Radiation Curing of 3-D Printable Polymers

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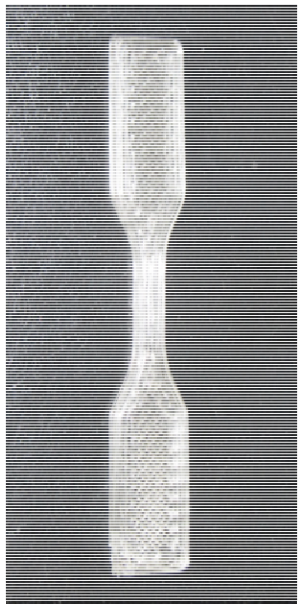
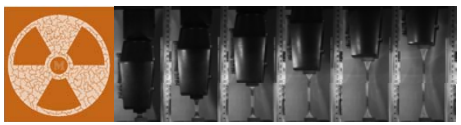
[2]Mechanical Engineering
University of Texas at Dallas

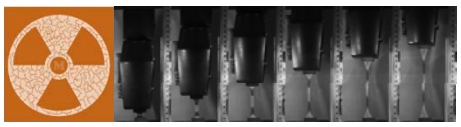
Chief Technology Officer
[3]Syzygy Memory Plastics





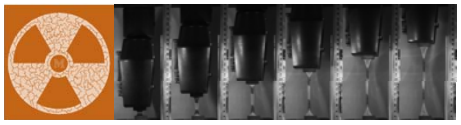
Background and Education

- BS in Computer Science from UT Dallas in 2005
  - Inaugural class of Eugene McDermott Scholars
  - Worked at Zyvex and Los Alamos National Labs
- MS in Intelligent Systems (Artificial Intelligence) from UT Dallas in 2006
  - Erik Jonsson Fellow
  - Advisor: I. Hal Sudborough
  - Thesis: “Pipeline: A software tool to improve the pancake problem upper bound”
- PhD in MSE from Georgia Tech in 2009
  - Presidential Fellow, TI:GER fellow
  - Advisor: Ken Gall
  - Thesis: “Optimization of mechanical properties and manufacturing techniques to enable shape memory polymer processing”



UT Dallas Facilities – NSERL

192,000-square-foot facility houses 350 faculty, graduate students and post-docs from electrical engineering, materials science, chemistry, biology, bioengineering and behavioral and brain sciences.

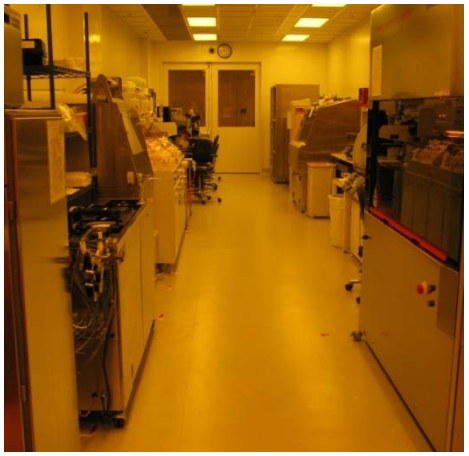


Cleanroom Facility (5000 ft^2 – class 10,000)

Thermal Processing

Metallization

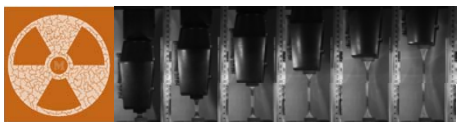
Photolithography



Wet chemistry

Characterization

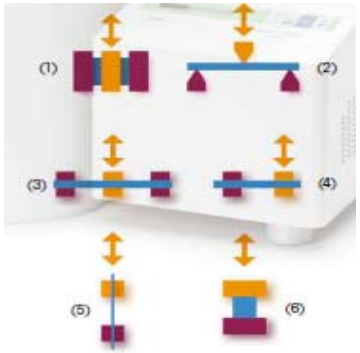
- **Thin Film Deposition – LPCVD, PECVD, ALD, Sputter, Evaporation (e-beam and thermal)**
- **Etch – Deep RIE, metal etch, dielectric etch, silicon etch**
- **Thermal - Rapid Thermal Processing, oxidation**
- **Lithography - UV contact printing, e-beam, pattern, etch, laser mask writer, Nanoimprint**
- **Characterization - Electrical, physical, thermomechanical**



Advanced Polymer Research Lab

UT Dallas

Dynamic Mechanical Analysis



Deformation Modes

DMA Shear Clamp: Up to 1000 Hz

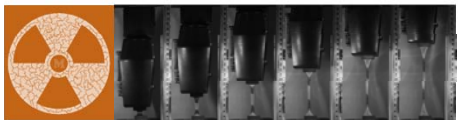
DMA 3 point bend fixture – Load Cell: 40N, multi-frequency

Universal Testing Machine

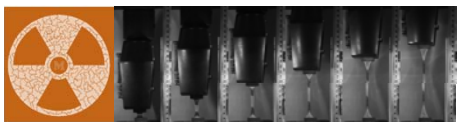
Differential Scanning Calorimetry

DSC Robotic Autosampler – Temp range -100 °C to 700 °C

Thermo Gravimetric Analysis



COLLABORATORS & CONFERENCES



Biomedical Device Laboratory

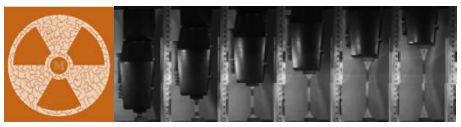
TEXAS A&M UNIVERSITY

BIOMEDICAL ENGINEERING

Dr. Duncan J. Maitland

Keith Hearon

Dept. of Biomedical Engineering
Texas A&M University



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Irradiation @ Nordion

nordion

CENTRE D'EXCELLENCE EN IRRADIATION
GAMMA CENTRE OF EXCELLENCE

- World leader in gamma technologies
- Leading provider of Co-60
- Designs and builds irradiators
- Customers include:
  - Contract sterilization service providers
  - Medical device manufacturers
  - Product manufacturers

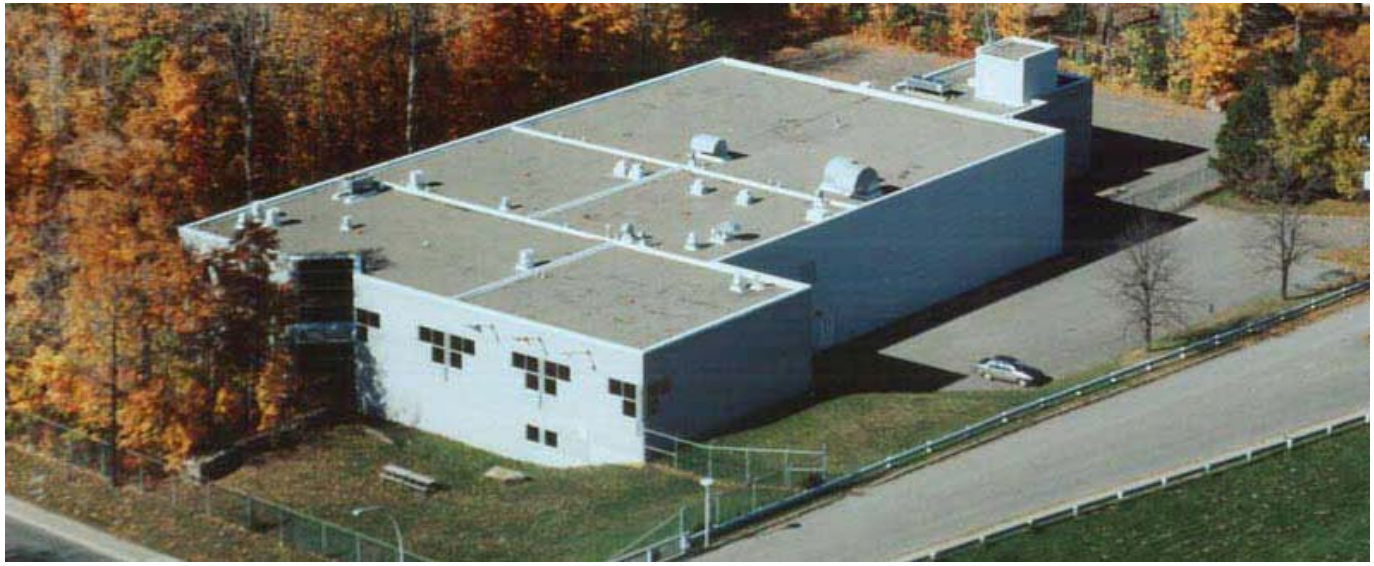
- www.nordion.com

Advancing The Science of Irradiation

nordion

CENTRE D'EXCELLENCE EN IRRADIATION
GAMMA CENTRE OF EXCELLENCE

- A world-class applied research and specialty gamma process facility
- R&D focus at Nordion
  - Gamma Center of Excellence (GCE) and Science Sterilization team are part of the Global Research and Development Group at Nordion
  - Nordion mandate to advance the use of gamma irradiation technology



Nordion's GCE vision

CENTRE D'EXCELLENCE EN IRRADIATION
GAMMA CENTRE OF EXCELLENCE

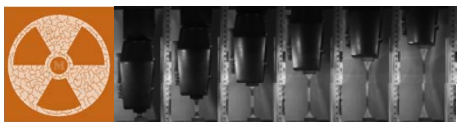
- Grow the use of gamma through investment in research and innovation
- Seek collaborations with industry and academic partners
- Provide knowledge and training to the industry
- Develop talent and expertise in next generation of gamma professionals

- www.nordion.com/gce

international irradiation association

International Meeting on Radiation Processing (IMRP)
Shanghai, China
early November 2013

Chair: Byron Lambert Chair
Vice Chair of the Program Committee: Wang Chuanzhen
Chairman of the Organizing Committee: Paul Wynne



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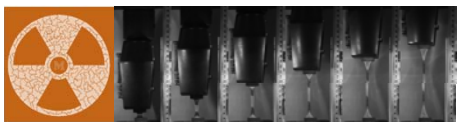
Technical Overview

- Bulk effects resulting from the interaction of shape memory polymers (SMPs) and ionizing radiation
- Independent control of glass transition temperature (T_g) and rubbery modulus (E_R) in polyacrylates
- 3-D printing and thermoplastic resins



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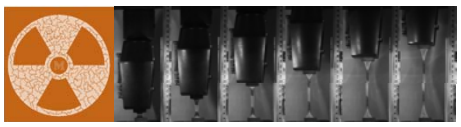
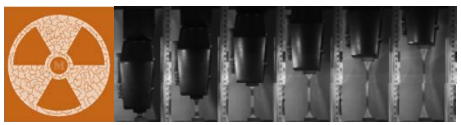
Acronyms

- Shape-memory polymer (SMP)
- Crosslinker (XL)
- Glass Transition Temperature (T_g)
- Rubbery Modulus (E_R)



In-Hospital Device Manufacturing

- Supply chain reliability in time of disaster
- Aim to allow hospitals to manufacture needed polymer medical devices
  - Infusion pumps for insulin, endo/laproscopic device fittings, arthroscopic shaver handles



3D Printing

- Capability to rapidly manufacture devices
- Fused Deposition Modeling (FDM) printing requires low M_w polymer
- Many common FDM 3D printed polymers exhibit poor mechanical properties

Mass Manufacturing of SMP's

Process:

1.) tunable thermoplastic polymer synthesis,

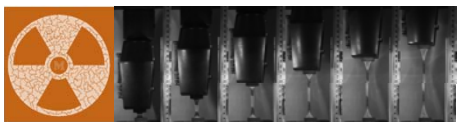
2.) crosslinker blending,

3.) plastic molding and

4.) high-energy radiation

5.) to control final thermo-mechanical properties

6.) in a custom device.



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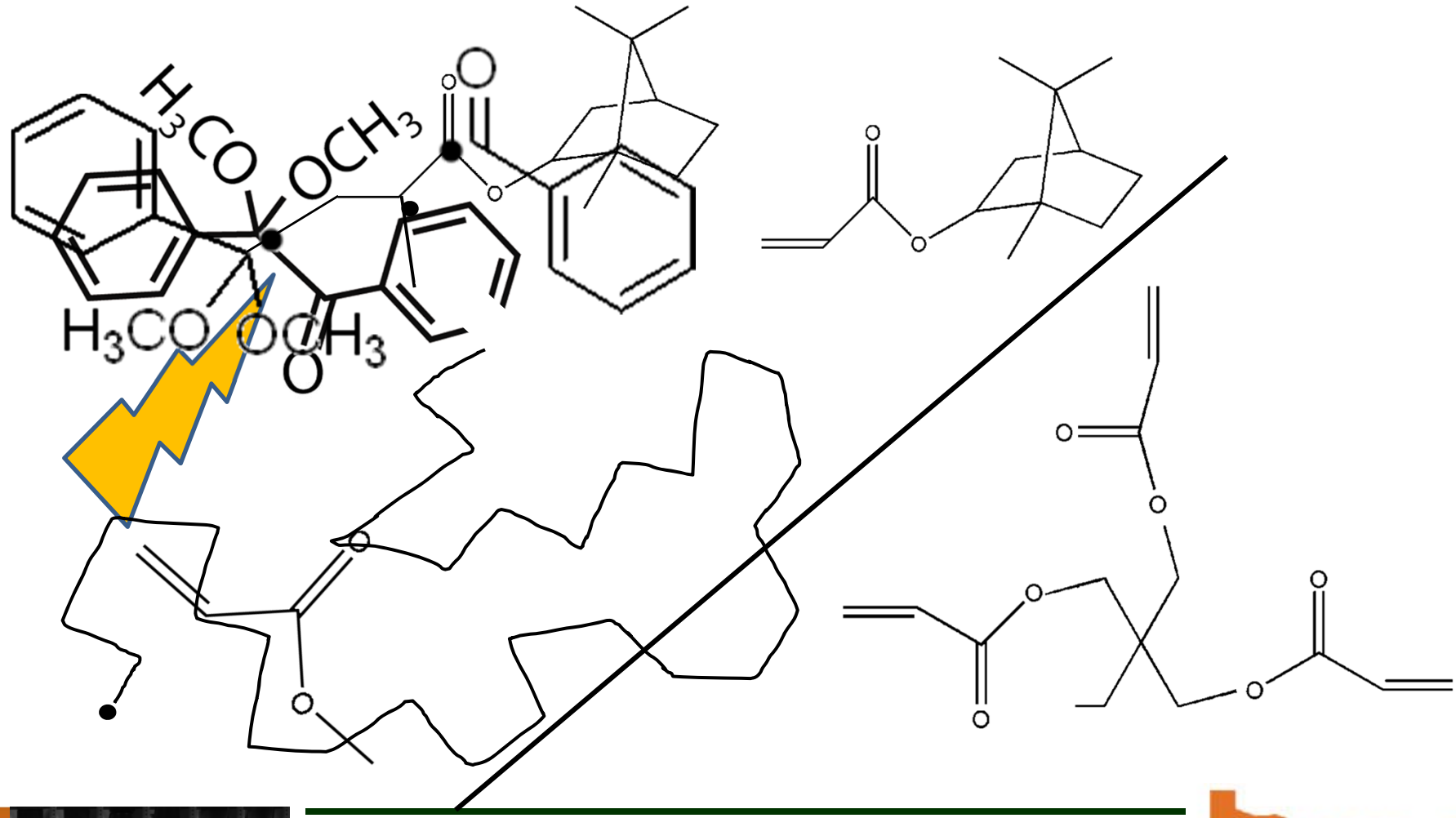
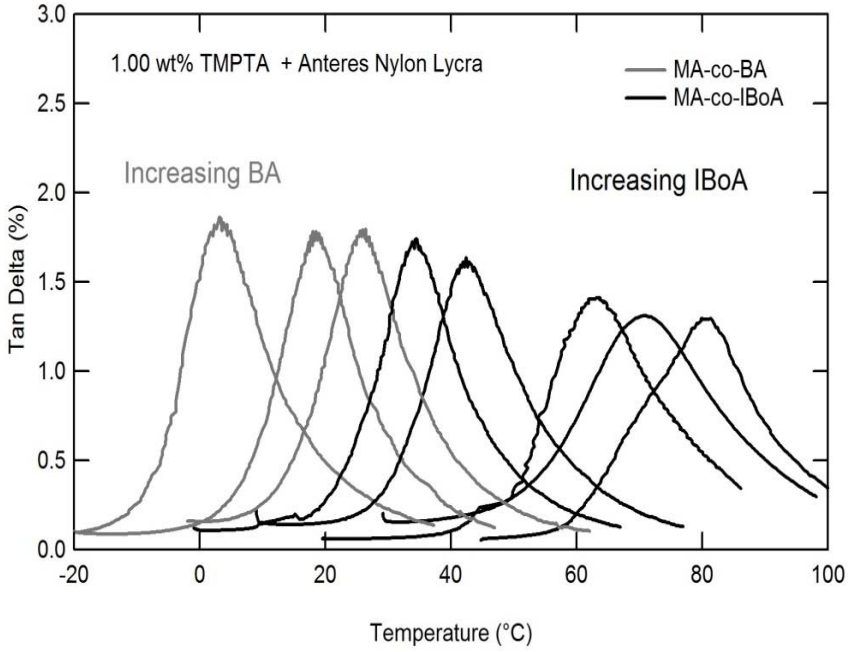
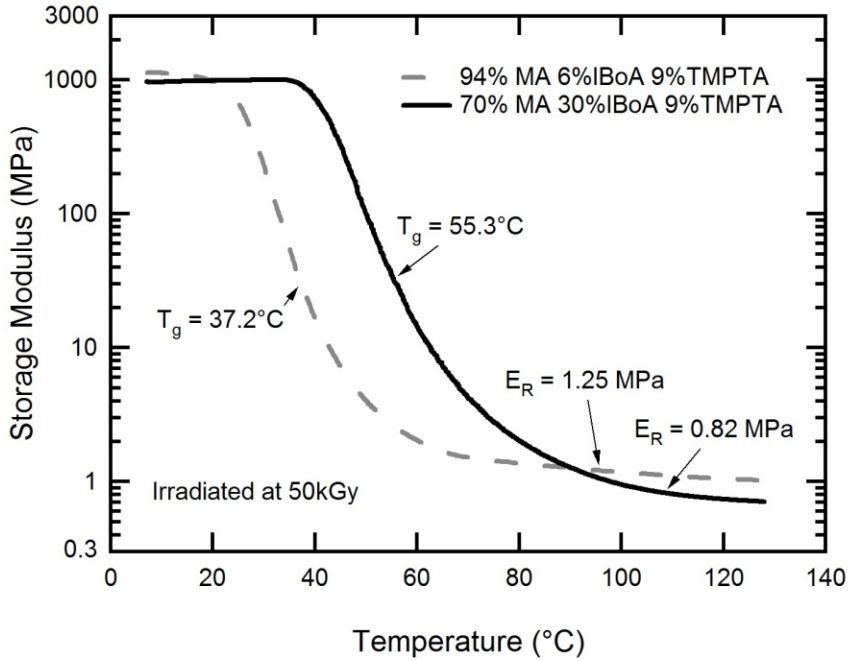
Polyacrylate Polymer Synthesis

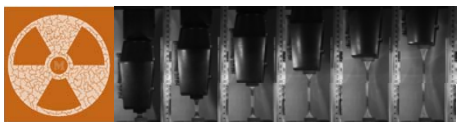


Altering Glass Transition

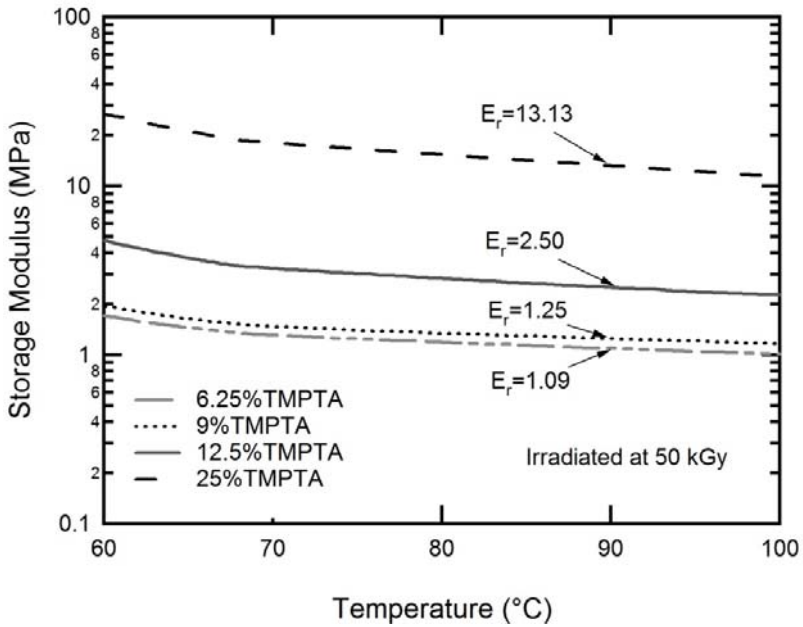




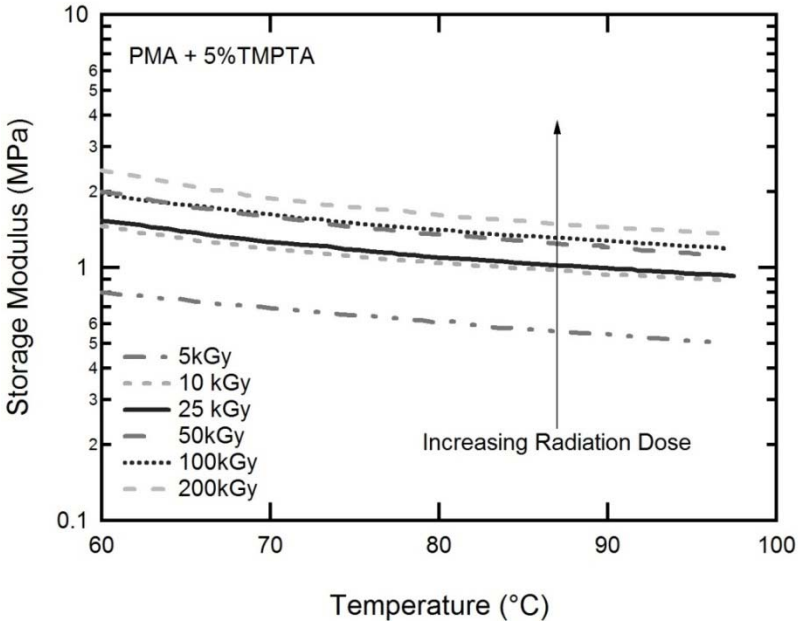
Ware, Ellson, Kwasnik, Drewicz, Gall and Voit (2011). "Tough Shape Memory Polymer Fiber Composites." J. Reinforced Plastics and Composites. **30**(5):371-380



Altering Rubbery Modulus

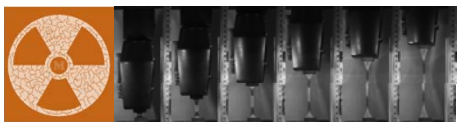


1. Changing crosslinker concentration



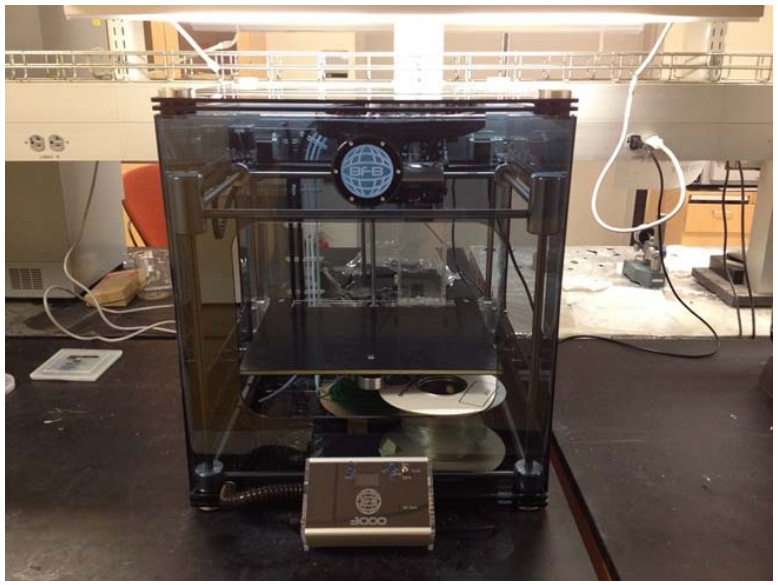
2. Changing dose

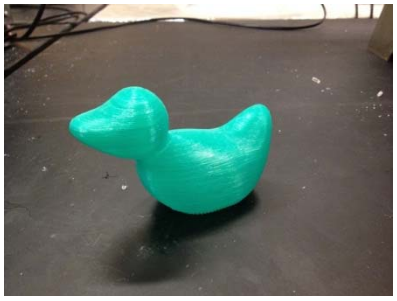
Voit, Ware, and Gall (2010). "Radiation Crosslinked Shape Memory Polymers." Polymer. **51**(15):3551-3559



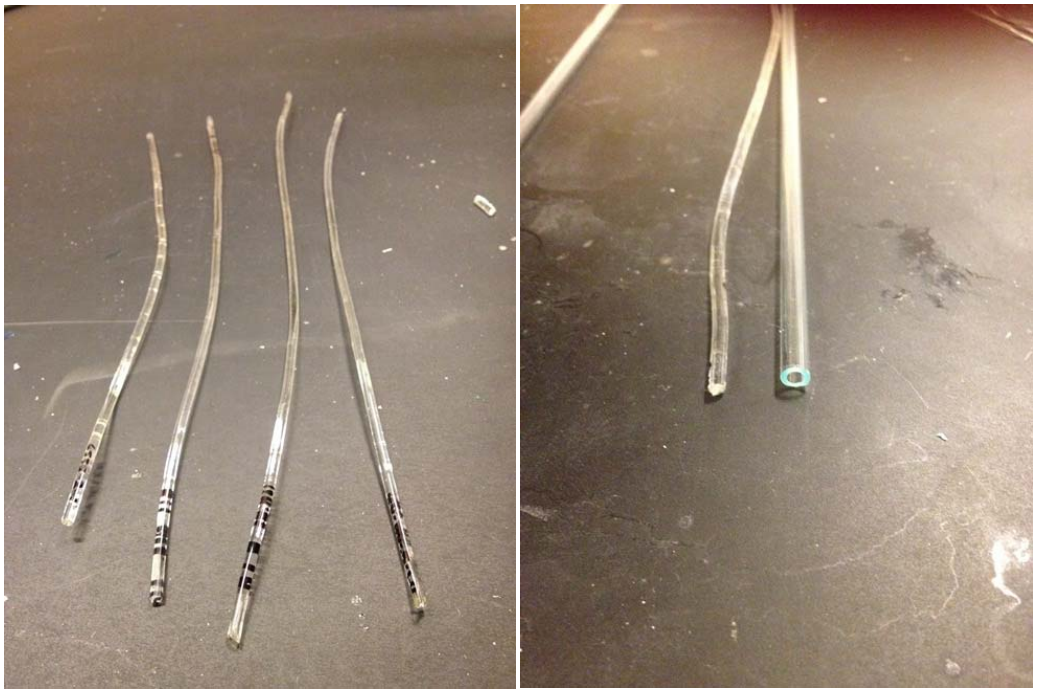
3D Printer

- BFB 3000
  - Fused Deposition Modeling
  - 3mm filament
  - Temp Range: 0°-260°
  - Feed Rate: 0-12.5mm/s
  - 0.5mm extrusion nozzle

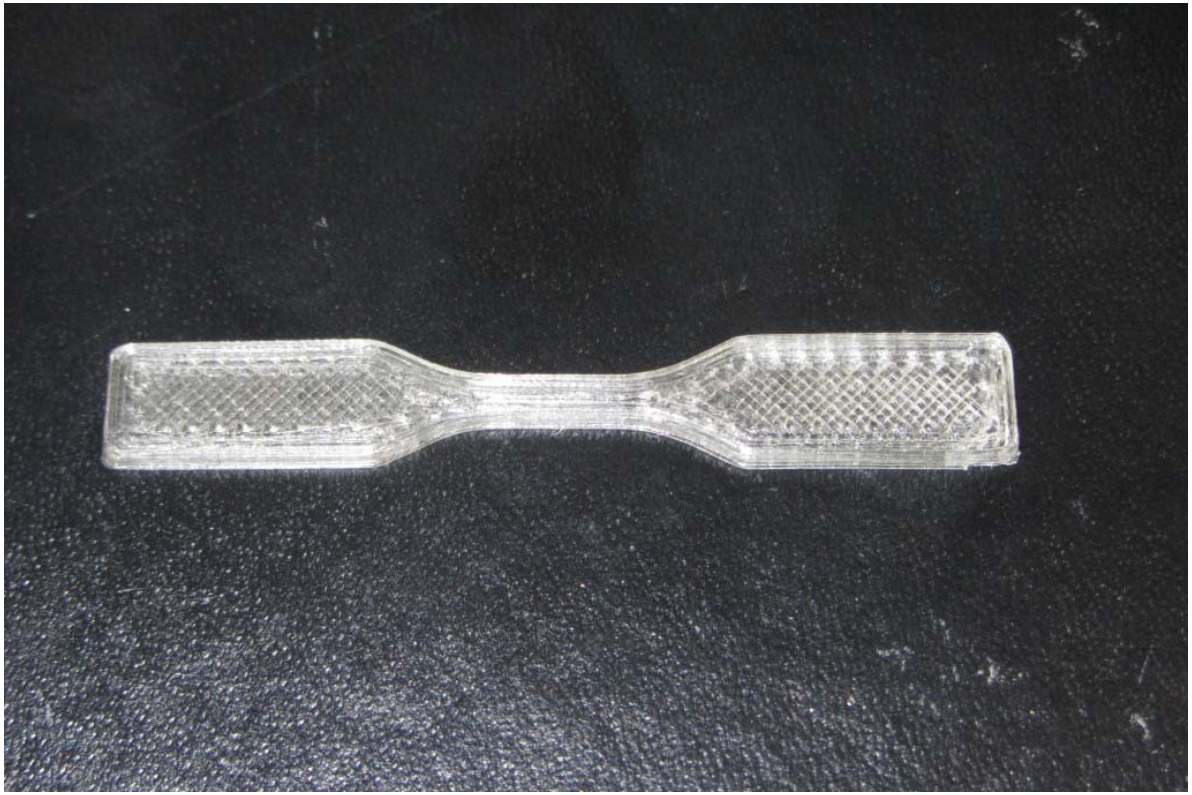




Preparation of Thermoplastic resin

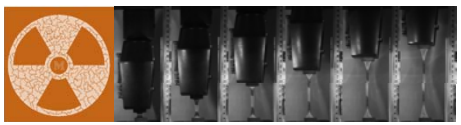


3D Printed Dogbone



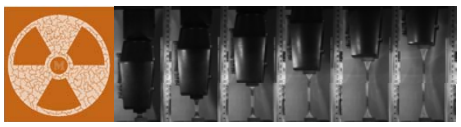
Time/Temperature Resin Stability

- Inhibitor: Hydroquinone
- Prevents undesired crosslinker reactions due to heat or long storage time



Future Studies

- Can we understand the effects of temperature relative to the T_g on crosslinking?
- Can the effects of anisotropy in 3-D printed materials be reduced through post crosslinking by radiation?
- Will post-crosslinked, 3-D printed PLA and SMP composites add value for biomedical or other devices?



Broad Impacts Today

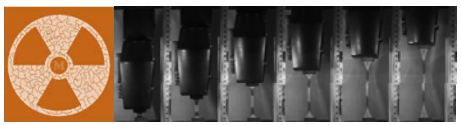
Syzygy Memory Plastics is developing the most advanced, effective, and comfortable hearing protection on the market.

- Ineffective hearing protection is the leading cause of Noise Induced Hearing Loss (NIHL)
- NIHL is the **#1 occupational disorder** in the world, afflicting over 17% of all adults in the US with permanent damage to their hearing
- NIHL is **100% preventable** through better designed hearing protection.

CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

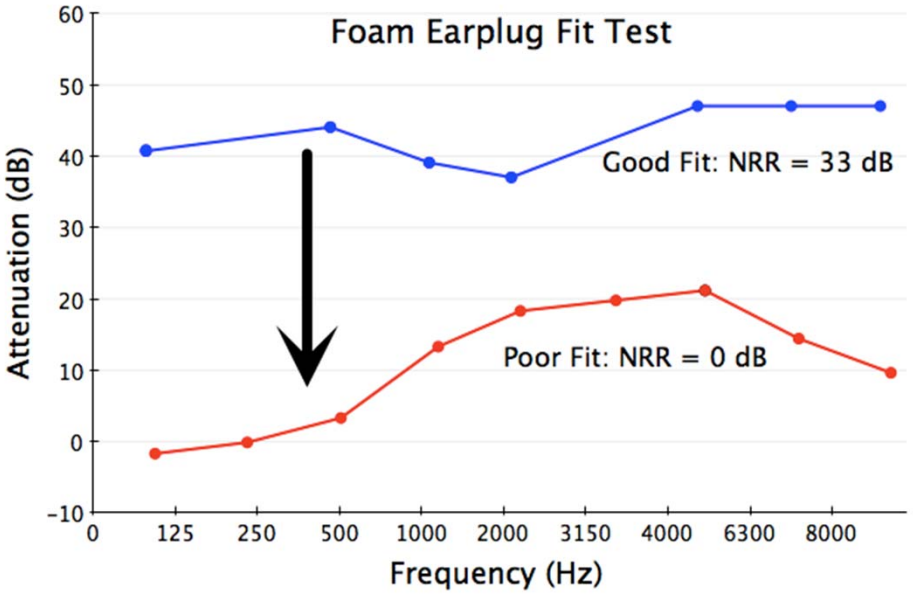
NATIONAL INSTITUTES OF HEALTH

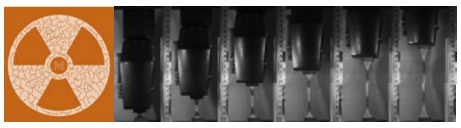
OSHA®



Technical Problems

- Current earplugs are inadequate
  - Not comfortable over long time periods
  - Users must choose sound attenuation vs. comfort
  - One size does not fit all, only fraction of users
  - Custom earplugs are expensive ($100+) AND not dynamic
  - Insertion error -> poor fit -> ineffective sound attenuation



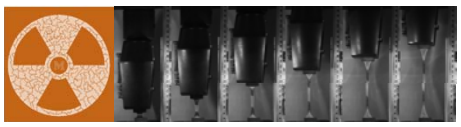


Solution: PrēmEar Plugs™

Unique, patented material and design that enables the following features, benefits and advantages:

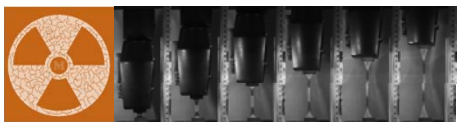
- Heat activated material that creates a self-customized fit thus enabling more comfortable protection
- Dynamically comfortable to better seal the ear canal creating greater protection
- Simple to insert thus enabling a more fail-safe earplug to more effectively block unwanted sound
- Priced comparably to existing reusable earplugs, making comfort and high protection affordable to all users

Insert **Comfort**



Conclusions

- Devices can be crosslinked using ionizing radiation after manufacturing by 3-D printing
- T_g and E_r are able to be tuned independently
- Poly (lactic acid) copolymers and blend can potentially serve as interesting components in 3D printing systems
- SMP earplugs are a near commercial demonstration of advanced polymer technologies



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- **Academic Collaborators**: Drs. R. Rennaker, E. Keefer, M. Kilgard, D.W. Smith, R. Roeser, M. Quevedo, B. Gnade, S. Wagner, K. Wooley, B. Wester, Y. Hanein (and M. David-Pur), J. Elisseeff, H. Lu, D. MacFarlane, and S. Priya
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