MAGNETIC MATERIALS IN THIN FILM SENSORS AND ACTUATORS

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Introduction

Magnetic thin film transducers lend themselves to a wide range of applications, both in the area of sensors as well as actuators. The key to their successful development and application is the availability of appropriate magnetic thin films and their deposition and patterning technology. The film thickness requirement for sensors ranges from micrometers down to tens of nanometers, while energy conversion considerations in actuators may lead to films with a thickness of a couple of ten micrometers.

Sensor Materials

Typically, a sensor is taking advantage of a particular transducer effect, but it also may be based or it may include a design using a highly permeable material for flux guiding purposes. One of the sensors with a rather wide field of applications is a magnetic field sensor. They are used for anti-lock break systems (ABS) and for the electronic stability program (ESP) in the automotive area, but are also utilized in many areas for length and angle measurements as well as for current measurements. Magnetic materials lending themselves for field sensing are soft magnetic conductors taking advantage of the anisotropic magneto-resistive (AMR) effect. The thin film material used most commonly is NiFe81/19, a soft magnetic material with a maximal relative permeability μ_r of app. 1,000 for a film thickness in the micrometer range. Magnetic field sensing may also be accomplished using the giant magneto-resistive (GMR) effect. In this case, thin sandwiches ("spin valve sensor") containing both ferromagnetic (NiFe81/19,Co) and antiferromagnetic materials (e.g. CoCrPt) are required. The film thickness of the ferromagnetic material typically is as low as a couple of ten nanometers.

Magnetoelastic materials lend themselves for measuring strain, allowing the build up of force sensors. For measuring strain and forces, magnetoelastic materials, taking advantage of the Villari effect, may be used [1]. A for instance for such a material is NiFe45/55. Compared to NiFe81/19, this NiFe alloy not only is highly magnetostrictive, it also has a much greater saturation flux density Bs (1.6 T for NiFe45/55 compared to 0.9 T for NiFe81/19).

Inductive devices typically require high permeable flux guides. NiFe81/19 is the magnetic material most commonly used for this application. An example of an inductive device is the eddy current sensor.

Actuator Materials

For electromagnetic or electrodynamic actuators, both soft and hard magnetic materials are required. For soft magnetic materials, a high relative permeability μ_r and saturation flux density B_s. NiFe81/19 as well as NiFe45/55 are appropriate candidates. Typically, NiFe45/55 is the superior material although its coercivity (H_c) is slightly greater than the one for NiFe81/19 (Tab. I).

For hard magnetic materials used in actuator applications, the key requirement is a great *BH*-product. Such a material is sputter deposited SmCo83/17 [2]. After deposition, it requires annealing at 500°C. For that reason, thick layers can only be deposited without delamination on wafer materials with a matching thermal extension factor, like Al_2O_3. A hard magnetic material capable of being electroplated is CoP. However, its BH-product is substantially lower than the one of SmCo83/17.

A new promising material for actuators are magnetic shape memory alloy like NiMnGa [3]. So far, such a material is only available in discrete samples, there are international efforts to come up with a deposition process.

Table I
Typical properties of magnetic thin films

Material	Layer thickness [µm]	Deposition rate [µm/h]	Deposition type	Other properties
Soft magnetic materials:				
NiFe 81/19	max. 15/75	2/7	PVD/electro plating	B_s=0.9T,H_c=400A/m, $\mu\mu_{r,max}$=1000-200
NiFe 45/55	max. 15	2/7	PVD/electro plating	B_s=1.6T,H_c=650A/m, $\mu\mu_{r,max}$=1600-200
Hard magnetic materials:				
SmCo 83/17	max. 50	5-10	PVD	B_r=0.72T,H_c=1,140kA/m BH_{max}=85[kJ/m^3]
CoP	max. 40	10	Electro-plating	B_r=0.3T,H_c=160kA/m, $\lvert BH\rvert_{max}$=5[kJ/m^3]
Antiferromagnetic materials:				
CrMn Pt	-	0.93	PVD	-

Deposition Techniques

The deposition technologies of choice for sensor materials are PVD processes like Sputter Deposition or Ion Beam Deposition. On the other hand, for actuator components, but also for flux guides for sensors, used in conjunction with microcoils, electrodeposition is the technology of choice [4], typically used in combination with photomasks serving as micromolds. This technology is particularly important for actuator applications with rather thick magnetic films. For some magnetic thin film materials, like NiFe81/19 or NiFe45/55, either PVD or electroplating processes may be used. However, so far no electroplating processes exist for providing thin film hard magnets with a good BH-product.

Conclusion

The spectrum of magnetic materials available for thin film deposition by now basically fulfills the requirements for both the magnetic sensor and actuator technology. In the actuator area, there is a need for hard magnetic thin film materials with a sufficient BH-product that may be electroplated. A new promising approach is using a new generation of magnetic shape memory metals.

References

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