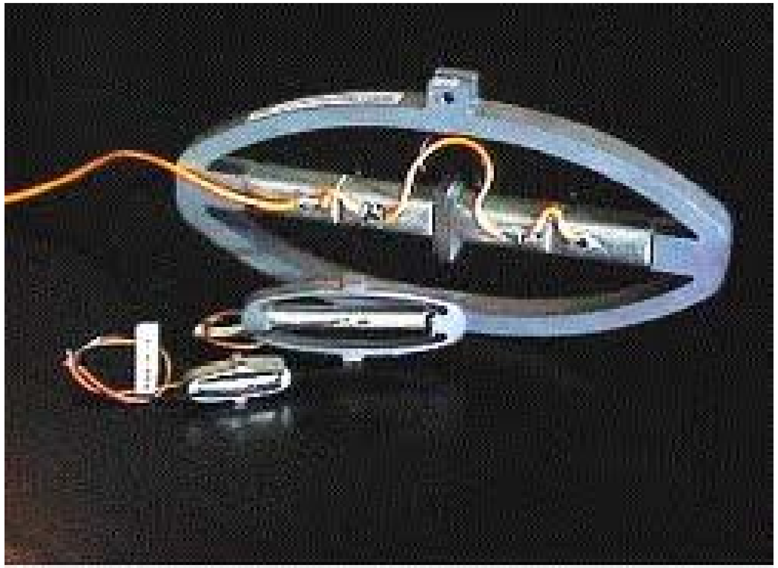
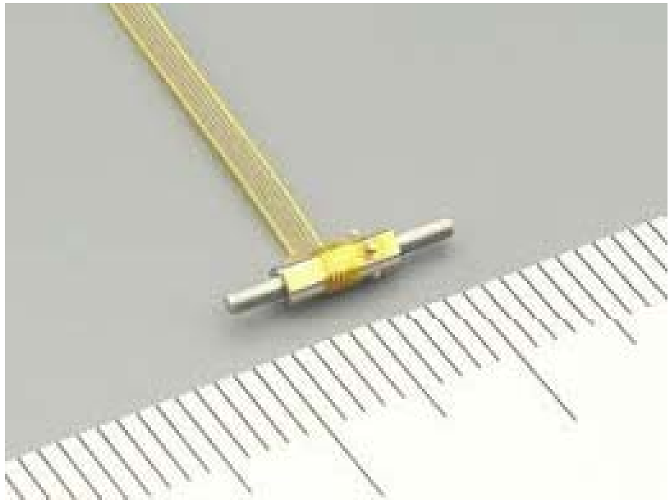


APA230L, APA150M, APA100S

Module 5: Actuators & Sensors based on HBLS Smart Materials



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Topics Covered in the Last two Modules

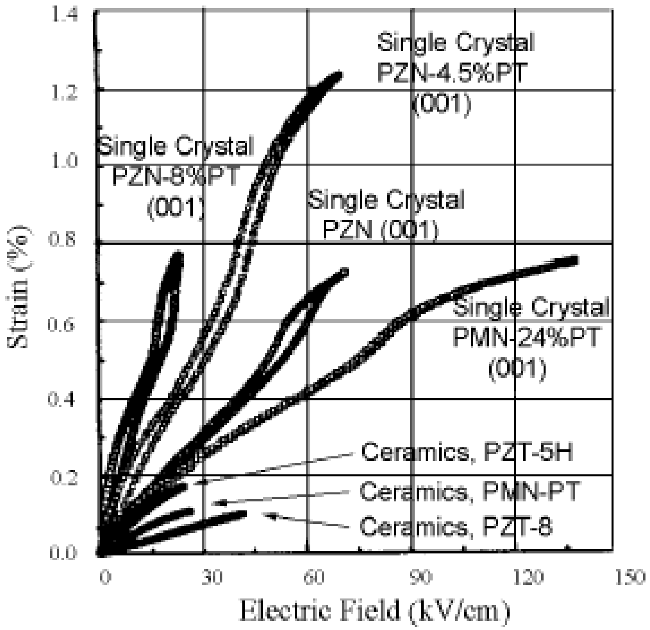
- **Introduction to Composites**
- **Failure of Composites**
- **Ply Mechanics of Composites**
- **Macro Mechanics of Composites**

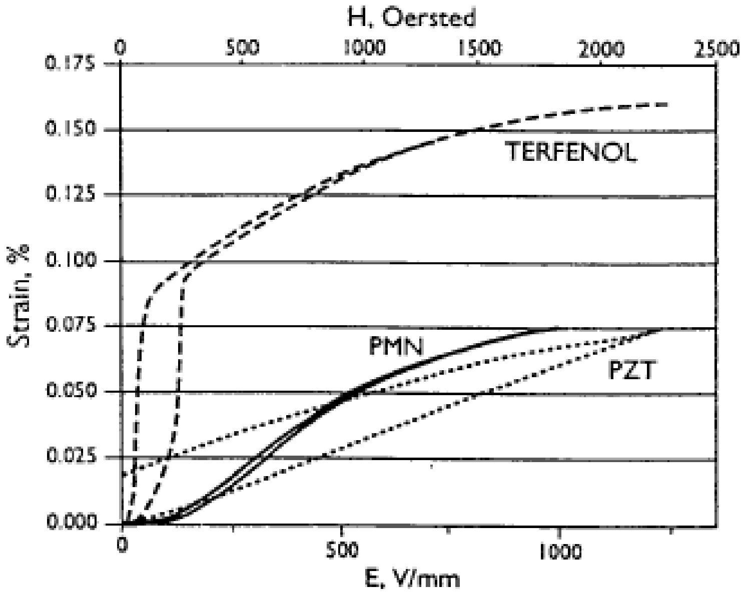
LECTURE 33
Modelling of Smart Composite Beam
(Part 1)

Organization of this Lecture

- What are HBLS Materials?
- What are Smart Laminated Composites?
- Model of a Smart Composite Beam

What are High Band-width Low Strain Smart Materials?





Reference: ACTUATORS AND SMART STRUCTURES by Victor Giurgiutiu

How small is 1.2% strain?

- Consider a small scale of size 15cm or 150mm.
- You can expect an elongation of 1.8 mm from this scale if it is piezoelectric
- Most of the piezo-ceramic actuators are of size less than 20mm (because these are too brittle)
- Hence, you can expect an elongation of about 200 micron meter (two times the width of human hair)!

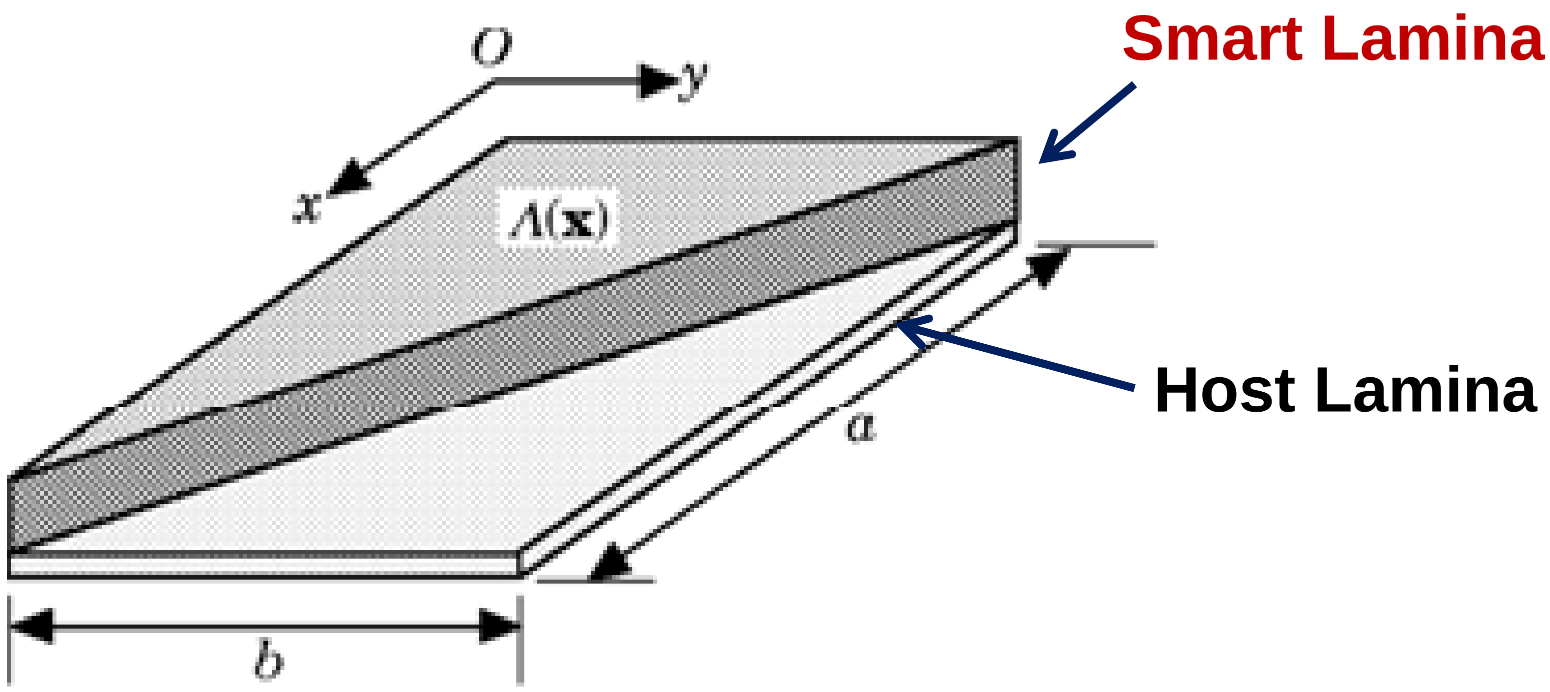
High Bandwidth Low Strain Smart Materials

- Piezoelectric Actuators
  - Piezoceramic Unimorph and Bimorphs
  - Amplified Piezoactuators
  - Piezoelectric Composites
  - Piezo-transducres
- Electrostrictive (PMN) Actuators
- Magnetostrictive Actuators
  - ➢Terfenol-D Actutaors as MMA
  - ➢Terfenol-D Composites

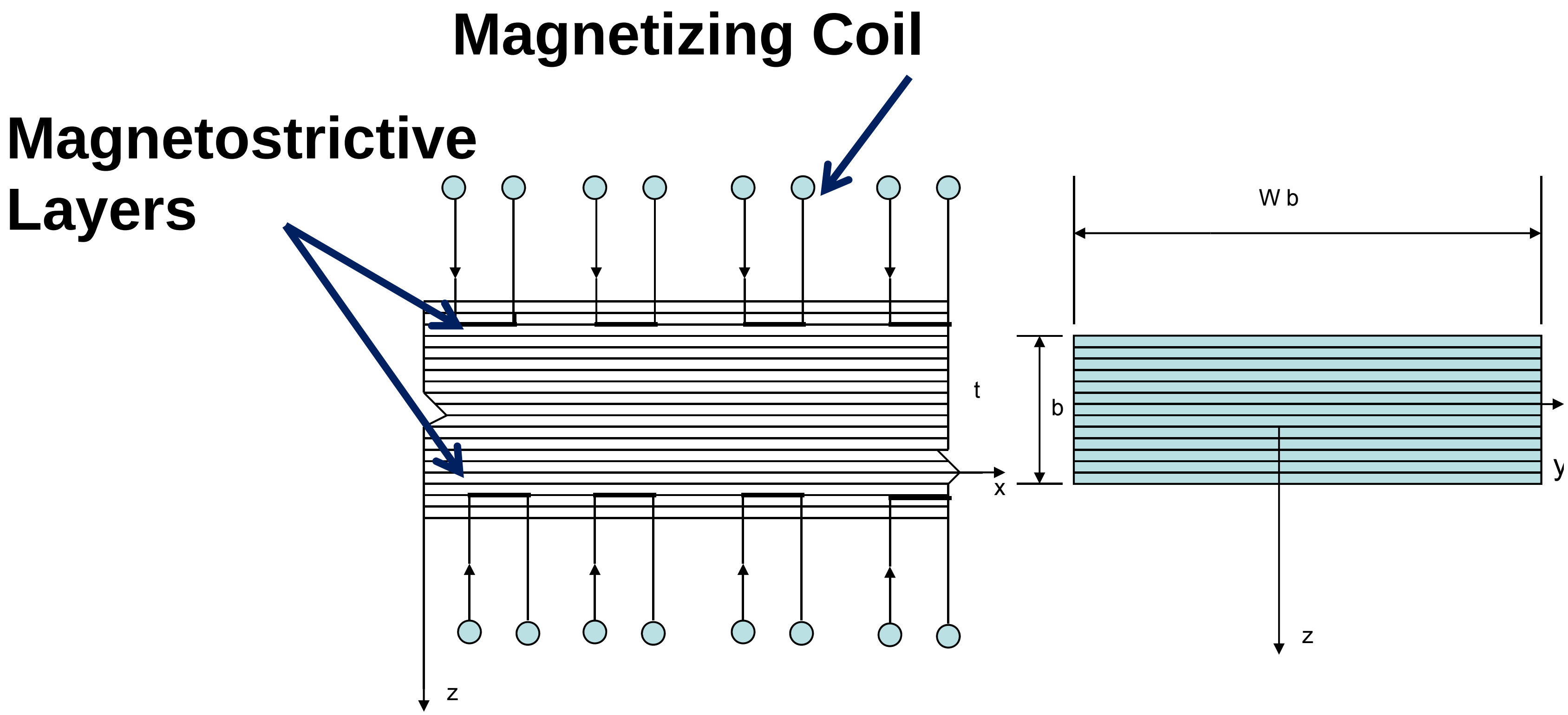
Motivation

- Smart Sensors and Actuators are either Surface Bonded or Embedded
- Embedded sensors and actuators are preferred as they do not pose any constraint on the boundary profile. They are usually easily embeddable in polymeric matrix composites.
- However, embedding often poses serious challenge to the Structural Integrity
- Hence, it is important to study how smart sensors/actuators would behave while embedded inside the laminated composites.

Laminated Smart Composites



Magnetostrictive Smart Composite



Analytical Model of Smart Composite Beam

Strain and Displacement

$$\boxed{U\,(x,z,t) = -z\,w_{,x}(x,t);\;\; W(x,z,t)n = w(x,t)}$$

($_{,x}$) denotes differentiation with respect to *x*. The total strain in any (*i*-th) layer of the beam consists of two parts; the elastic strain given by

$$\boxed{\epsilon^{i}{}_{x_s} = S\,\sigma^{i}_{x_s}}$$

and the active strain , present only in the active layer. Thus, the expression for strain in any layer can generally be written as

$$\boxed{\epsilon^{i}_{x} = S\sigma^{i}_{x_s} + \delta_{ia}\,\epsilon^{i}_{x_a}}$$

- Here, δ_{ia} is the Kronecker's delta and its value is 1 when $i = a$, (*i.e.* for active layer) and is zero for other layers.

- Also, from the constitutive relationship; for isotropic active layer, the compliance modulus $S = 1/E_a$

- For orthotropic composite layers with fibre-angle θ the relationship will be explored in the next lecture.

References

- Crawley, E.F. and Luis, J.D., Use of Piezoelectric actuators as elements of intelligent structures, *AIAA Journal*, Vol. 25 (10), 1371-1385, 1987
- Anjanappa M. and Bi, J., Magnetostrictive mini actuators for smart structure applications, *Smart Materials and Structures*, Vol. 3, 383 390, 1994
- Nguyen, C. and Kornmann, X., A comparison of dynamic piezoactuation of fiber-based actuators and conventional piezo patches, *Journal of Intelligent Material Systems and Structures*, Vol. 17, 45-56, 2006

END OF LECTURE 33

The beam consists of n ply layers in which the mth and $(n - m + 1)$ th layers, symmetrically placed with respect to the geometric mid-plane are active layers.

Assume that bonding is perfect between composite and active layer.

The thickness of the bonding layer may be neglected.

The active layers are made of either magnetostrictive or piezoelectric material.

Fiber direction in the other composite layers could be arbitrarily specified except the condition that they are to be symmetric with respect to the mid-plane.

Further Assumptions

- The beam is taken to be slender, so that effect of rotary inertia and shear deformation can be neglected.
- Single layer theory of composite beam is used for analysis.
- Flexural motion of the beam in *XOZ* plane can be modeled taking the displacement field as