Improved Vibrational Energy Scavenging Ferroelectric Domain Configurations

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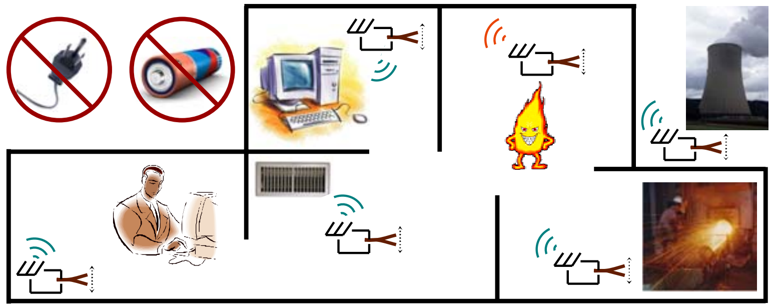
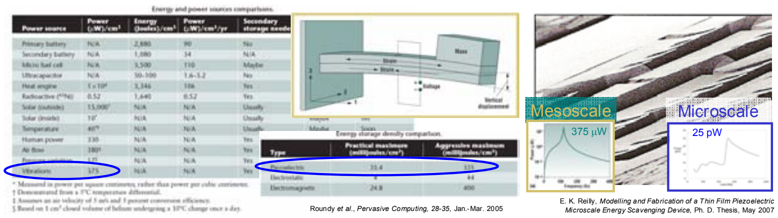
Vision

Ubiquitous wireless sensor networks have extraordinary potential for use in environmental monitoring, process control and medical device applications. Realization of these networks for wide-spread market use requires that the sensor nodes be small, maintenance-free, and compatible with integrated circuit manufacturing processes. A microscale energy scavenger can harness environmental vibrations to provide a replenishable source of power for the sensor node while simultaneously reducing the volume occupied by the power generator.

Piezoelectric vibrational energy scavenging is an ideal energy source for indoor applications where solar and wind power are not available. Piezoelectric scavengers can be fabricated as MEMS devices, free from external power sources or complex three-dimensional designs that are required by electrostatic and electromagnetic vibrational scavengers.

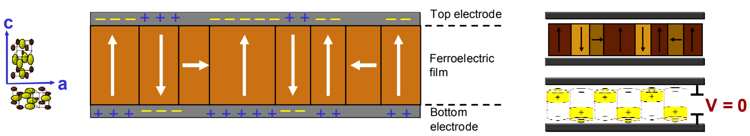




Roundy et al., Pervasive Computing, 28-35, Jan.-Mar. 2005

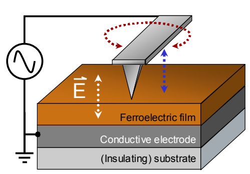
E. K. Reilly, Modelling and Fabrication of a Thin Film Piezoelectric Microscale Energy Scavenging Device, Ph. D. Thesis, May 2007

Competing domains reduce energy conversion by charge compensation

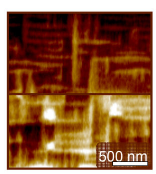


Methods

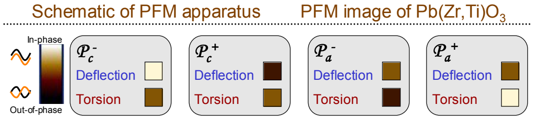
Piezoelectric force microscopy (PFM) is a standard technique for mapping the local piezoelectric response of a material. An ac electrical bias is applied across the film of interest, and the mechanical response is detected by a cantilevered tip in contact with the film. The amplitude of the response indicates the strength of piezoelectricity and the phase delay indicates the direction of electric polarization.



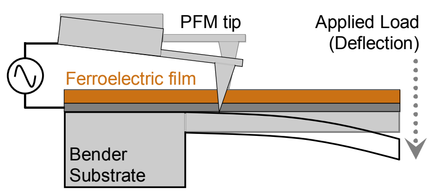
Schematic of PFM apparatus



PFM image of Pb(Zr,Ti)O_3



While typically performed on rigid substrates, we have been able to produce clear images even when scanning on highly compliant benders such as those used for vibrational energy scavenging.



This allows us to examine the domain configuration of the film under conditions that an operating scavenger would experience.

Research Questions

Vibrational energy scavengers that have been miniaturized to be compatible with silicon-based MEMS processes are significantly less efficient than their mesoscale counterparts.

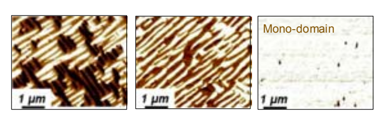
What is causing this loss of performance?

We believe the answer lies in the nanoscale polarization domains within the active ferroelectric film.

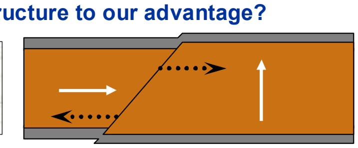
What is the as-grown domain configuration pattern?

How does this pattern impact mechanical-electrical transduction?

How can we control the domain structure to our advantage?



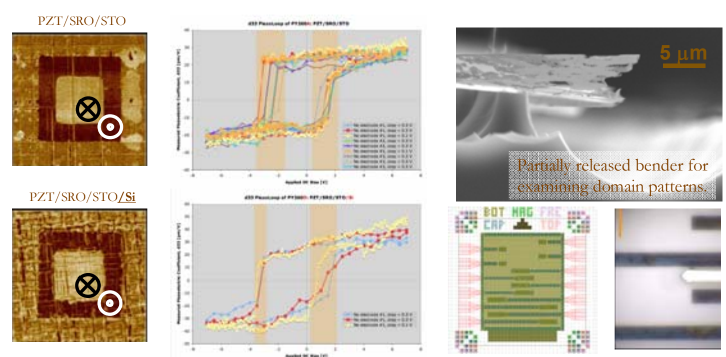
Example domain structures Y.-H. Chu et al., Adv. Mater. 19, 2662-2666 (2007)



90° domain wall motion enhances the piezoresponse

Findings

PFM images of the prototypical ferroelectric film, Pb(Zr,Ti)O_3 [PZT], show that a polarized single domain state is stable when the film is grown on a similar substrate, $SrTiO_3$ [STO], but not on silicon. Cycling the applied bias also reveals the presence of an additional stable orientation, corresponding to the preferred in-plane domains.



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