SAND2013-7882P

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Radiation-detecting Capacitors

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Introduction/Acknowledgements

- Who am I?

- People to thank: Dave Wheeler, Roger Rasberry, Michele Denton, Patti Sawyer, Patrick Finnegan

Problem

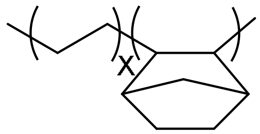
- Current methods for detecting neutron rays (Gas-Filled, Scintillation, & Solid State Detectors) have certain limitations (e.g. shortage of Helium-3). Thus, a new inexpensive method of detection which may enable new detection modalities is attractive. For example, broadly dispersed neutron detectors for large area sampling would be enabled by inexpensive neutron detectors with simple transduction methods.

Goal

- Functionalize Gadolinia (Gd_2O_3) particles to optimize their loading into a polymer capacitor.
- Create capacitors containing Boron and TOPAS® films of varying concentrations to create a set of parallel data points for comparison to previously created Gd_2O_3/TOPAS® capacitors.

Background: Functionalization

- Polymer capacitors containing Gd_2O_3 filler have shown the ability to respond to the presence of neutron radiation.
- Higher concentrations of Gadolinium (Gd) in the polymer dielectric would yield a better sensing ability of neutron radiation for the resulting capacitor. However, the limit of Gd_2O_3 in the polymer matrix (TOPAS®) when not functionalized is low.



TOPAS®

Procedure: Preparation of Film Dielectric

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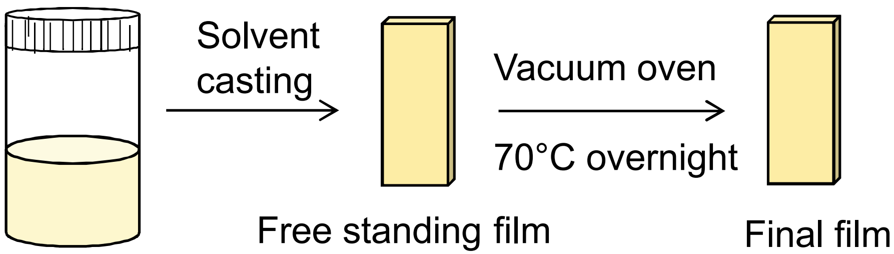
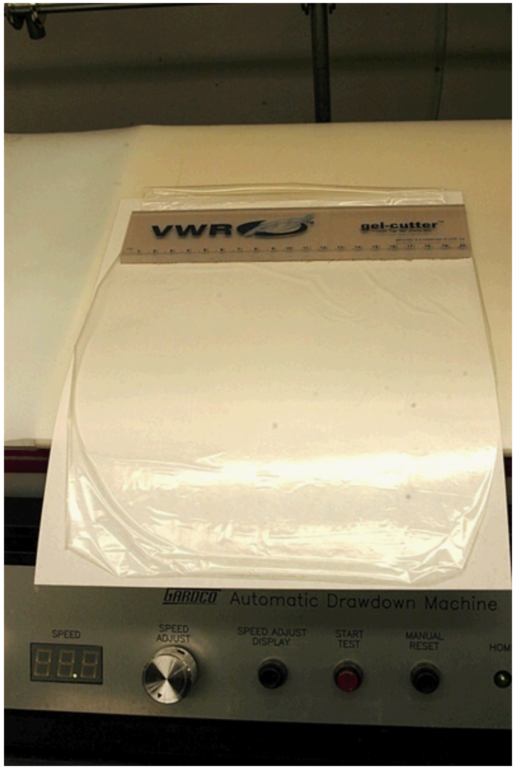
- Film solutions were made in 3 g of xylenes.

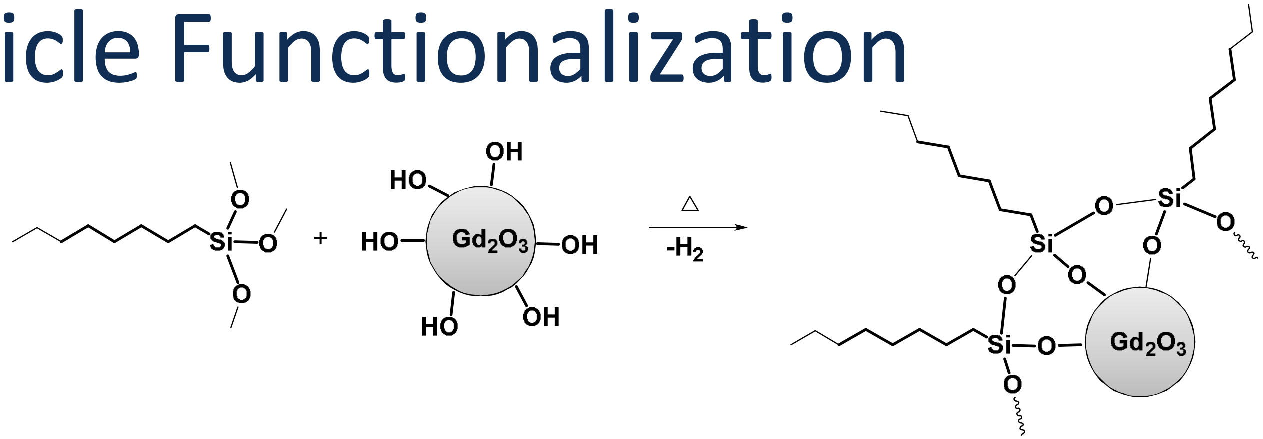


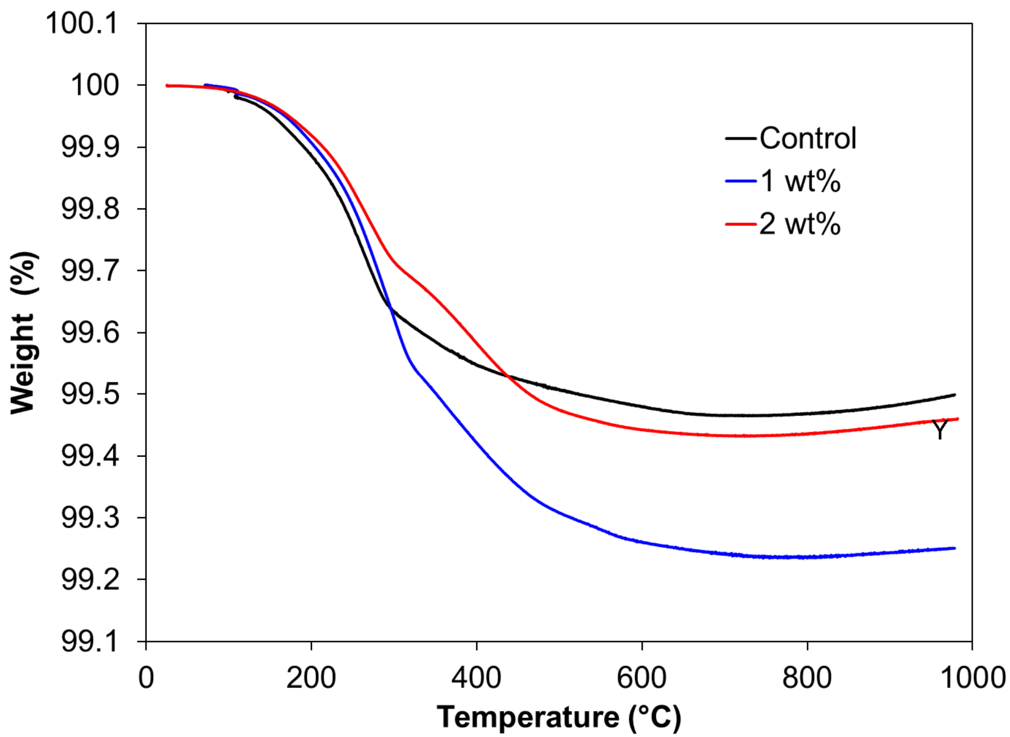
- Films were made with a target width of 40 µm and a tolerance of ±15 µm.
- Wt% of additive ranged from 10% to 90% with 10% intervals.



The draw-down bench is level and has a smooth surface. The film is poured onto paper with a Teflon® surface, so as it dries it will not stick. A doctor blade is used to spread the film evenly.

Results/Discussion: Particle Functionalization





- Gd_2O_3 placed in vacuum oven overnight, then added to flask with toluene and refluxed overnight with n-octyltrimethoxysilane, the chosen silane coupling agent (SCA)
- Minimal exposure to atmosphere desired after drying to ensure water-free reaction
- Thermo-Gravimetric Analysis (TGA) shows the sample with 1 wt% SCA had most weight-loss; that functionalization was most successful

Results/Discussion: Loading in Polymer Films

- After functionalization, films up to 80 wt% Gd_2O_3 were created; without functionalization, the highest was a 70 wt% film that was too brittle to work with.

Hydrophobicity Test
Control (far left), samples with n-octyltrimethoxysilane as SCA (2 wt% mid-left, 1 wt% mid-right), and sample with hexamethyldisilazane as SCA (far right)

Conclusions: Functionalization of Gd_2O_3

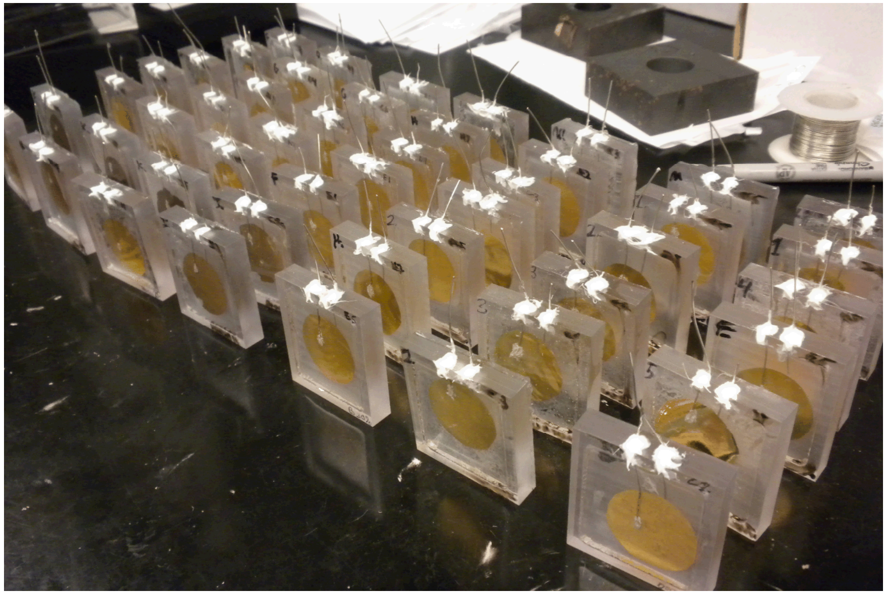
- Hydrophobicity tests, TGA, and higher maximum loading into polymer film showed that functionalization of the Gd_2O_3 led to a better interface with TOPAS®
- Films consisting of higher concentrations of Gd_2O_3 could be made, and therefore capacitors with higher sensitivity to neutron radiation could be created.

Background: Why start with gadolinium? Why boron?

- Gd has the highest neutron absorption cross section of any element.
- Second is boron- capacitors made with boron should still provide results.
- Gd releases only electrons in response to neutron bombardment, while boron releases much higher energy particles– ions. The ions from boron will travel farther and hopefully have a more intense effect on the capacitor.

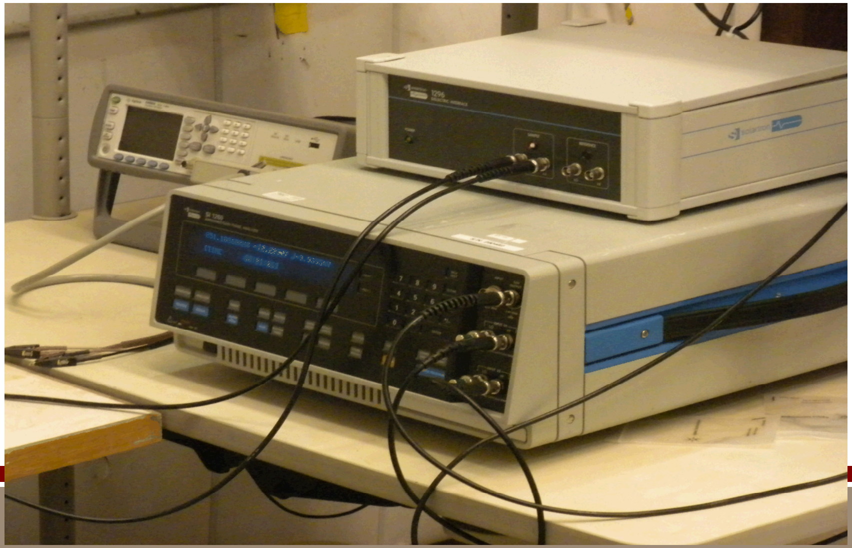
Procedure: Preparation of Capacitor

- Films were created using previously explained methods; one set with boron powder (heterogenous), one set with o-carborane (homogenous)
- Films were coated with 50 nm of gold by gold evaporation to make electrodes.
- Copper wire, coated with tin was used to make leads, which were attached to the electrodes with silver epoxy.
- The electrodes were potted by placing them in epon epoxy molds, pouring epon resin on top, and allowing the epoxy to harden.



Results/Discussion: Boron Capacitor Testing

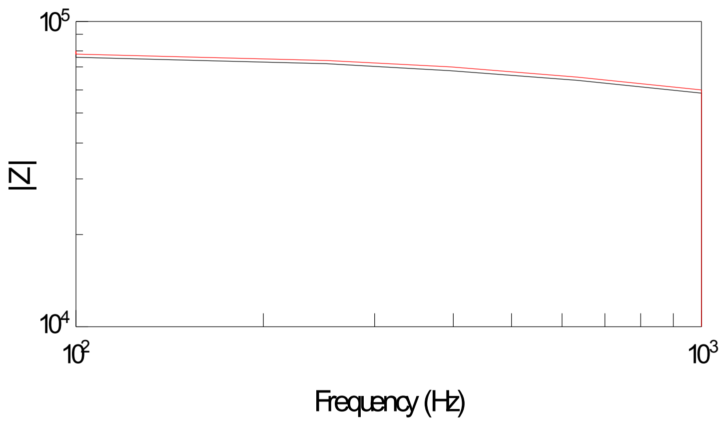
- The boron powder capacitors and the carborane capacitors were tested by Electronic Impedence Spectroscopy (EIS) before exposure to a Californium radiation source, during exposure, and after exposure. (Pictured)
- The process models a circuit to find changes of capacitance and resistance with changing AC current frequency.

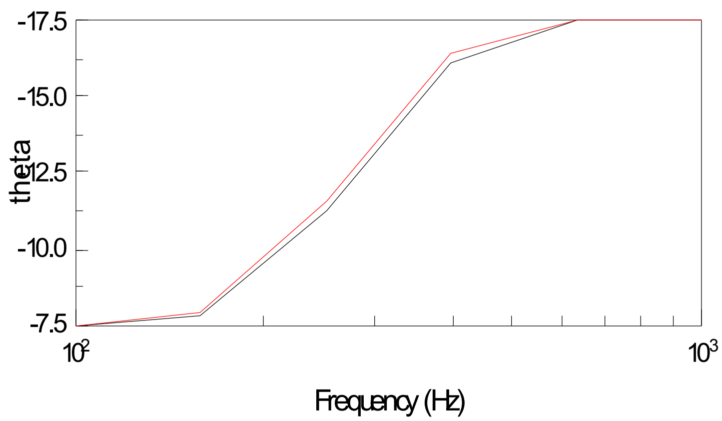


Results/Discussion: Sensing Ability of Boron Dielectrics

- Data shows that there is significant change in resistance during exposure to neutron radiation in the boron powder-containing samples, but not in the carborane samples.

Gd_2O_3, Boron Powder, O-Carborane	wt%	Capacitance % change	Fit uncertainty	Resistance % change	Fit uncertainty
-	commercial 0	0.400%	0.740%	-95.43%	35.68%
-	0	0.068%	0.087%	-0.023%	0.045%
Gd	5	0.027%	0.075%	2.92%	1.11%
Gd	20	0.070%	0.080%	-3.97%	1.39%
Gd at 40V DC	20	0.080%	0.150%	-6.93%	2.27%
Boron	10	0.012%	0.050%	0.1406%	0.127%
Boron	20	0.070%	0.293%	2.94%	0.4223%
Boron	50	0	0.397%	2.51%	0.247%
Carborane	10	0	0.009%	N/A	N/A
Carborane	50	0.0001%	.009%	N/A	N/A





Conclusions: Boron-filled Capacitors

- Capacitors with boron powder as the additive to polymer dielectric films changed their electrical properties in the presence of a neutron radiation source. The capacitance did not return to previous values when the source was removed.
- The homogenous carborane films may be ideal capacitors, and so a measure in resistivity could not be measured.
- Another option for creating a refined neutron radiation detector is potentially available.

This summer, I learned…

- laboratory techniques and skills
- the functions of several advanced pieces of equipment
- how to work collaboratively on a large, multi-faceted project
- a staggering amount of technical knowledge about chemistry, electronics, and physics
- that I could really enjoy a career like this.

Questions?