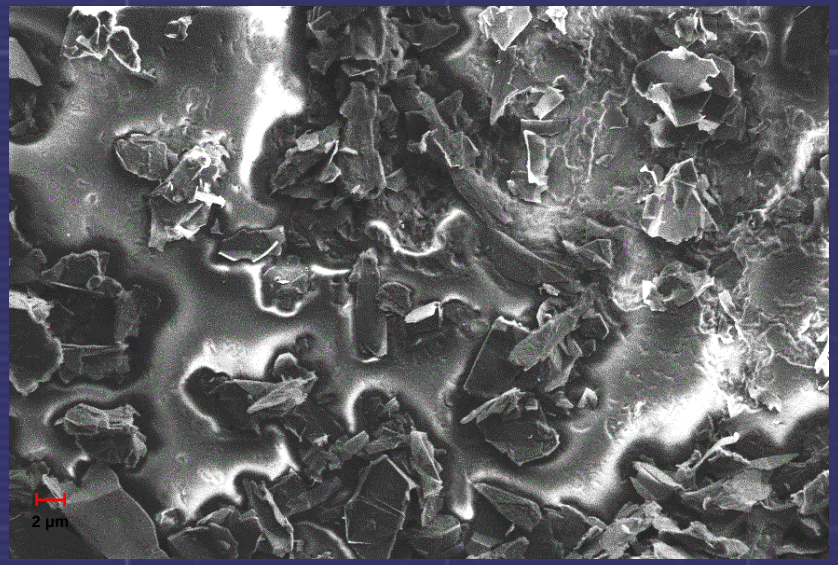


1-Pyrenesulfonic acid sodium salt

Graphene Polymer Coating

- Graphene platelets dispersed in methanol or isopropal alcohol deposited on polyurethane or polyethylene
- Hand held sprayer used to coat polyurethane or polyethylene
- Coverage is non-uniform
- Coated films hot pressed to form laminate composite

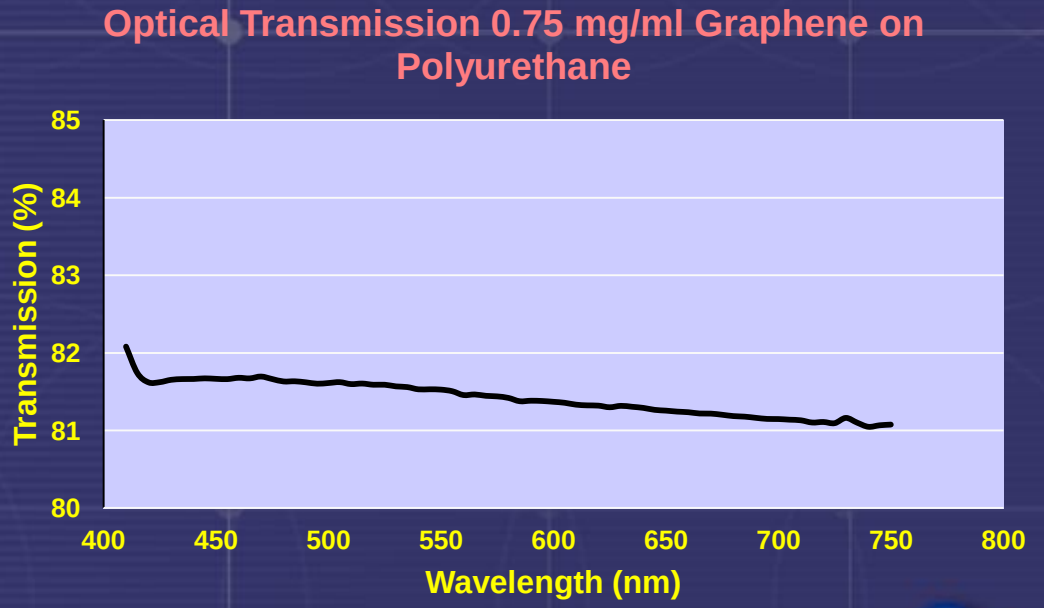




Graphene Polymer Composites

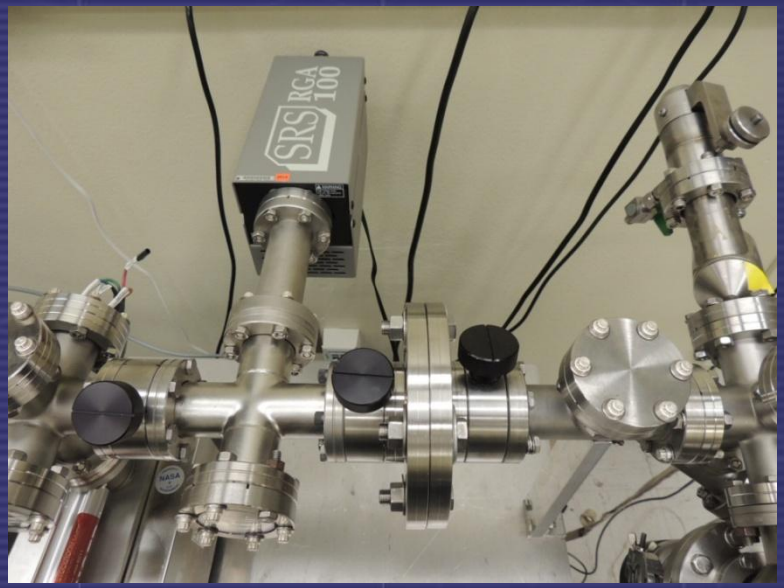
- Laminate composite consist of 2 or 3 ply of polymer sheets hot pressed
- Polyurethane 0.0015”, 0.005”, 0.02”
- UHMW Polyethylene 0.005”
- Graphene solutions range in concentrations from 0.25 – 1.0 mg/ml
- Semi-transparent laminate composites over visible light spectra

0.75 mg/ml graphene in isopropanol
9 layered coating

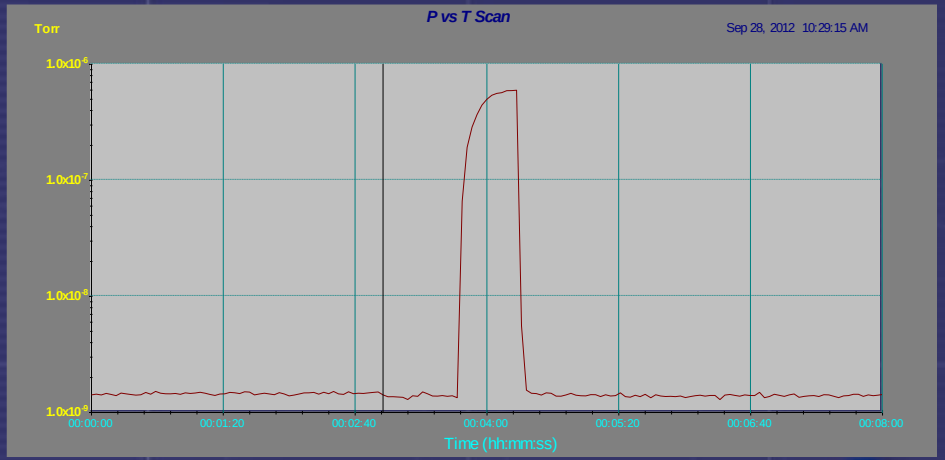


Permeation Testing

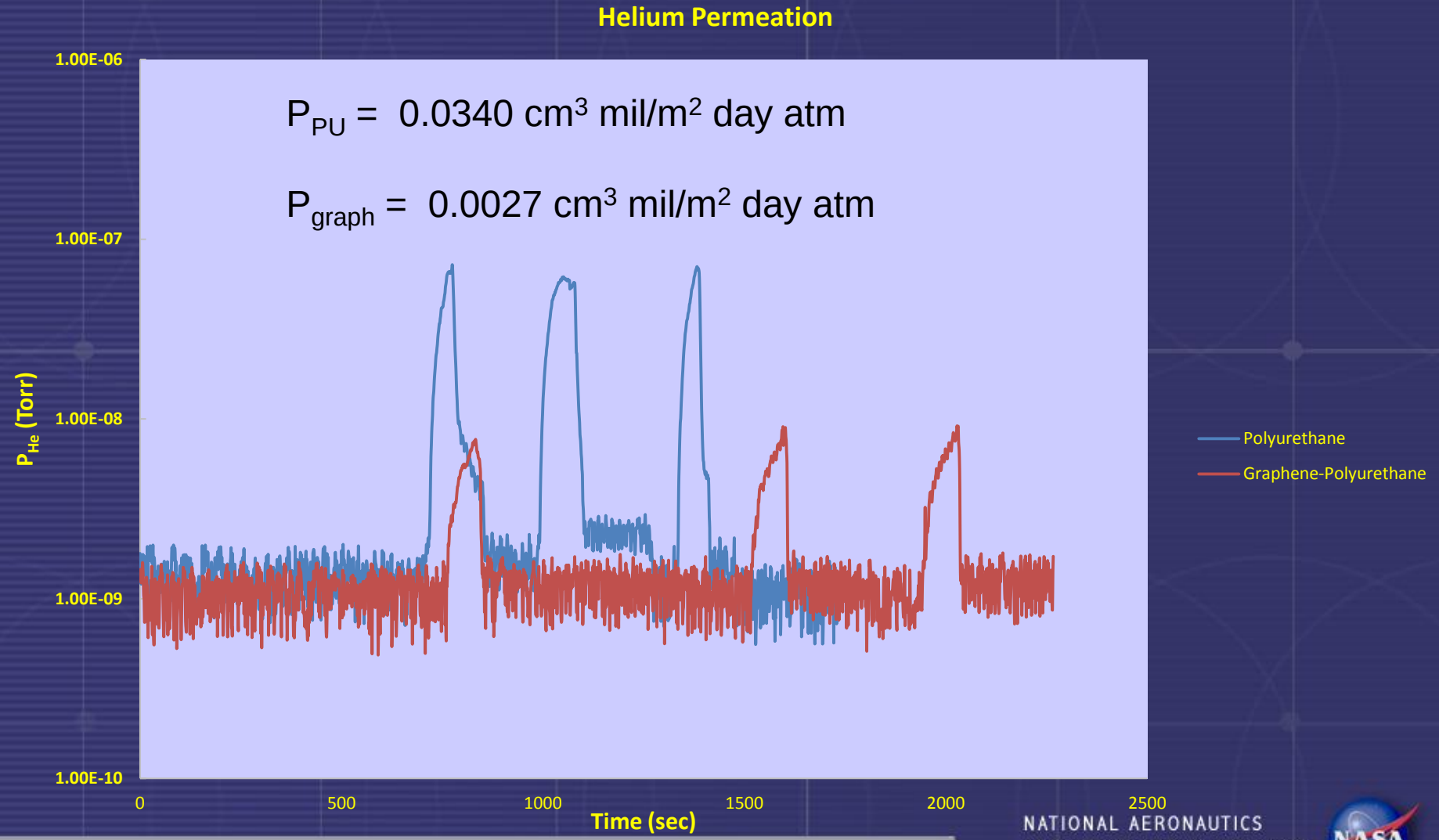
- Permeation testing in custom built vacuum apparatus
- System differentially pumped with turbo and ion pumps
- Composite films placed between ASA flanges to make vacuum seal
- One side held at high vacuum the other side 1 atm He
- Residual gas analyzer used measure He partial pressure increase
- Composite permeation calculated from slope of permeation curve



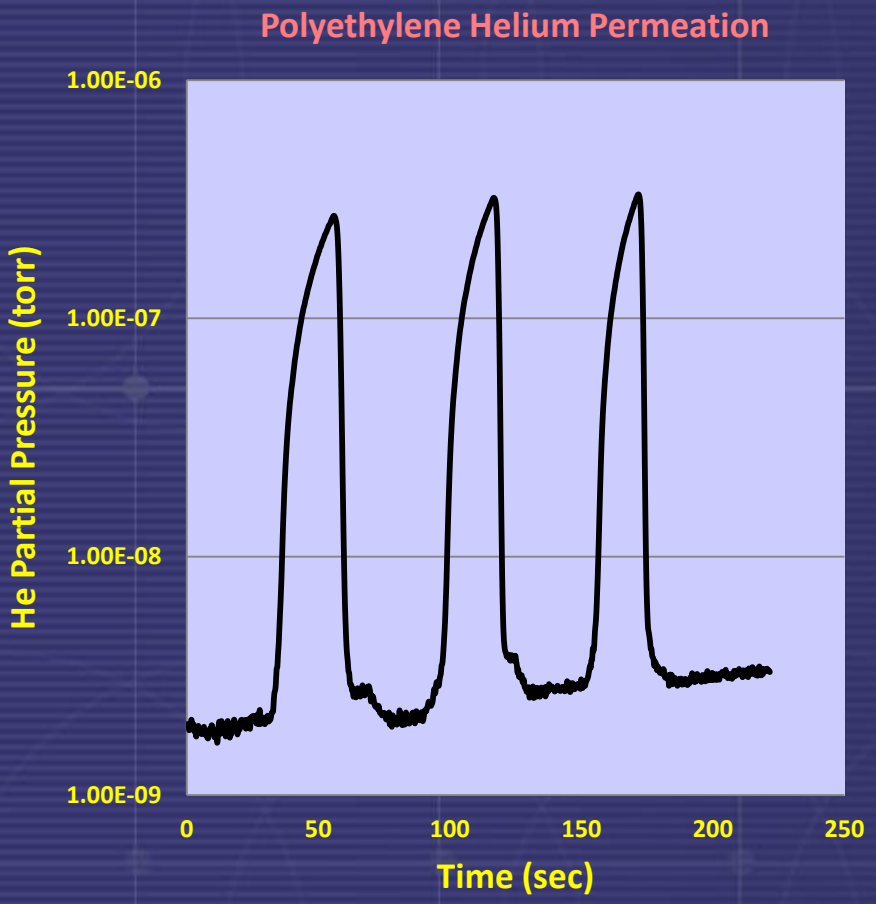
$$\frac{\text{Volume (STP)} \times \text{thickness}}{\text{Area} \times \text{time} \times \text{pressure gradient}}$$

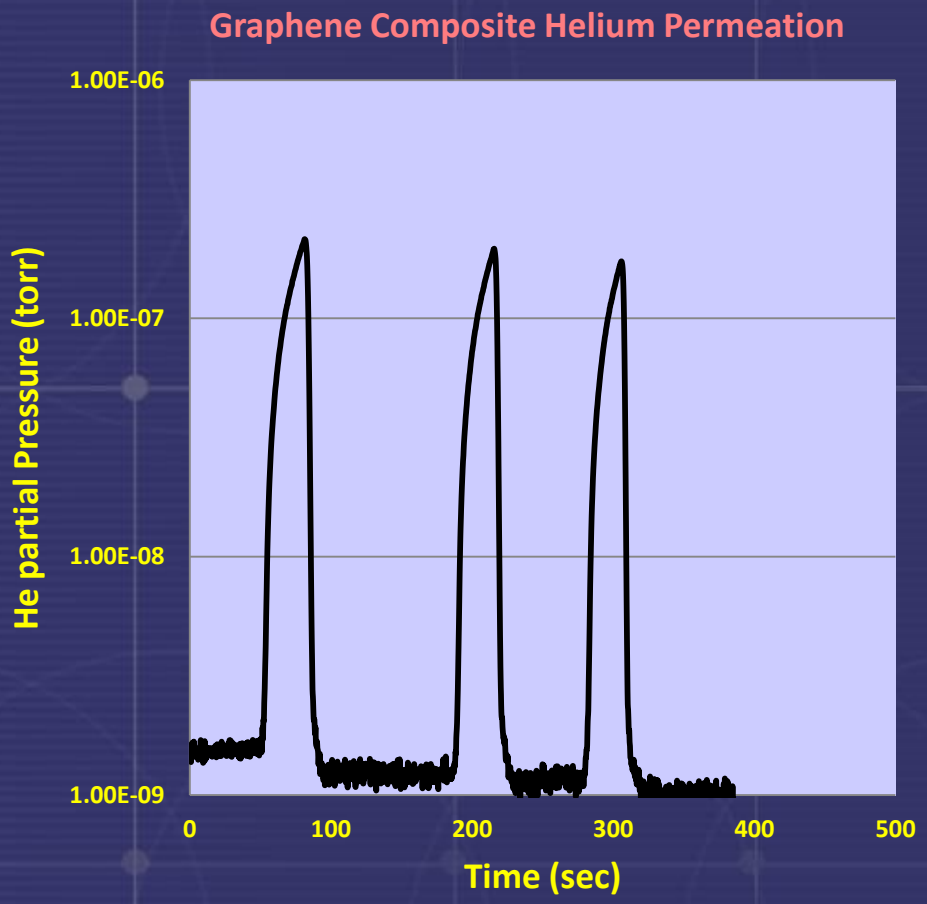


Polyurethane Composite Permeation

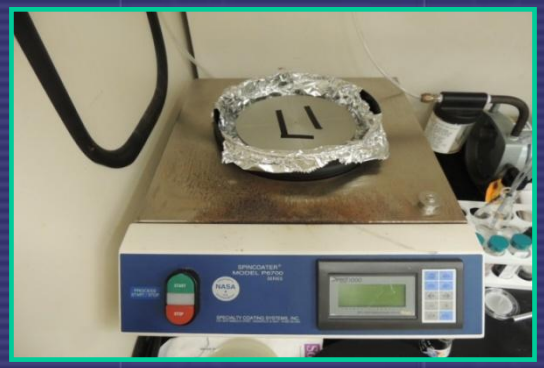


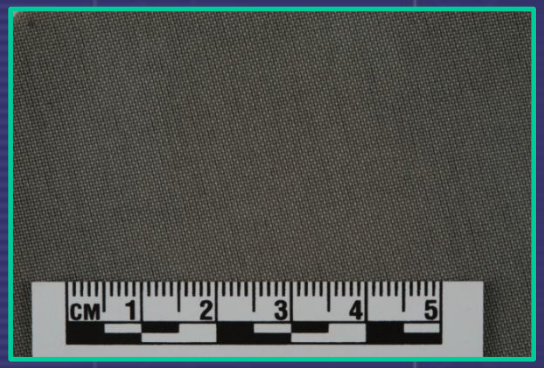
Polyethylene Composite Permeation

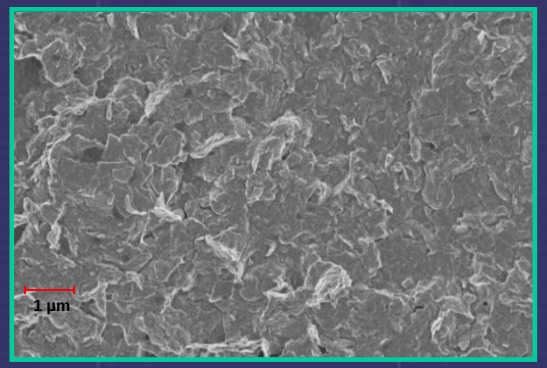


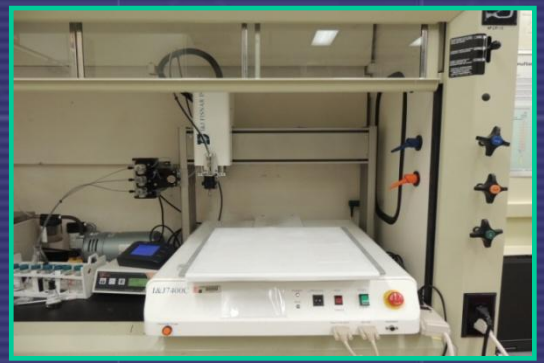


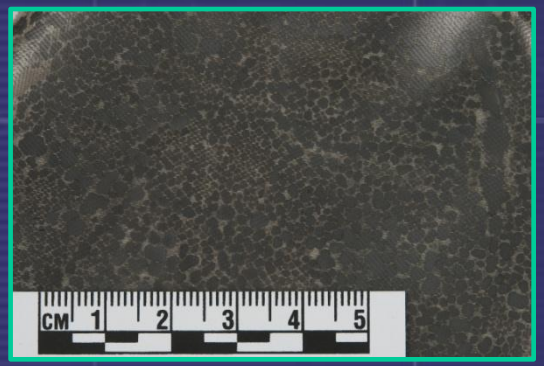
Graphene-Oxide Deposition on Polymer

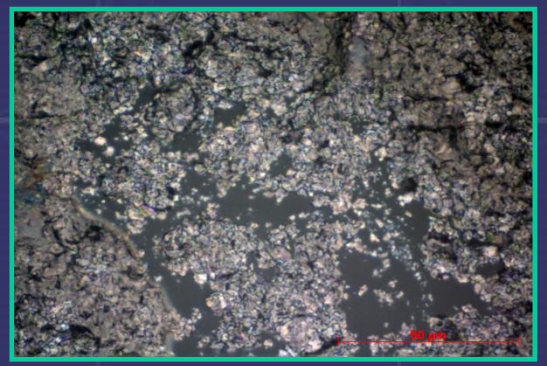


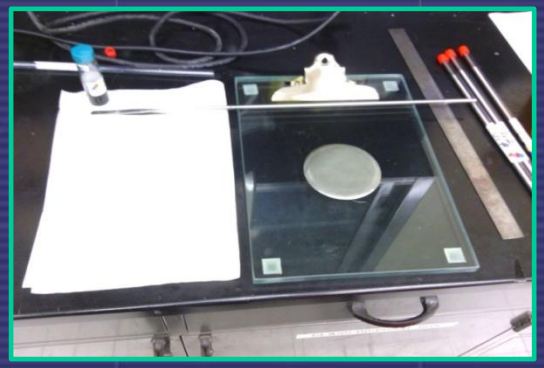


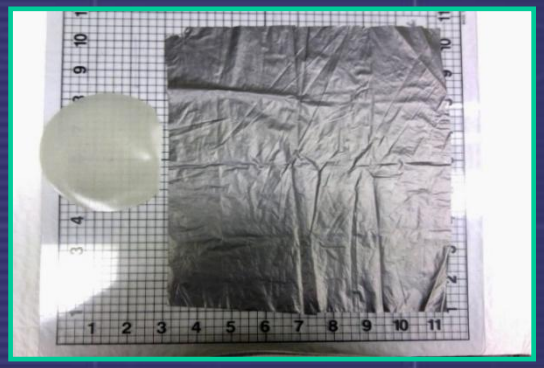






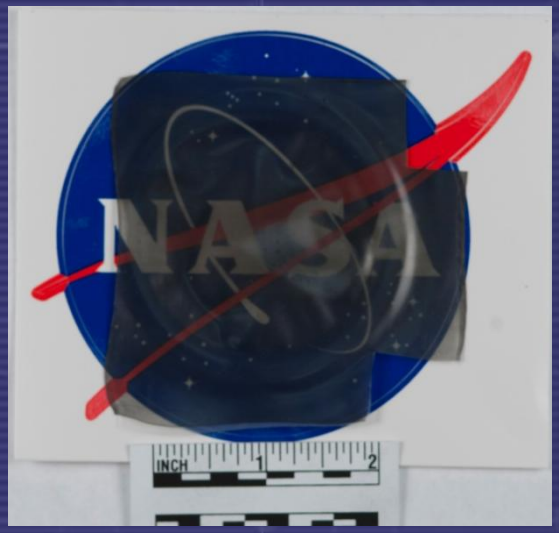




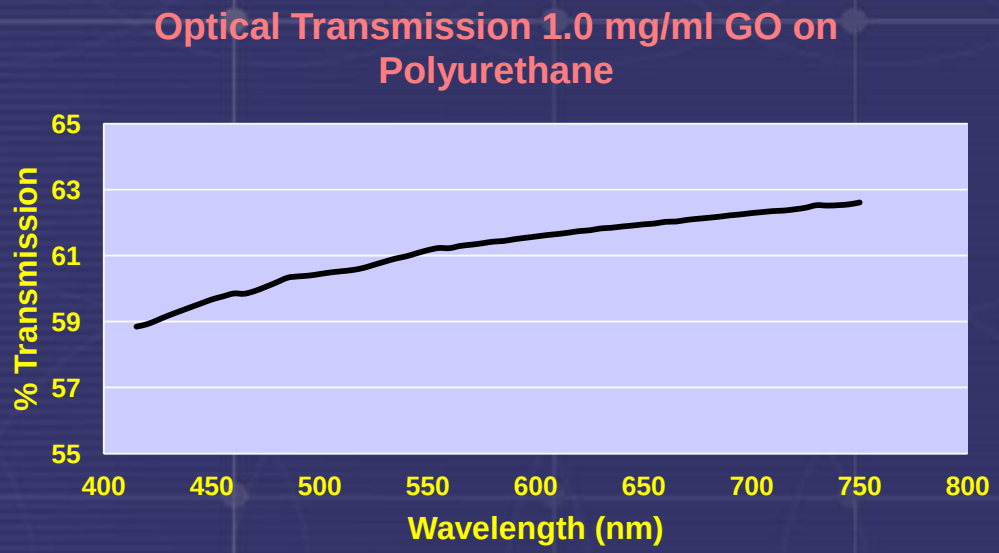


Graphene-Oxide Polyurethane Composites

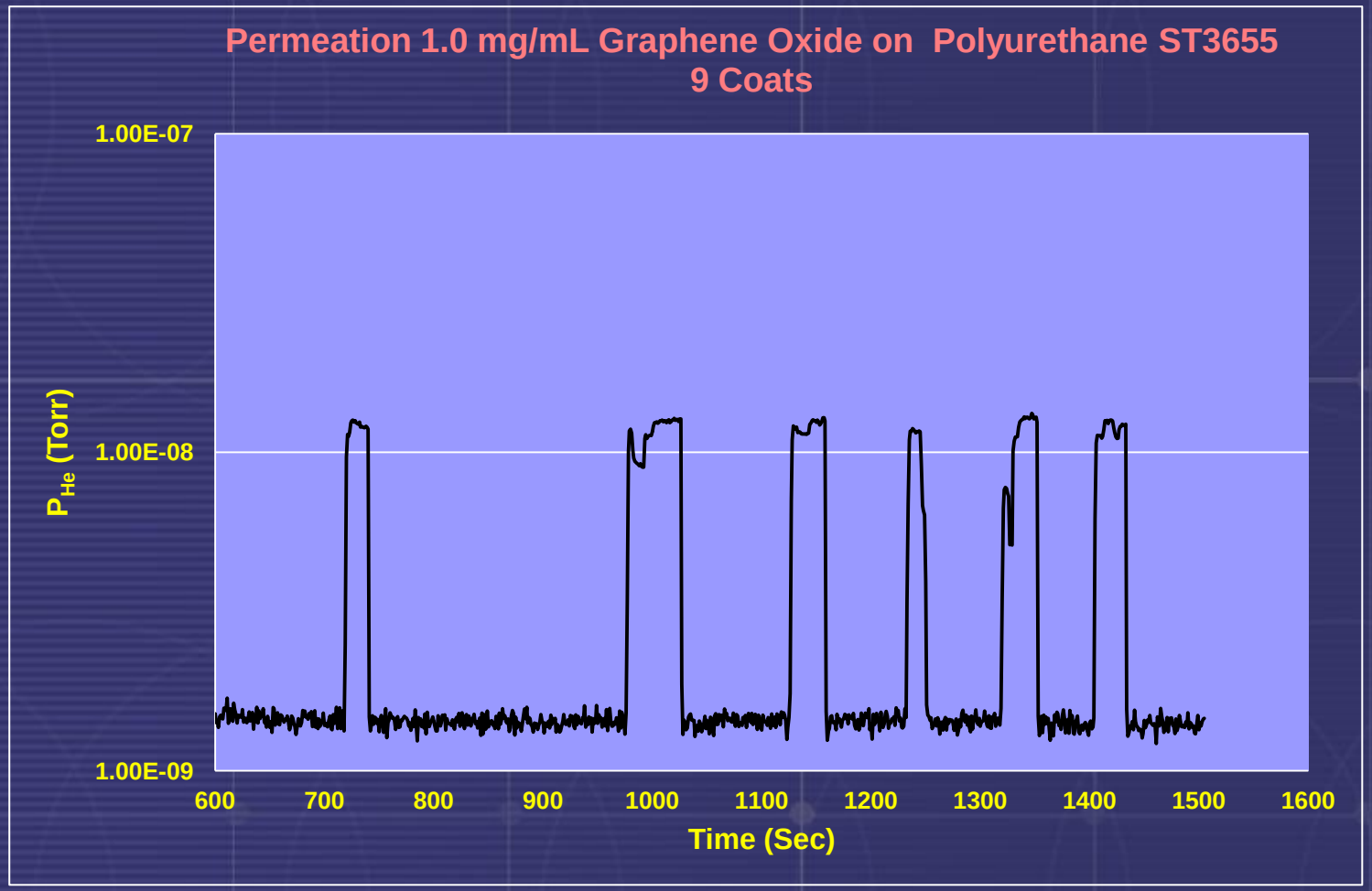
- Graphene oxide composite consisted of 9 coats from 1.0 mg/ml solution
- Coating are much more uniform across due to better dispersion stability
- Same number of coats relative to plain graphene result in thicker coatings, result in lower transmission in visible region



1.0 mg/ml graphene oxide in methanol

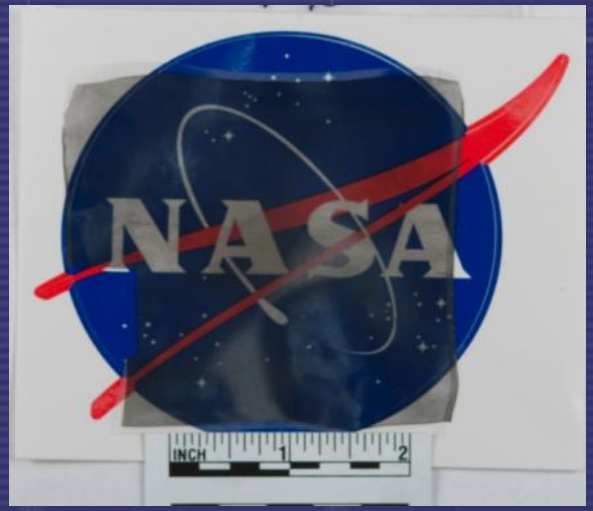


Graphene-Oxide Composite Permeation

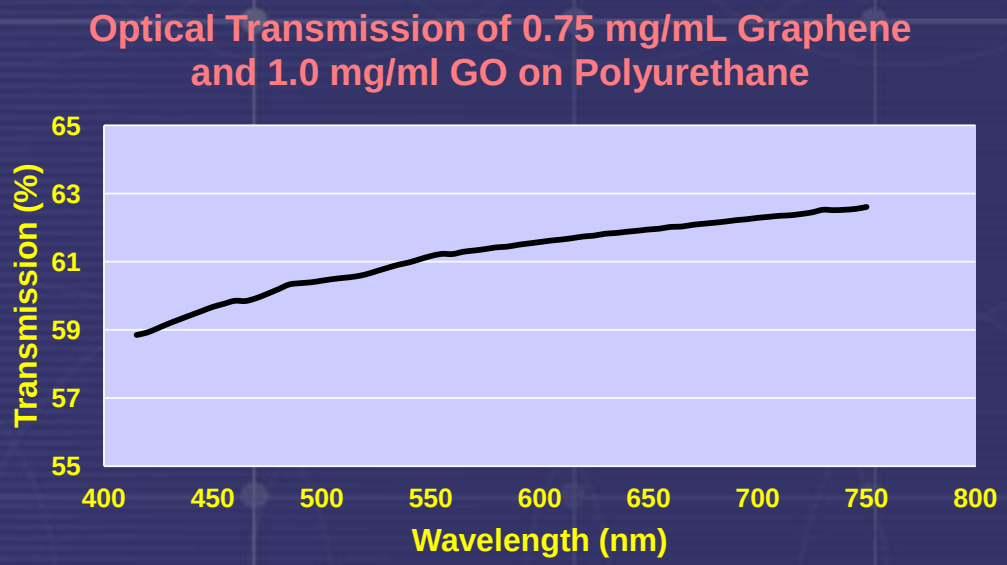


Graphene/GO Composite Fabrication

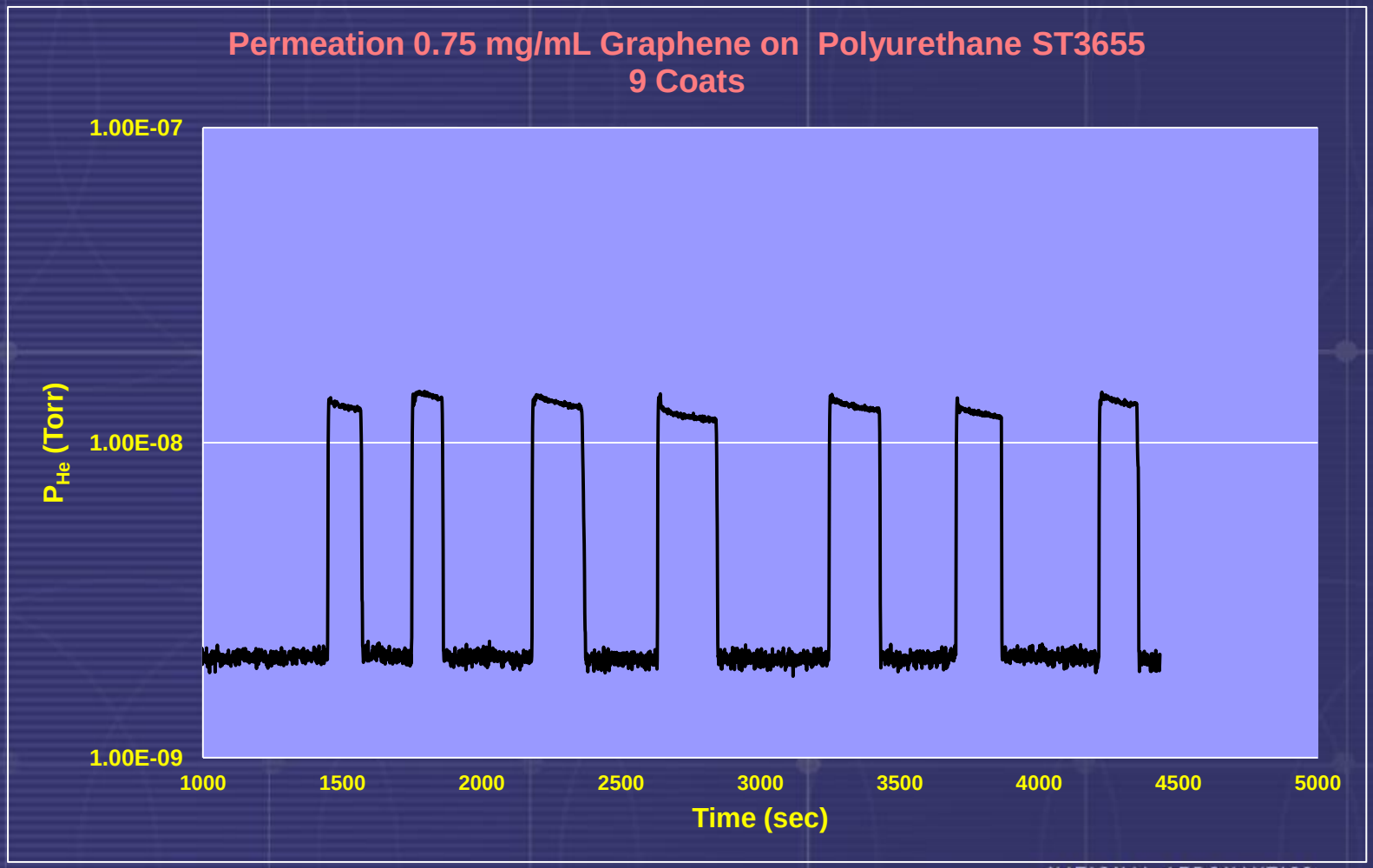
- Use GO as a seed layer to allow better deposition of the pure graphene
- Polyurethane sheet coated with 6 layers GO followed by 6 layers graphene
- Optical transmission on the same order as laminate composites composed of 9 layers of GO



1.0 mg/ml graphene oxide and 0.75 mg/ml graphene in methanol



Graphene/GO Composite Fabrication



Conclusions

- Graphene oxide allows for better dispersion stability in aqueous and organic solvents
- Stabilizers provide dispersion of pristine graphene
- Roll coating provide the best coverage of polyurethane sheets
- Graphene and GO coated polyurethane used to fabricate flexible laminate composite
- Permeation testing indicates that pristine graphene acts as a better gas barrier material
- Continuous graphene films are expected to provide even better gas barrier properties

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