Printing of PZT-Silane Nano-Composite Sensors and Actuators

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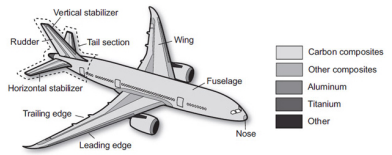
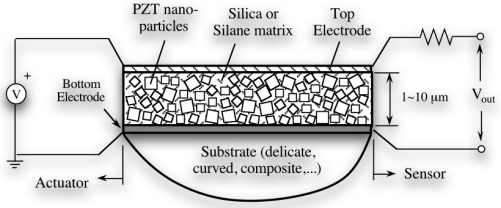
Motivation

- Structural health monitoring:
  - Early detection of impinging damage
  - Piezoelectric-based (specifically PZT) sensors
  - Studied by many researchers in lab environments
- Constraints in real applications to composite structures:
  - Low processing temperature (less than 120°C) to protect composite substrate
  - Curved surfaces and odd geometry
  - Compatible with composite manufacturing process
  - Interconnects and packaging; reliability
- Need low temperature fabrication to protect host structures.
- 3-D printing utilization to accommodate complex geometry, integrate manufacturing and minimize weight penalty.



Various composite structures on the Boeing 787. Courtesy: seattlepi.com

Proposed Technology

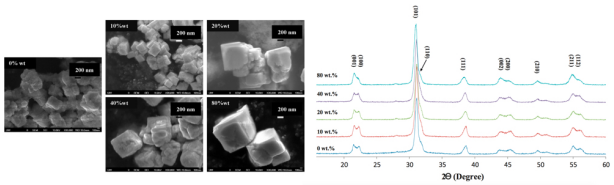


PZT-silane nano-composite film

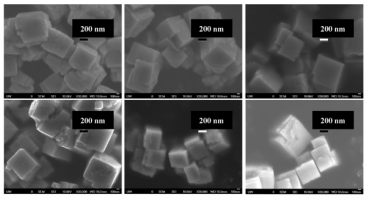
- Disperse PZT nano-particles in silane ink.
- 3-D print PZT-silane ink (and also electrodes and package) on substrate.
- Cure the ink under UV light or low temperature (< 120ºC) to form a PZT-silane thin film.

PZT Nano-particles

- Hydrothermal synthesis of PZT nanoparticles using controlled ramping and cooling rates, 200-800 nm in size and patent available.
- Expedited hydrothermal process (EHP): no ramping and fast cooling, 2.5 M KOH mineralizer, 50 wt.% excess lead, 200°C for 2 hours.



SEM images (x30,000) and XRD patterns for lead concentration trials

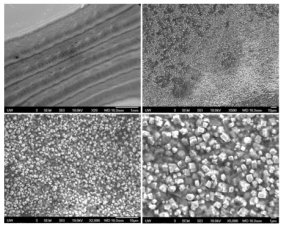


SEM image (×30,000) of EHP samples from various batches.

PZT-silane Ink

- Achieved fairly stable colloidal ink using ethanol as solvent.
- The ink can be 3-D printed, drop casted and spin coated on the electrodes.

PZT colloidal ink



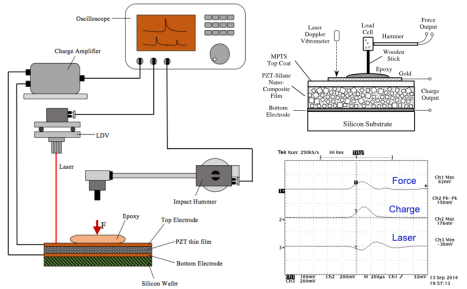
3-D printed PZT film

IP Disclosures

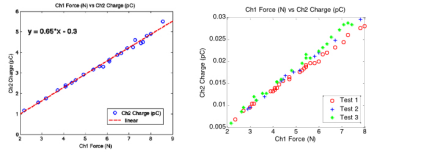
- Patents Issued: Jeff Duce, Scott Johnston, I. Y. Shen, G. Z. Cao, Hsien-Lin Huang, "Method and System of Fabricating PZT Nanoparticle Ink Based Piezoelectric Sensor. United States Patent No. 8,614,724, issued on December 24, 2013 .
- Patents Filed: Filed 1 patent application on PZT nano-particles in the summer of 2011. Received favorable response in the latest Office Action notification.

Characterization of PZT Thin Film Sensors / Actuators

- The piezoelectric performance can be evaluated via a charge-to-force ratio in the time domain.
- Finite element static analysis shows that charge measures localized strain of the PZT film and can be used to estimate sensor's d_{33}.

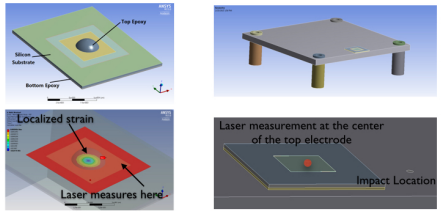


Experimental setup to evaluate piezoelectric performance of PZT-silane films



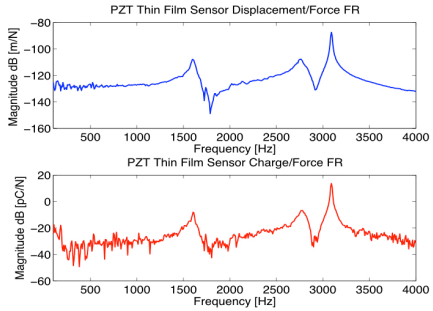
Charge-to-force ratio | Repeatability

Actuator poled @ 250Hz and 690 Hz Response is in sync



FEA model shows strain distribution | FEA model for sensor application

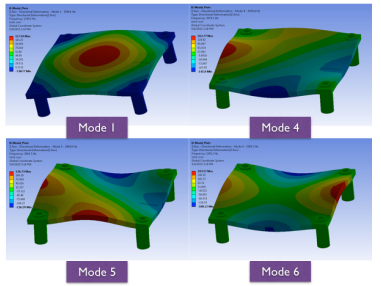
- For sensor application, peaks shown in charge output of the dropped film (w/o protective epoxy on top) when the structure is in resonance.



Measured frequency response functions

Freq. (Hz)	1	2	3
Experiment	1596	2764	3092
FEA	1798	3077 /3082	3281

Comparison between experiment and simulation



Finite element modal analysis

Publications

- Hsien-Lin Huang, G. Z. Cao, and I. Y. Shen, 2014: Hydrothermal Synthesis of Lead Zirconate Titanate (PZT) Nano-Particles Using Controlled Ramping and Cooling Rates. Sensors and Actuators A—Physical, vol. 214, pp.111-119 .
- Weiwei Xu, Hsien-Lin (Stacey) Huang, Yifeng Liu, Chuan Luo, G. Z. Cao, I.Y Shen, 2014, "Fabrication and Characterization of PZT-Silane Nano-Composite Thin-Film Sensors," Sensors and Actuators A—Physical,(in preparation).

Conclusions and Future Work

- Fabricated PZT nanoparticles, PZT ink and PZT-silane nano-composite thin films.
- Developed experimental setups for characterizing the piezoelectric performance of the PZT thin-film sensors/actuators.
- Performed finite element analysis to better understand the experimental test results.
- Further improve PZT nano-particles and PZT-silane ink. Instrumentation: 3-D printing.
- New applications: Strain sensors and shape sensors for complex 2-D surfaces.