Active Polymer Composites for Detection of Abnormal Thermal and Optical Environments

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Sandia National Laboratories

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Challenges

- Develop non-powered sensors to detect abnormal thermal and optical environments.
- Achieve sensing mechanism via stimulation of piezoelectrics with thermally or optically active shape-memory polymers (SMP).
- Tune SMP properties to achieve varied SMP/piezoelectric composite sensor characteristics.
- Develop model to predict thermomechanical SMP behavior.
- Model piezoelectric vibratory response and electrical signal generation
- Implement SMP model and model for piezoelectric deformation into a common framework.

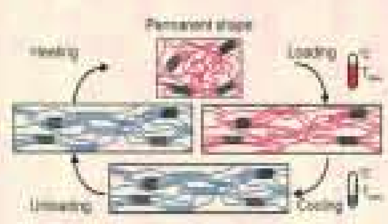
Shape-memory effect in polyurethane foam

Manual piezoelectric stimulation

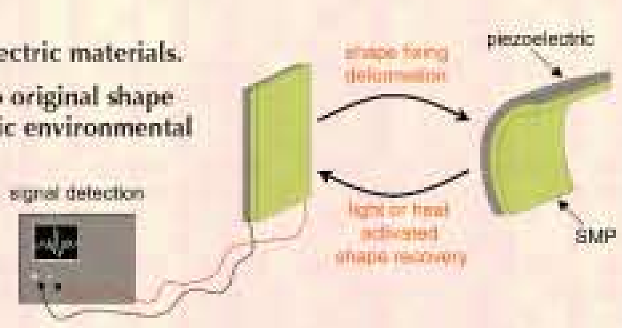
Principles of SMP/Piezoelectric Actuation

(Landlein 2005)

- SMP Materials
  - Flexible materials with relatively fast recovery rates.
  - Multiple activation/recovery cycles possible.
  - Tunable characteristics to optimize for a variety of conditions.

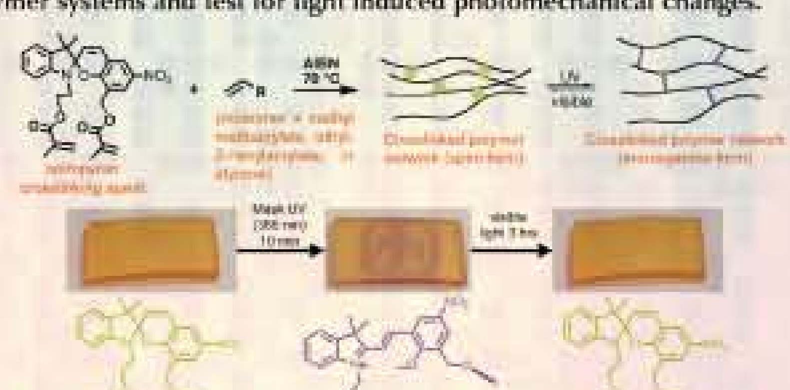


- Sensor Mechanism
  - Composite SMP/piezoelectric materials.
  - Activated SMP reverts to original shape upon exposure to specific environmental conditions.
  - Shape change induces deformation of piezo material leading to signal generation.



Light Activated SMP Networks

- Prepare light-actuated SMP that operates under ambient light conditions (500-700 nm).
- Develop photomechanical system derived from light induced molecular rearrangement of spiropyran ring system to open form zwitterionic merocyanine form.
- Incorporate spiropyran ring structure into polymer networks and known thermally activated SMP polymer systems and test for light induced photomechanical changes.



Heat Activated SMP Polyurethanes

- Screening study identified a Sandia polyurethane to have desired SMP properties as well as toughness and good processability.
- Thermomechanical properties of SMP-0 were investigated to provide parameters for material models.
- These properties were compared to commercially available SMPs, heat shrink films and non-SMP controls.

SMP foam formulation

Ingredient	SMPU-0 (original)	SMPU-1 (adjusted)
Voranol 490 polyether polyol	72.0	72.0
DABCO-33LV catalyst	0.17	0.15
Isonate 181 diisocyanate	134.05	108.48

SMPU-0 shows excellent [illegible] recovery response behavior

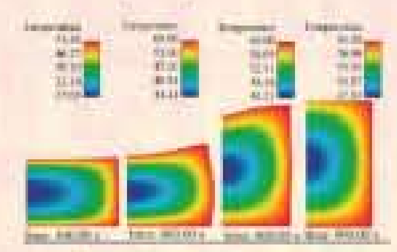
Compressed foam cylinders at [illegible] recoveries [illegible]

[illegible] recovery [illegible] "Shrinky Dink" [illegible]

Development of an SMP Material Model

- Physically based material model is needed to predict the thermomechanical behavior of SMP a material model.
- Incorporate non-equilibrium kinetics of glass transition (Tg), deformation recovery and stress relaxation. Include dependency of deformation on heating/cooling rates.
- Implement material model and model for large deformation of piezoelectric materials into a common FEA framework (code).

Stress-strain response for isothermal uniaxial compression



Simulation showing non-uniform heating of an SMP device

Publications

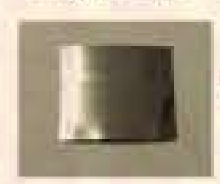
"Finite deformation thermo-mechanical behavior of thermally induced shape memory polymers"; Qi, Nguyen, Castro, Yakacki and Shandas; *Journal of the Mechanics and Physics of Solids*, 56 (2008) 1730-1751

"A Thermoviscoelastic Model for Amorphous Shape Memory Polymers: Incorporating Structural and Stress Relaxation", Nguyen, Qi, Castro and Long, *JMPS* (2008) In Press

Active Polymer Devices

PVDF Film

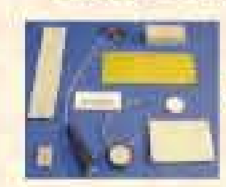
- Source: MSI Sensors
- Polymer based polyvinylidene fluoride
- Available in thin (28 micron) flexible sheets
- Voltage output > 830 V



PVDF film metallized on both sides

PZT Fibers

- Source: Advanced Cerametrics
- Ceramic lead zirconium titanate material
- Fiber diameters from 5-250 microns
- Voltage output up to 700 V



PZT fibers embedded in various shapes and materials

The input rate required to to stimulate the necessary electrical response is much faster (< second, vibratory) than the fastest SMP can provide.

- Direct stimulation of piezoelectrics with SMPs has not been studied, but development of a suitable trigger mechanism should en able the viscoelastic response of an SMP to stimulate a piezoelectric material.

Device design concepts

➢ Bistable Switch

Manual testing of a bistable piezo "switch" gave a 4 V signal.

➢ Linchpin

A linchpin plus spring design is another potential device candidate

Significance

- No one has used SMPs to stimulate piezoelectrics, but design possibilities exist.
- Improvements in the recovery force available from SMPs plus device designs for "trigger" mechanisms should enable the desired SMP/piezoelectric interaction.
- SMPs have inherent advantages (larger range of motion than metallic shape memory allows, heat and/or light activation) that will be useful to a variety of applications once better understood.

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