University Of Technology- Iraq
Department of Materials Engineering
General Materials Branch
Fourth class

Smart Materials

Lecture 7 : Types of Magnetoretictve Alloys

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Materials for Magnetostrictive Effects

- The efficiency of a magnetostrictive vibrator as an electroacoustic transducer depends not only upon the material used but also on such factors as the size and the kind of laminations used.
- Generally, the elements used in magnetostrictive materials are Iron, Nickel, Cobalt, Terbium, Dysprosium, Samarium, Gadolinium, Holmium, Erbium, Thulium, Metglas, etc.

Materials for Magnetostrictive Effects

- Specific categories of materials such as

1. iron-based alloys
2. Ni-based alloys
3. Terfenol-D
4. Metglas
5. Ferromagnetic shape memory alloys

Iron-Based Alloys

- The effective combination of large spin-orbit coupling of heavy elements, the strong spin polarization of Fe, nonbonding states around the Fermi level, and an adjustable number of electrons, are of great importance to improve magnetostriction of transition-metal systems.

- As a potential magnetostrictive material, Fe-Al alloys exhibit excellent mechanical properties, low cost, and moderate magnetostriction, but the magnetostriction mechanism is still a mystery.

Iron-Based Alloys

- The dependence of the room temperature magnetostriction is there on substituting Fe by different X elements (X = Al, Ga, Si, Ge)
  As a potential magnetostrictive material, Fe-Al alloys exhibit excellent mechanical properties, low cost, and moderate magnetostriction, but the magnetostriction mechanism is still a mystery.
- All Fe-X alloys exhibit at the Fe-rich side a similar phase diagram. The magnetostriction increases with increasing substitution exhibiting a first maximum close to 20 at.% for Ga and Al, 10 at. % for Ge, and 5 at. % for Si.
- The reported magnetostriction behavior of Fe-Ga is similar to that of Fe-Al alloys,

Iron-Based Alloys

- while the magnetostriction behavior of Fe-Ge is similar to that Fe-Si alloys
- . However, for all these alloys, the increase of magnetostriction is observed in disordered A2 structures.
- Also with Tb doping into the Fe-Al alloy results in fivefold magnetostriction. Galfenol, Fe xGa1 =x, and Alfenol, FexAl1 = x, are newer alloys that exhibit 200–400 microstrains at lower applied fields (~200 Oe) and have enhanced mechanical properties from brittle Terfenol-D

Iron Based Alloy

- Fe-Co alloys, being magnetostrictive materials, are also suitable for energy harvesting applications due to their rich elements and lower cost compared with Terfenol-D and Galfenol. Fe-27% Co alloy is a good candidate for onboard power transformers core because of its very high

Iron Based Alloys

- An excellent giant-magnetostrictive material, Tb-Dy-Fe alloys (based on $Tb_{0.27–0.30}Dy_{0.73–0.70}Fe_{1.9–2}$ Laves compound) can be applied in sonar transducer systems, sensors, and micro-actuators.
- Nowadays, there are two different ways to substitute high-cost Tb and Dy alloying elements. One is to partially replace Tb or Dy with cheaper rare earth elements, such as Pr, Nd, Sm, and Ho; and the other is to use non-rare earth elements, such as Co, Al, Mn, Si, Ce, B, Be, and C, to substitute Fe to form single $MgCu_2$-type.
- Cobalt exhibits the largest room-temperature magnetostriction of a pure element at 60 microstrains. Cobalt ferrite (CoO,Fe_2O_3) has high saturation magnetostriction (~200 parts per million

Ni- Based Alloys

- Ni-Fe alloys are among the most important soft magnetic alloy systems. Ni-Fe alloys are of particular interest because a broad variety of qualitatively different magnetic properties can be obtained by adjusting the composition and the preparation process. Ni-rich alloys are called Permalloys
  The most exploited Ni-Fe alloy corresponds with 80% Ni and 20% Fe content. Both the crystal anisotropy and the magnetostriction cross the zero value for compositions around 80 wt.% Ni. The high magnetic permeability exhibited by this material makes it interesting for magnetic cores and magnetic shielding applications

Ni- Based Alloys

- In addition, the low coercivity, negligible magnetostriction, and large anisotropic magnetoresistance, together with the possibility of reducing its size at the nanoscale, favor a wide range of applications. Treatments on materials with approximately this composition (and the deliberate introduction of other elements like Mo, Cu, and Cr) yield materials with extremely low hysteresis losses (coercive field less than 1 Am-1), and a variety of hysteresis loop shapes controlled by induced anisotropy

Ni- Based Alloys

- The combination of low hysteresis losses and low classical losses makes these materials most suited to applications at high frequencies.
- Ni-Zn, Ni-Cu, Ni-Zn, Ni-Cu-Co, Ni-Cu-Zn-Co systems, and so on, also exhibit significant magnetostrictive properties

Metglas
(Metalic Glass)

- A new magnetostrictive material was introduced in 1978 which is based on amorphous metal, produced by rapid cooling of Fe, Ni, and Co alloys together with one or more of the elements Si, B, P. These alloys are known commercially as Metglas (metallic glass) and are commonly produced in thin-ribbon geometries
- Because of the extremely high coupling coefficients ($k > 0.92$), Metglas is a prime candidate for sensing applications in which a mechanical motion is converted into an electrical current or voltage

Metglas
(Metalic Glass)

- . Metallic glass alloys such as metglas 2826 MB based amorphous alloys are the best-known candidates for magnetostrictive sensors because these amorphous alloys exhibit

1. Large saturation magnetostriction,
2. High saturation magnetization,
3. Low anisotropy energies,
4. Low coercivity.

- At present, these alloys are available only in the form of ribbons of thickness ranging from 10 to 50 μm.

Metglas
(Metalic Glass)

- A series of posttreatment process, such as high-temperature annealing and epoxy treatment, is further required for amorphous alloy ribbons to be used as sensors.
- Therefore there are many difficulties in fabricating systems based on amorphous ribbons for micro-sensor applications.
- Magnetoelastic materials in the form of thin films are an alternative to ribbons and they can be integrated easily in Micro/nanoelectromechanical systems.

Metglas
(Metalic Glass)

- This not only allows the miniaturization of sensor elements but also enables the same micro-fabrication technologies to be used in the production of both electronic and magnetic devices.
- In comparison with other MEMS technologies, for example, those incorporating piezoelectric materials, Magnetic MEMS offer

1. A high power density,
2. Low-performance degradation,
3. Last response times, and ease of fabrication.

Metglas
(Metalic Glass)

- Thin films based on metallic glasses can be prepared by techniques such as

1. Thermal evaporation.
2. Flash evaporation.
3. Electrodeposition.
4. Molecular beam epitaxy.
5. Pulsed laser deposition .
6. Sputtering.

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Metglas
(Metalic Glass)

. The amorphous alloy Fe81Si3.5B13.5C2 has a high saturation-magnetostriction constant, λ, of about 20 microstrains and more, coupled with low magnetic-anisotropy field strength, HA, of less than 1 kA/m (to reach magnetic saturation). It also exhibits a very strong ΔE-effect with reductions in the effective Young's modulus up to about 80% in bulk. This helps build energy-efficient magnetic MEMS [73].

Terfenol-D

- Terfenol-D, an alloy of the formula $Tb_xDy_{1-x}Fe2$ (x = 0.3), is a giant magnetostrictive material. Due to its material properties, Terfenol-D is excellent for use in the manufacturing of low frequency, high-powered underwater acoustics. Its initial application was in naval sonar systems.
- Among alloys, the highest known magnetostriction is exhibited by Terfenol-D, exhibits about 2000 microstrains in a field of 160 kA/m (2 kOe) at room temperature, and is the most commonly used engineering magnetostrictive material.

Terfenol-D

- Terfenol-D is used in

1. Active noise and vibration control systems,
2. Low-frequency underwater communications (sonar),
3. Linear and rotational motors,
4. Ultrasonic cleaning,
5. Machining and Welding,
6. Micropositioning, and the
7. Detection of motion, force, and magnetic fields.

Terfenol-D

- Terfenol-D is currently available in a variety of forms, including

1. monolithic rods,
2. particle-aligned polymer matrix composites,
3. thin films .

- The alloy has the highest magnetostriction of any alloy, up to 0.002 m/m at saturation.
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Terfenol-D

- Terfenol-D has a large magnetostriction force, high energy density, low sound velocity, and a low Young's modulus. At its most pure form, it also has low ductility and low fracture resistance.
- TerfenolD is a gray alloy that has different possible ratios of its elemental components that always follow a formula of $Tb_xDy_{1-x}Fe_2$. The addition of dysprosium made it easier to induce magnetostrictive responses by making the alloy require a lower level of magnetic fields.
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Terfenol-D

- When the ratio of Tb and Dy is increased, the resulting alloy's magnetostrictive properties will operate at temperatures as low as 200 C, and when decreased, it may operate at a maximum of 200 C. The composition of Terfenol-D allows it to have a large magnetostriction and magnetic flux when a magnetic field is applied to it.
- This case exists for a large range of compressive stresses, with a trend of decreasing magnetostriction as the compressive stress increases. Magnetic heat treatment is shown to improve the magnetostrictive properties of Terfenol-D at low compressive stress for certain ratios of Tb and Dy

Other Materials

- We report on the magnetostriction of hexagonal $HoMnO_3$ and YMnO3 single crystals in a wide range of applied magnetic fields (up to H = 14 T) at all possible combinations of the mutual orientations of magnetic field and magnetostriction.
- It is found that the nonmonotonic behavior of magnetostriction of the $HoMnO_3$ crystal is caused by the Ho^{3+} ion; the magnetic moment of the Mn^{3+} ion parallel to the hexagonal crystal axis.

Other Materials

- The anomalies established from the magnetostriction measurements of $HoMnO_3$ are consistent with the phase diagram of these compounds. X_6Fe_{23}, X = (Tb, Dy, Ho, and Er) compounds exhibited large magnetostrictions at 77 K.
- Among these compounds, the largest effect being obtained for Tb_6Fe_{23}. In Er_6Fe_{23}, the main source of magnetostriction in this compound is the Er ion. YCo_5, $SmCo_5$, $GdCo_5$, $LaNi_5$, and $GdNi_5$ systems are involved in the magnetostrictive effect. It is reported that the linear thermal expansion and magnetostriction effect are shown in $CeRu_2Si_2$ in magnetic fields up to 52.6 mT and at temperatures down to 1 Mk