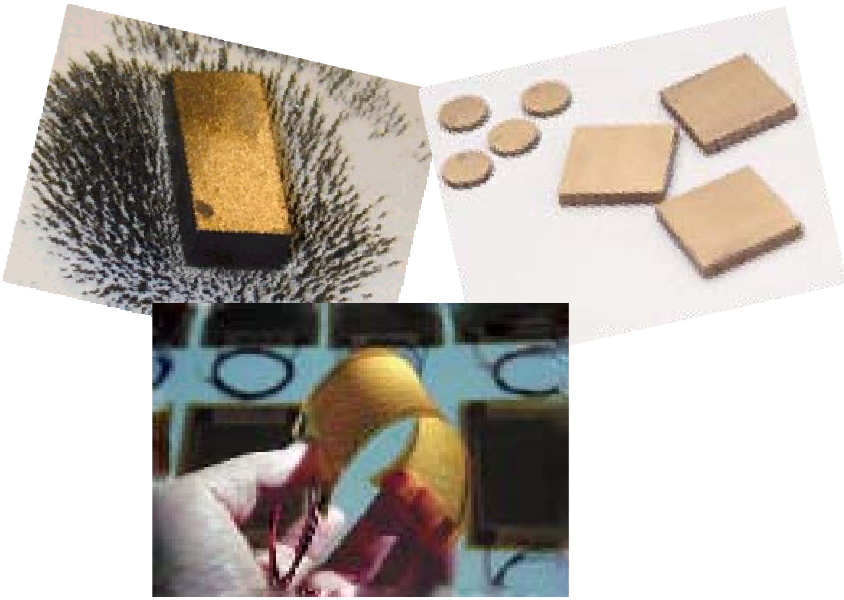
Module 1: Overview of Smart Materials



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Topics Covered in the Last two Lectures

- Application of Smart Material
- Smart systems using Smart Materials
- Smart Actuators
- Direct and Reverse Effects
- Piezoelectric Materials

LECTURE 3:

Magnetostrictive Smart Materials (Part -1)

Preface

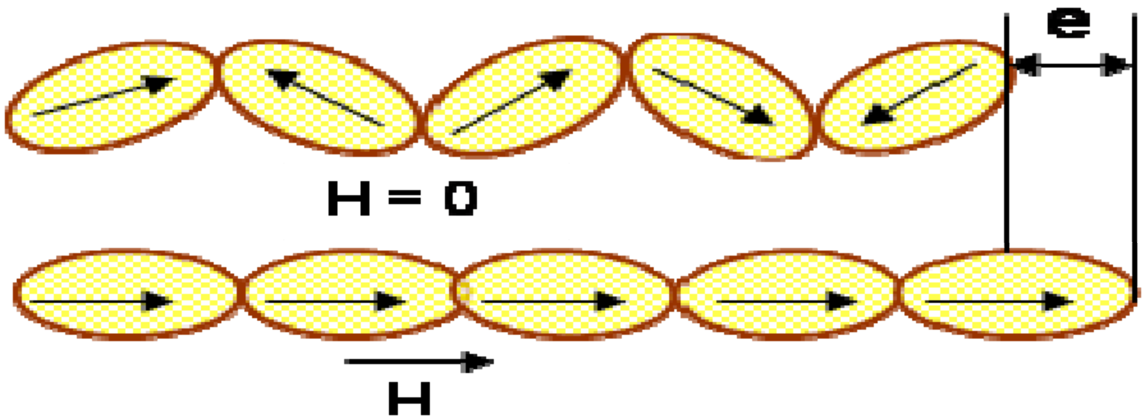
Magical power of magnets awed people of early civilizations as a strange force from the rocks that attracts shoes and swords without revealing itself!

In 1842, James Joule noted that a ferromagnetic sample changed its length with the application of Magnetism.

Organization

- What is Magnetostriction?
- Some Examples
- A Brief History of Magnetostrictive Materials
- What are the different effects of Magnetostriction?

What is Magnetostriction?



Magnetostriction (e) in materials due to domain migration and reorientation under applied magnetic field H

If a crystal of ferromagnetic material is initially at a compressed state, the effect of Magnetostriction becomes more pronounced.

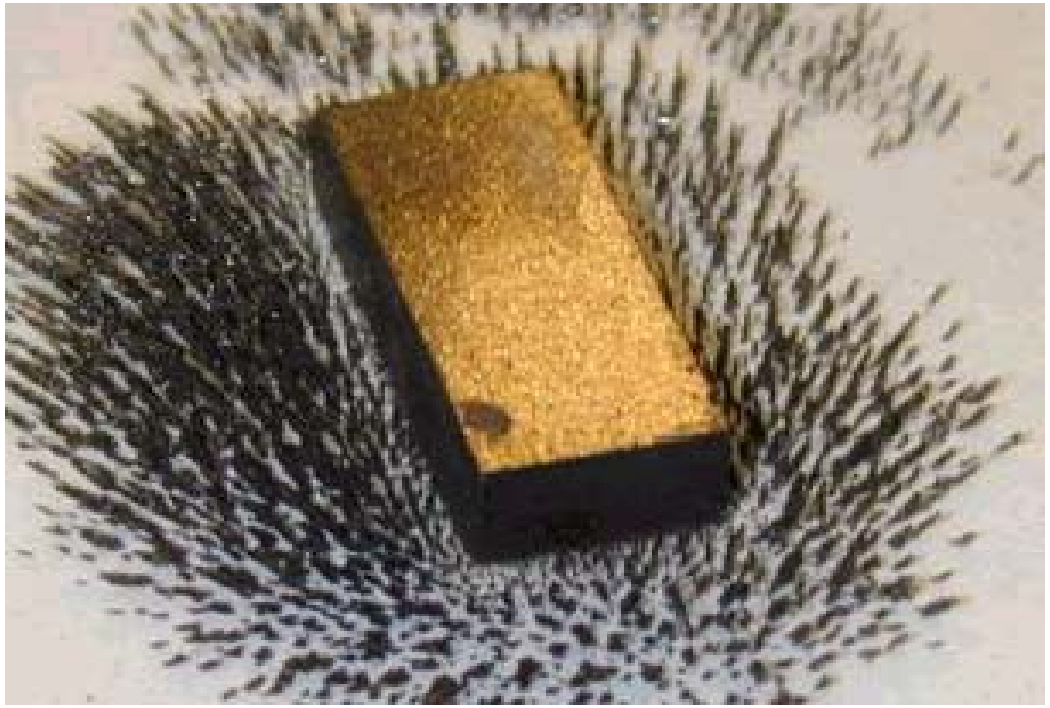
All ferromagnetic elements show Magnetostriction to different degree.

It is observed that the maximum one can achieve is for Cobalt which saturates around 50 μstrain (ppm).

Some Magnetostrictive Materials

Material	Magnetostriction (ppm)	Curie Temp (K)
Fe	14	633
Ni	33	1043
Co	50	350
Permalloy	27	713
$DyFe_2$	650	635
$TbFe_2$	2630	703
$Tb_{.6Dy}.7Fe_{1.9}$	2400	653

Terfenol-D: A Magnetostrictive Smart Material

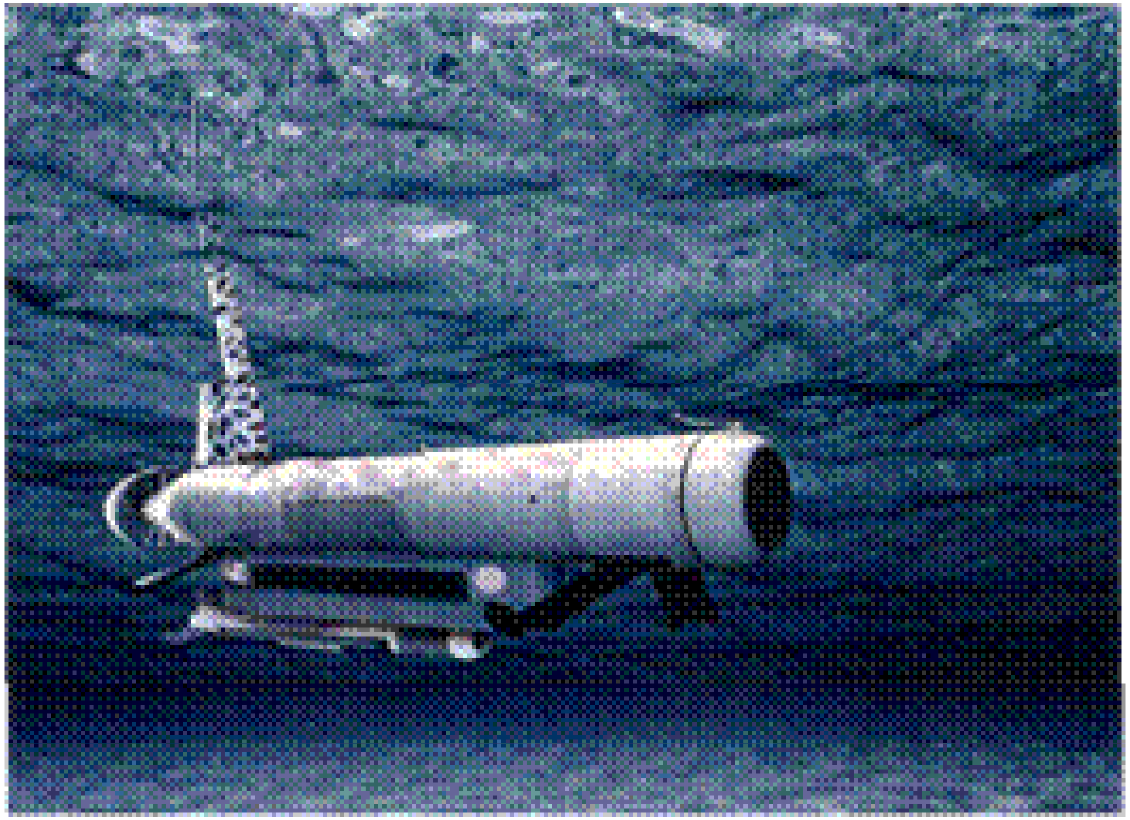


Terbium – Iron (Fe) – Naval Ordinance Laboratory - Dysprosium

A brief Time-Line

Year Event

- 1842 Magnetostriction discovered in Nickel by Joule
- 1865 Villari discovers inverse Joule Effect
- 1926 Anisotropy in single crystal iron
- 1965 Rare-earth metal magnetostriction in Terbium and Dysprosium by Clark
- 1972 $TbFe_2$ and $DyFe_2$ at 300 ^oK by Clark
- 1975 Terfenol-D by Clark
- 1994 Polymer Matrix and Terfenol-D particulate composite (Sandlund et al)
- 1998 Discovery of Galfenol – a more rugged MS material at NSWC (Clark)
- 2002 Oriented particulate Composite (Carman)



TALON (Tactical Acoustic Littoral Ocean Network) sonar system uses Magnetostrictive Terfenol-D for under-water submarine detection, source: *Etrema Products*

Attraction of Magnetostrictive Transducer

In general: Large Force , Deflection and Energy Conversion efficiency; does not decay with time.

Magnetostrictive transducers are found to be very much cost-effective in the low-frequency band and could be effectively used for deep-sea measurements due to superior mechanical properties.

Magnetostrictive Effects for Actuation

Direct Effects
Joule Effect: Magnetostriction: Change in Sample Dimension in the magnetic field
Wiedemann effect: Torque induced by helical magnetic field
Magnetovolume effect: Volume change due to magnetostriction

Indirect Effects for Sensing
Villari Effect: Change in Magnetisation due to Applied Stress
Matteuci Effect: Helical anisotropy and EMF induced by a Torque
Nagoka-Honda Effect: Change in the magnetic state due to change in the volume

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 3