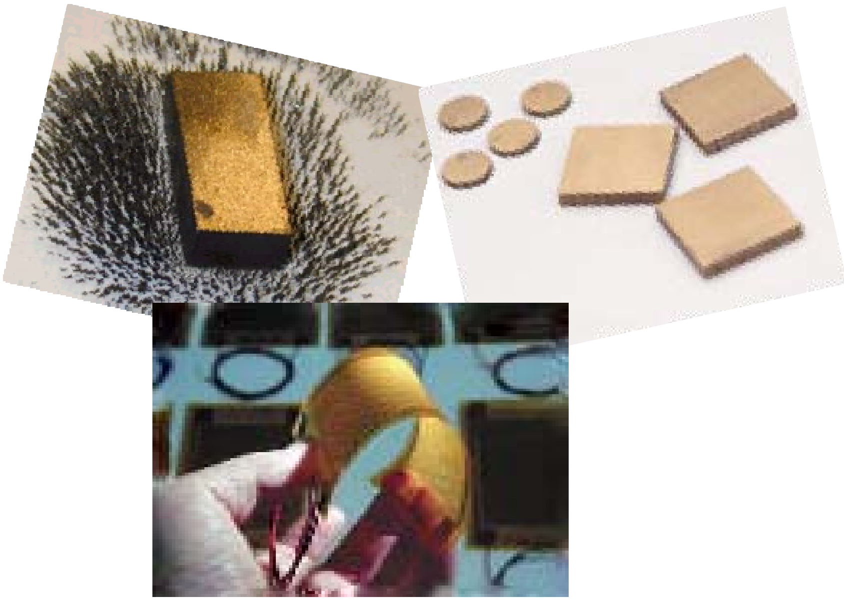
Module 1: Overview of Smart Materials



Bishakh Bhattacharya and Naciketa Tiwari

Department of Mechanical Engineering

Indian Institute of Technology, Kanpur

LECTURE 4:

Magnetostrictive Smart Materials (Part -2)

Organization

- The Constitutive Relationship
- Actuators Developed using Terfenol-D
- Sensors Developed using Terfenol-D
- Magnetostrictive Composites

Const. Eqn. of Magnetostrictive Material

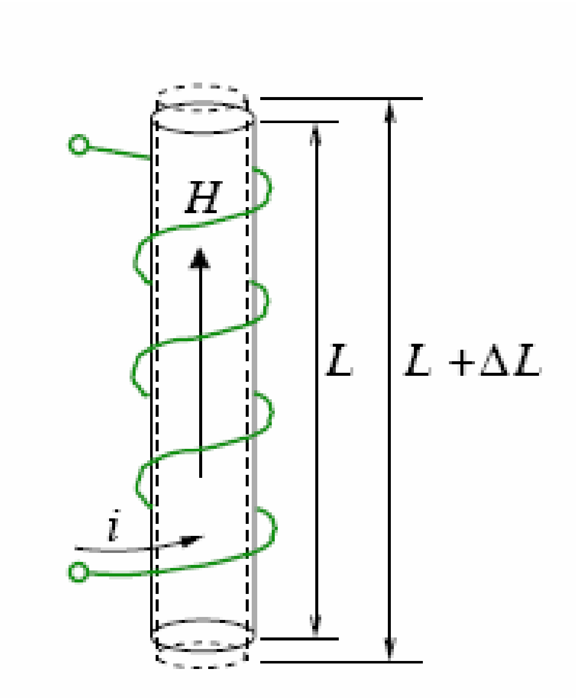
Joule Effect: $S_1 = \sigma_1/E_p + d_m H$

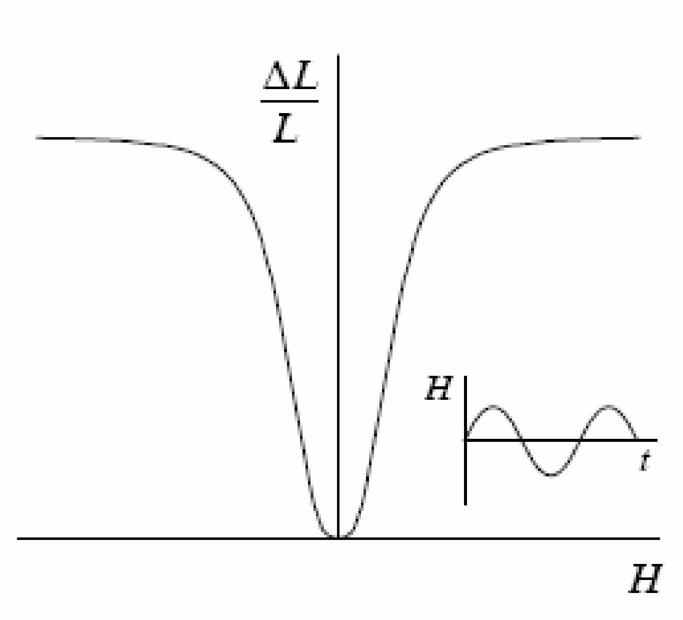
Villary Effect: $B = d_m \sigma_{1} + \mu H$

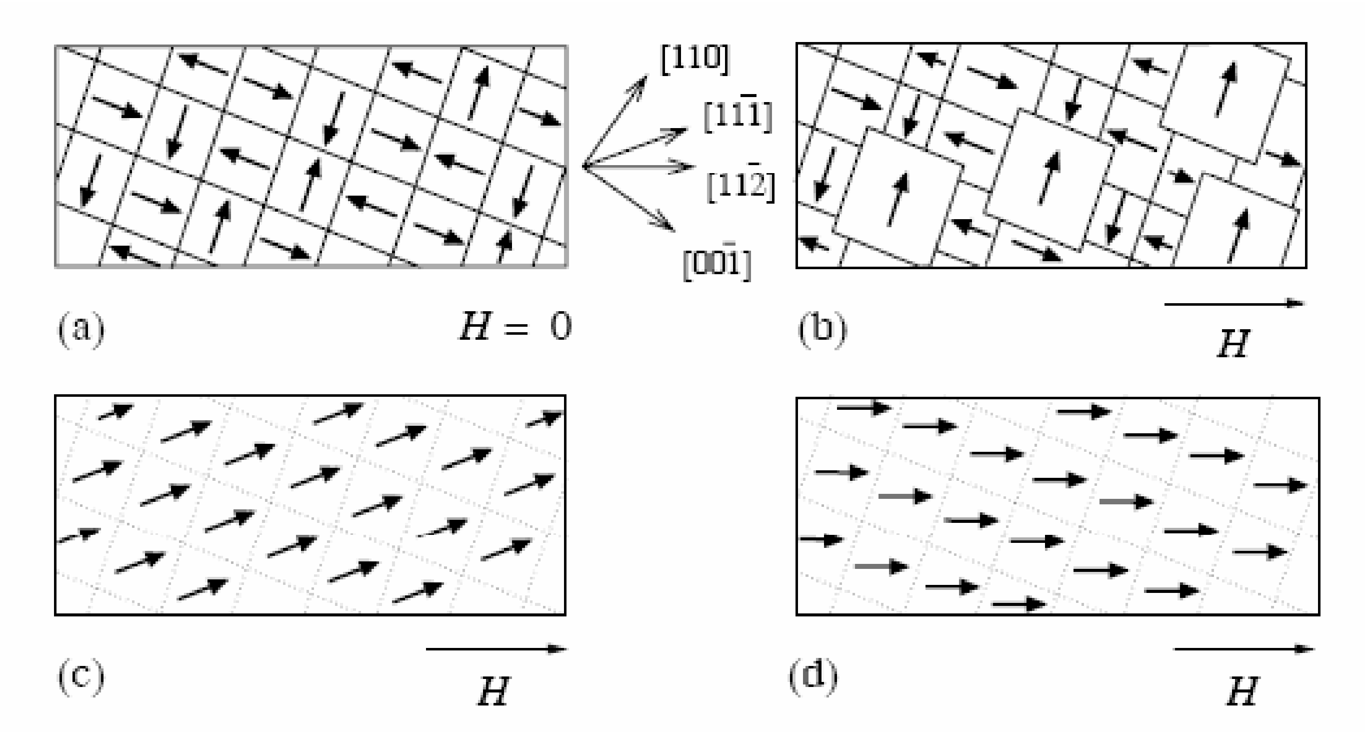
σ-stress, S-strain, B - magnetic displacement/flux density,

μ - permeability, d_m- magnetostrictive constant

Magnetostriction in Solid Rod

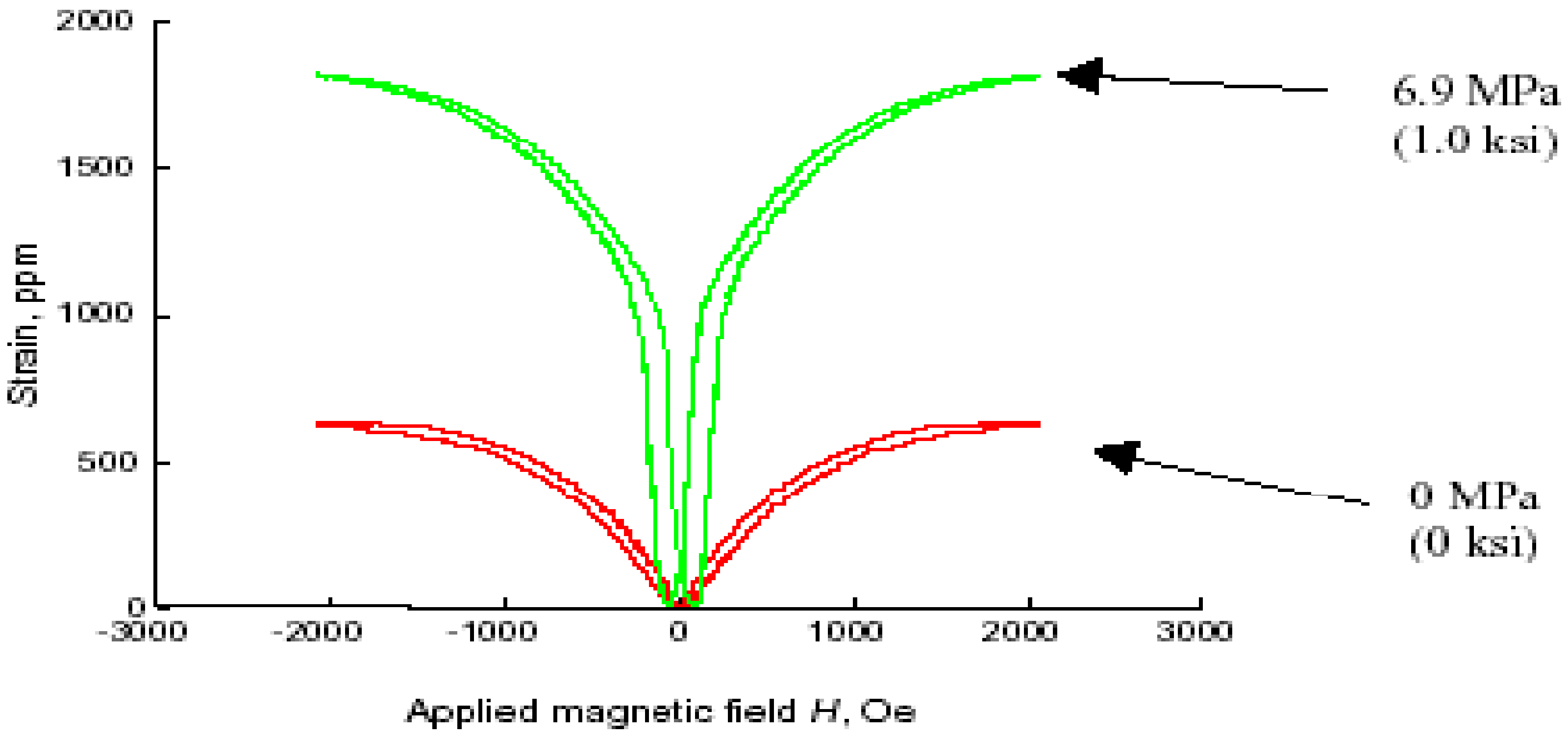




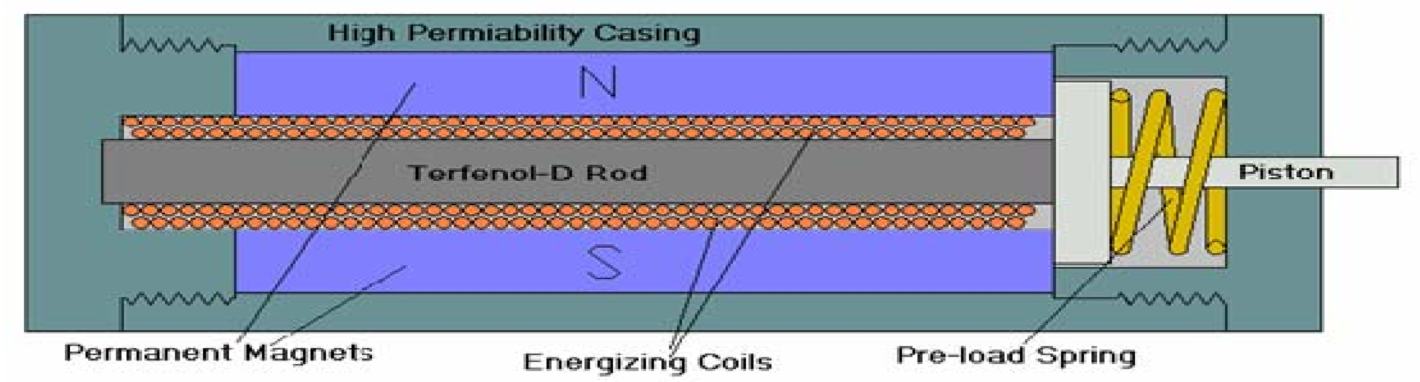


(a) Demagnetized State (b) Partial Magnetization
(c) Irreversible Domain Magnetization (d) Technical Saturation

Butterfly curve for TerFeNOL-D



Magnetostrictive Mini Actuator (MMA)



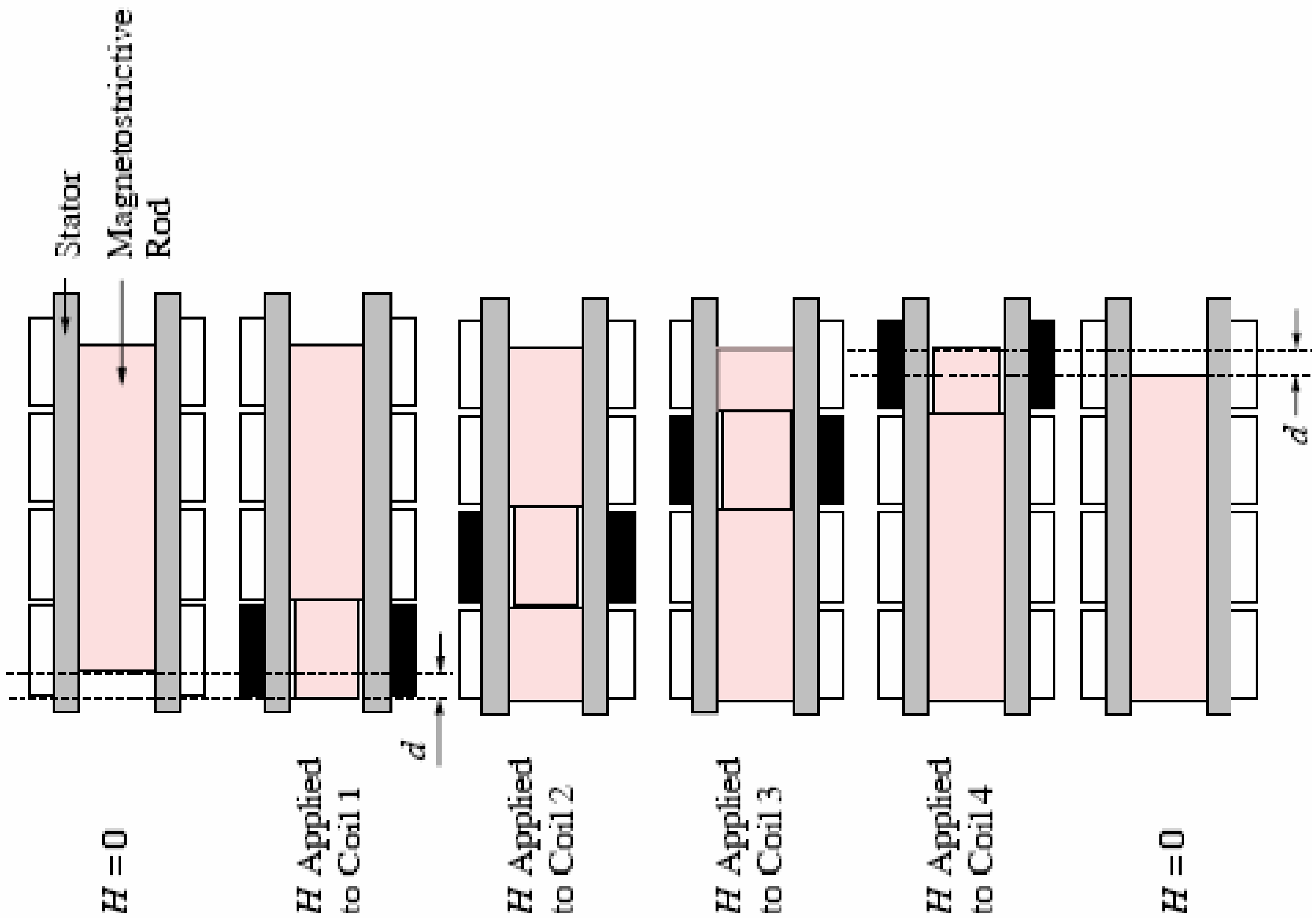
Pre-load springs and permanent magnets are used to put the piston in the zero-position and also to reduce hysteresis. The energizing coil around the rod is used to activate the Terfenol-D rod for dynamic application.

Actuation Strain by MMA

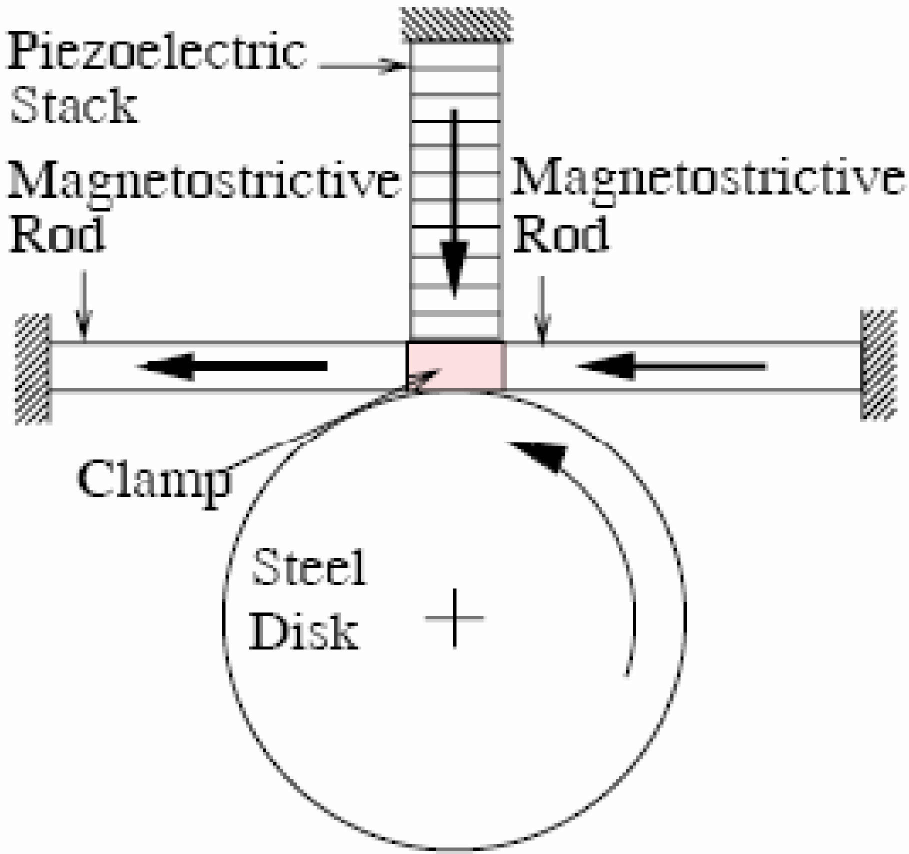
$$\varepsilon_c(t) = S(\sigma + \sigma_o) + d\,G\,i(t) + \alpha\,K \int e^{-t/C}\,i^2(t)\,dt$$

ε - strain, S- compliance modulus, σ - stress, σ_o – pre-stress, d – magneto-mechanical constant, G – control parameter, i(t) – control current, α - equivalent thermal coefficient of the housing, and C – a parametric constant

A Kiesewetter Inchworm Motor



Hybrid Transducers



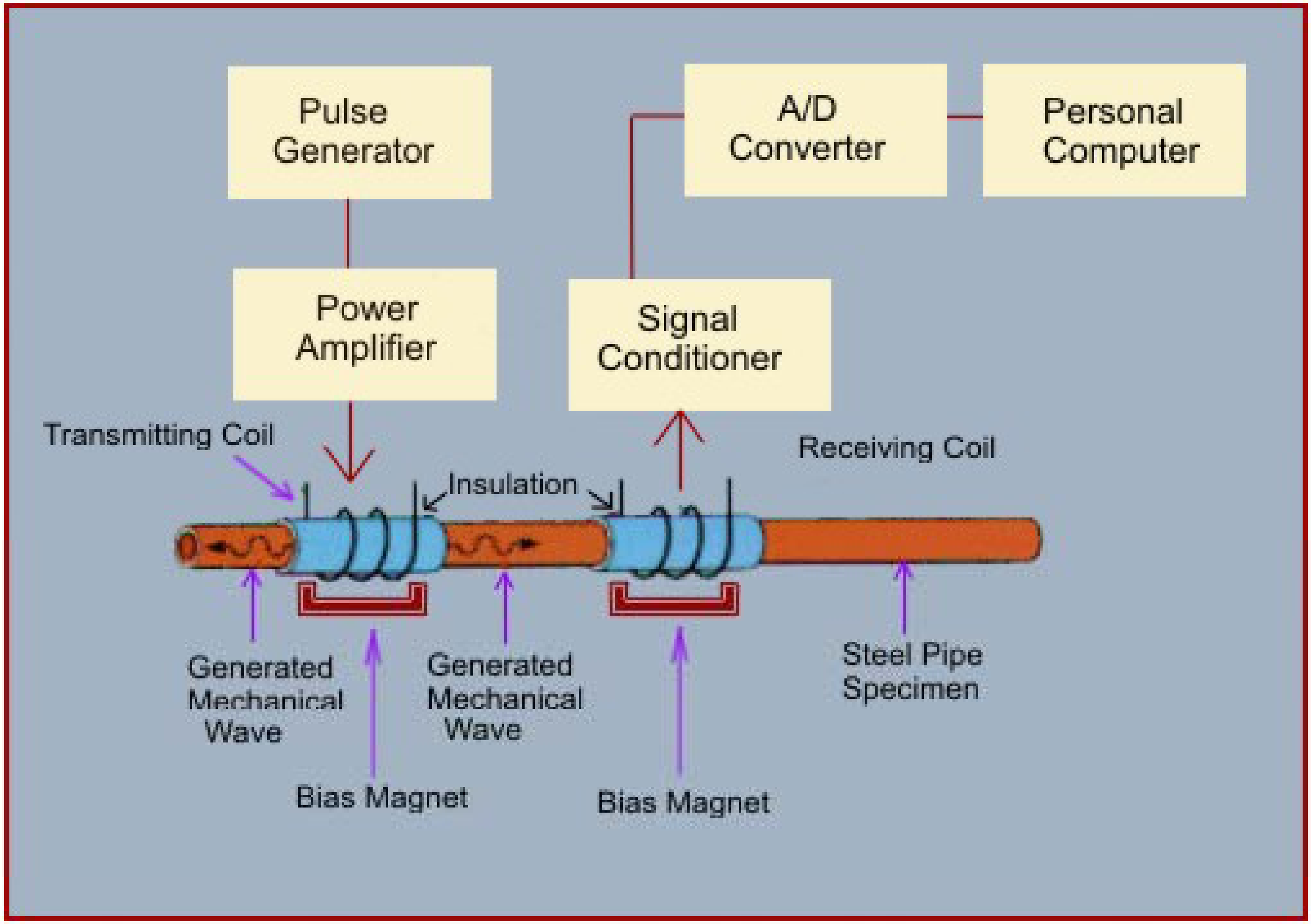
Vibration Sensing

Two approaches are taken to develop such sensors:

(a) Development of particulate composite: Terfenol-D particles of micron to sub-micron size is dispersed in a suitable resin and cured to form sensors

(b) Development of thin-film metallic glasses as magnetostrictive (MS) sensors.

Magnetostrictive Delay Line (MDL) Sensor



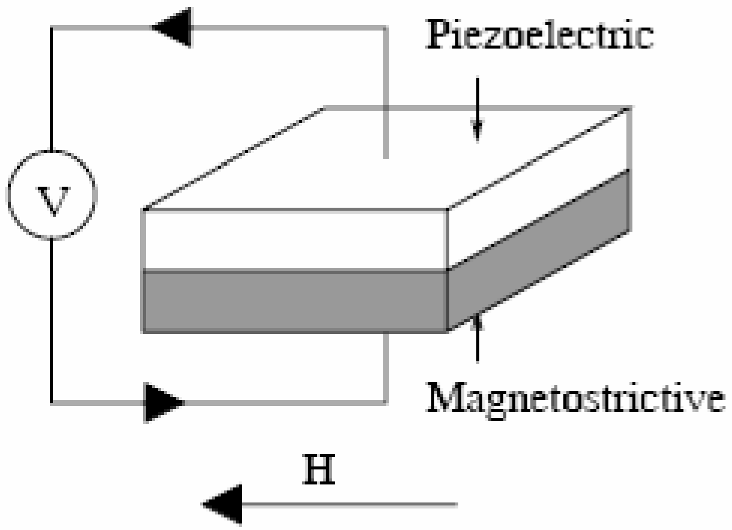
Constitutive Relationship

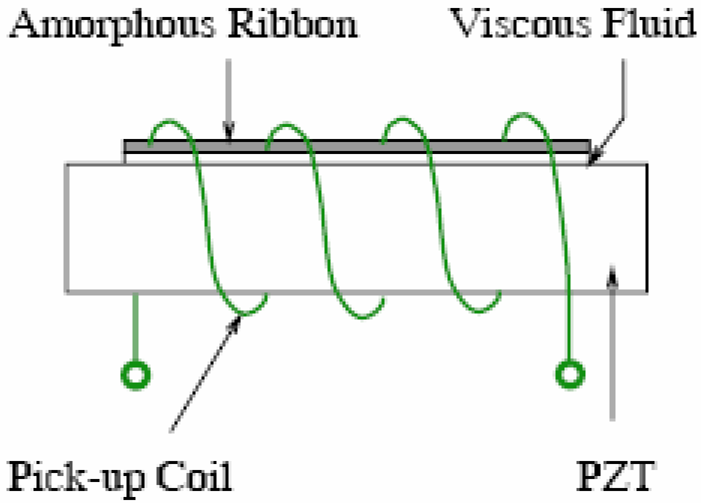
$H(x,t) = f(x)\ I(t) = 1/(\sqrt{(a^2 + x^2)}\ \ I(t)$

$\lambda(H) = \lambda_s\ (1-e^{-\alpha H^2}\ ),\ \ \alpha>0$

H – applied pulsed magnetic field, I(t) - applied current, a - distance between the pulsed conductor and MDL, λ_s - saturation magnetostriction, α - a material parameter

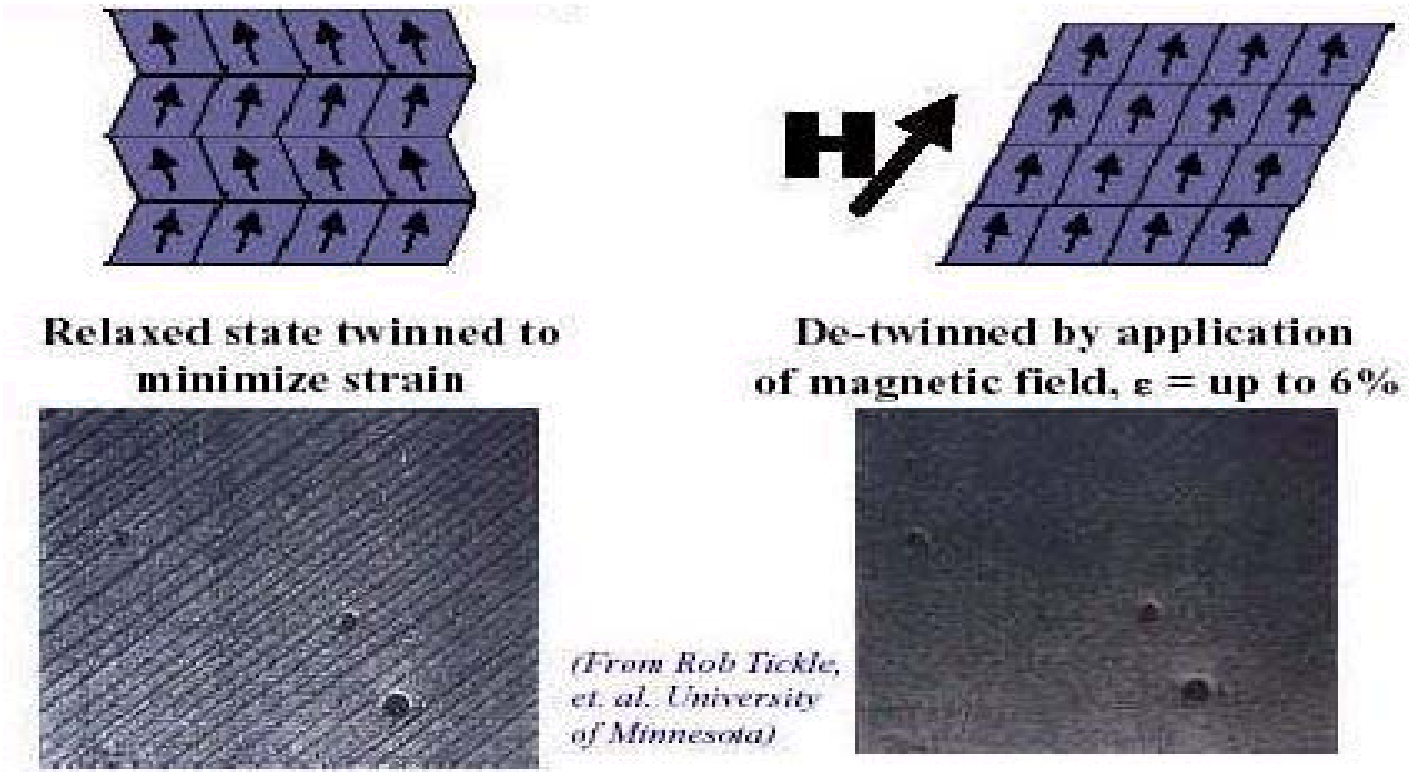
Hybrid Sensors





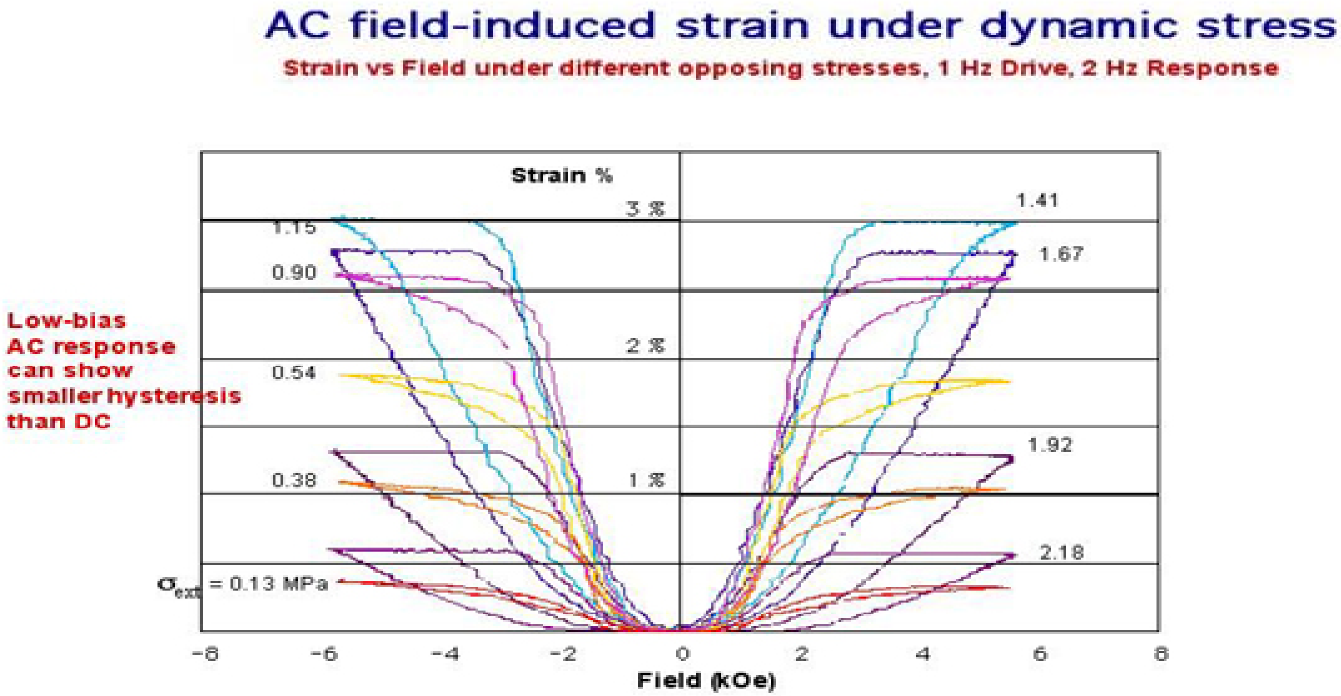
Future of Magnetostricve Materials?

Ferromagnetic Shape Memory Alloy

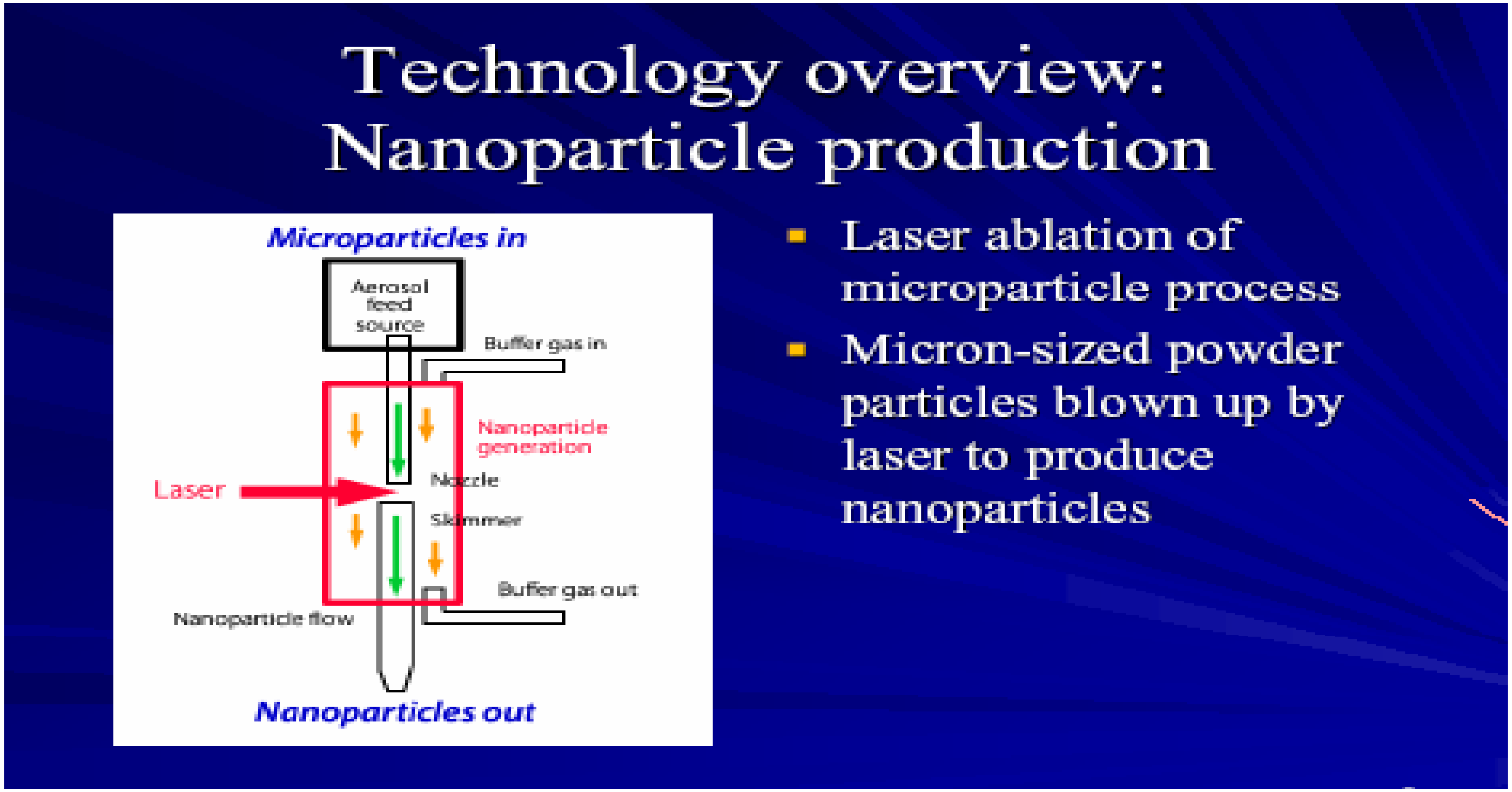


Material NiMnGa alloy

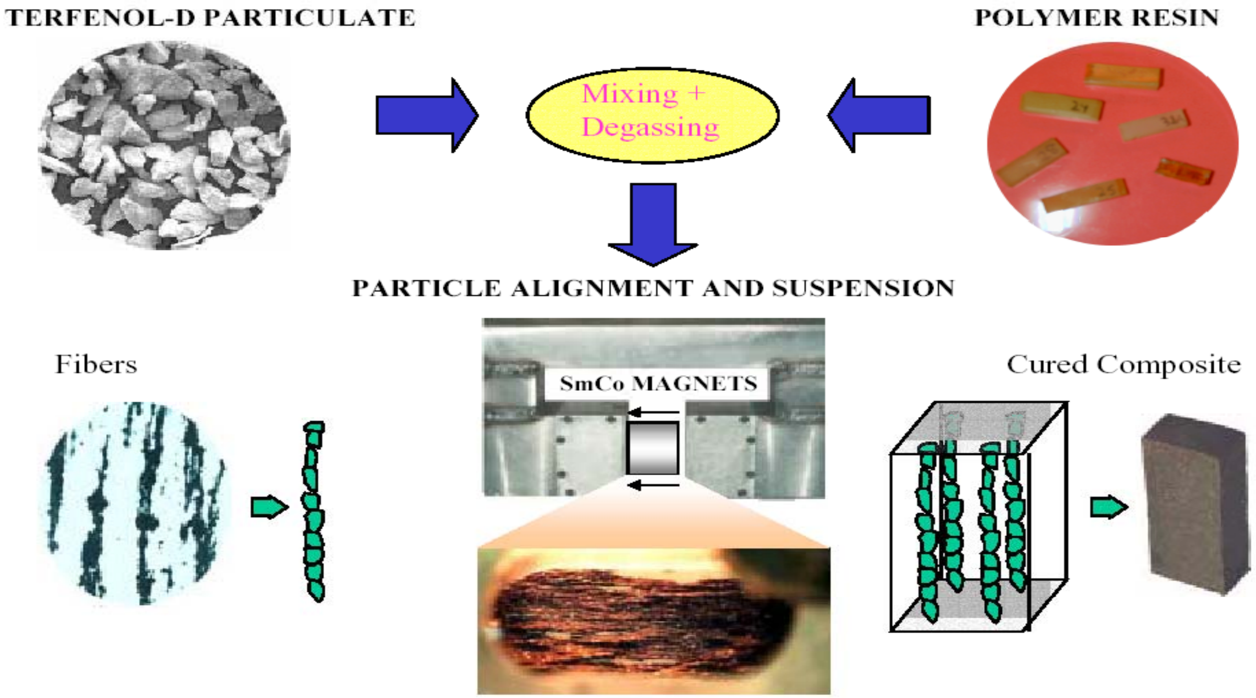
Strain induced in FSMA



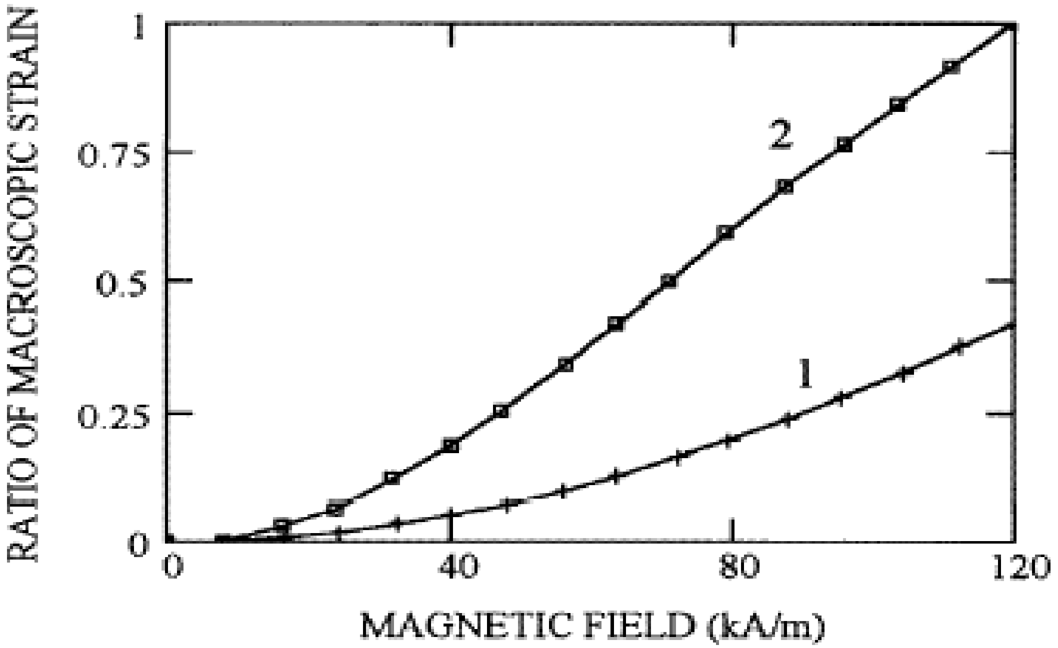
Magnetostrictive Nanocomposite



Magnetostrictive Nanocomposite



Comparison of Free-Strain between a Micron-level particulate composite and Nanocomposite



References

- M. Anjanappa and Y. Wu, “Magnetostrictive particulate actuators: configuration, modeling and characterization” Smart Materials and Structures, 6, pp. 393-402, 1997.
- M.J. Dapino, F.T. Calkins, R.C. Smith and A.B. Flatau, “A magnetoelastic model for magnetostrictive sensors”, Proceedings of ACTIVE 99, Vol. 2, pp. 1193-1204, December 02-04 1999.
- Mcknight, G. and Carman G.P., “Oriented Terfenol-D Composites,” Material Transactions, Vol.43 No.5 (2002) pp.1008-1014

END OF LECTURE 4