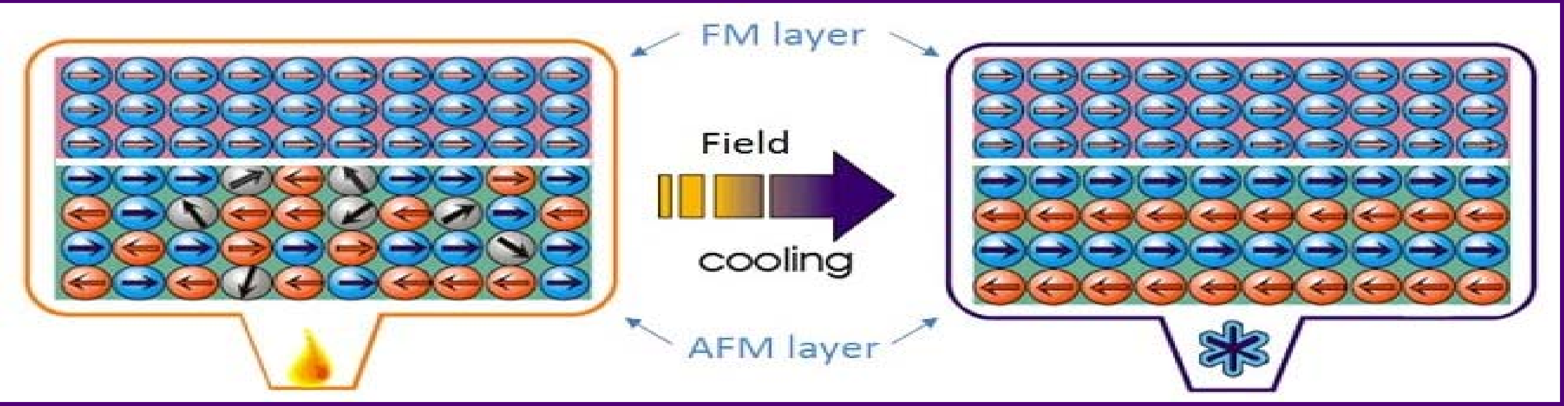
SpinTherm 1000

Magnetic Thermal Annealing System

Micro Magnetics
Sensible Solutions



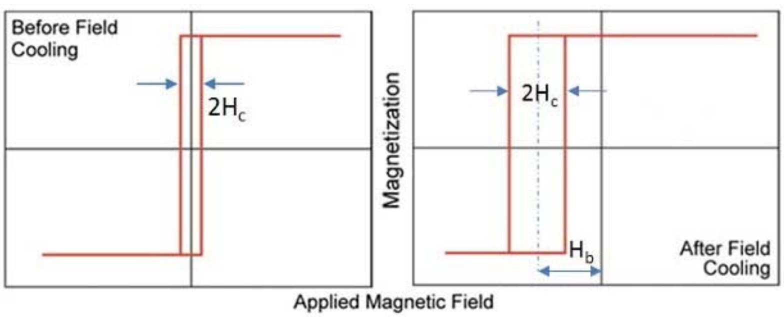
Micro Magnetics, Inc.

617 Airport Road, Fall River, MA 02720

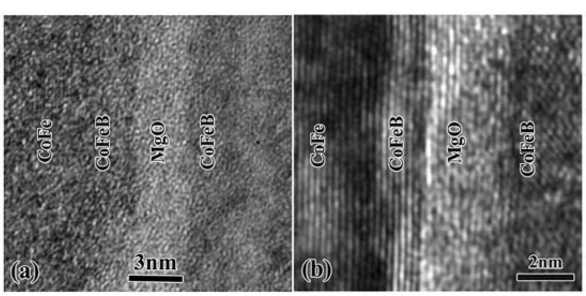
www.micromagnetics.com Sales@micromagnetics.com

Micro Magnetics' SpinTherm-1000 High Vacuum Magnetic Thermal Annealing System is used to enhance the performance of spintronic devices, magnetic materials and components. SpinTherm-1000 is fully automated with unlimited user defined recipes. Magnetic components such as thin films and devices in different shapes and forms can be thermally treated in temperatures up to 700˚C and in a strong and uniform magnetic field up to 0.4 Tesla, all in a high vacuum environment or inside a special gas with a selected pressure.

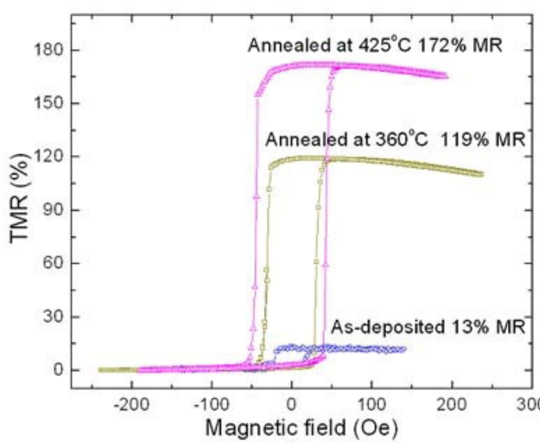
The availability of high vacuum eliminates potential oxidation of magnetic materials that can damage both crystalline and magnetic structures. The strong and spatially uniform magnetic field in SpinTherm-1000 allows the magnetization vectors of the samples to be perfectly aligned in one well-defined direction. The magnet system is well insulated from the high temperature furnace, and remains strong and uniform for many years of frequent operations. Furthermore, the SpinTherm-1000 offers highly uniform and spacious temperature region to cover a large sample volume, promising homogeneous magnetic properties throughout the samples. User can control the annealing temperature profile through the system's control system. Established thermal annealing recipes can be easily stored for future use.



Hysteresis loops demonstrating the appearance of exchange bias after magnetic thermal annealing.



Cross sectional images of a magnetic tunneling junction. Materials after annealing using SpinTherm-1000 (b) are much less disordered structurally than before (a).



The easy axis of a magnetic thin film is reoriented and strengthened after magnetic thermal annealing treatment using SpinTherm-1000, allowing for much higher magnetization in a magnetic field.

System Features

- Stainless steel high vacuum chamber with front door that will seal against a Viton O-ring. Standard ports include pumping port, roughing and vent ports, heater/temperature sensor feedthrough port, current feedthrough port for internal furnace, and ports for vacuum gauges. Three spare ports will be provided on the side walls for future use.

- 6”-viewport on the front panel of the vacuum chamber.

- Metal frame for holding the vacuum chamber with casters and leveling pads.

- Standard 19-inch wide electronics racks for housing all of the electronics components of the system including power distribution, power supplies, etc.

- Two pieces of 6” NdFeB magnets mounted on soft-iron magnetic frame structure designed for magnetic field enhancement.

- Magnetic field up to 0.4 Tesla with 2% magnetic field uniformity over 2” sample cartridge.

- Enclosed sample metallic cartridge box capable of holding ten 2” silicon wafers.

- Integrated and surround heaters for sample cartridge box capable of 450˚C with temperature uniformity of better than 1.5%.

- Built-in thermal couple monitoring interior sample cartridge box.

- Thermal isolation unit using Ceraseal to prevent heating the NdFeB magnets.

- The standard system also includes: Temperature controller with programmable annealing profiles; Power supply for sample cartridge heater; CryoTorr-8 cryogenic pump capable of generating high vacuum level; Gate valve between cryopump and vacuum chamber; Mechanical pump with oil-mist filter; Thermal couple high vacuum pressure gauge; Low Vacuum gauge.

- Safety features include an EMO button on the front of the main electrical rack and interlocks.

- Up to two days training at Micro Magnetics site is included.

Application Notes

When determining the strength, ductility, and hardness of a solid, certain structural factors need to be considered. Lattice and shape deformities in a material can significantly degrade its quality, and removing these anomalies in structure is necessary in order to achieve a high quality material and performance.

Thermal annealing is a common technique used to strengthen a solid, such as metal or glass, by raising, maintaining, and then slowly reducing its temperature. Annealing allows the atoms inside of a solid to diffuse more easily to find their proper locations, and maintaining a solid at a high temperature lets it achieve structural equilibrium, eliminating many structural imperfections that would otherwise reduce its utility. Annealing has been a widely used technique in metallurgy for a long time. However, a relatively new technique, called magnetic thermal annealing, puts a new spin on this traditional method. The major difference between the two treatments is that in magnetic annealing, an external magnetic field is applied during the annealing process. This has some very interesting effects, especially on ferromagnetic (FM) and antiferromagnetic (AFM) materials.

One of the most important effects of magnetic thermal annealing is the reorientation of the easy axis in a FM material, or the axis of spontaneous magnetization vector. In any FM material, the easy axis is primarily determined by the lattice structure, or the shape and internal strain of a solid. If the lattice shows specific symmetry, the easy axis will normally reflect this symmetry. However, if the lattice has many deformities, there may not be any major global symmetry, and the spontaneous magnetization will be weakened or randomized.

If a deformed FM lattice is annealed at a high temperature, the spins of each individual atom will align with the externally applied field. When maintained at a high temperature, this interaction between the spin and the magnetic field will begin to reorganize the lattice somewhat, due to the spin—orbit interaction (SO), i.e., the interaction between the atomic orbital and the electron spins inside a crystal lattice. Eventually, the system will attain equilibrium within this field, causing a lattice reorientation such that the easy axis becomes parallel to the applied field. When the temperature is reduced, the lattice becomes “locked or frozen” once again, and the magnet attains a new magnetization direction with a much robust and more well-defined easy axis.

Magnetic thermal annealing can also change the shape of the object. If a thin film has non-uniform thickness, the magnetic properties can be adversely affected. This poses a problem for magnetic thin-film applications that require a very consistent material. Thermal annealing can help the film achieve structural equilibrium, removing shape deformities as well as structural ones.

Application Notes

Setting up exchange bias in ferromagnetic/antiferromagnetic multilayers

One important application that magnetic annealing is used for is to create exchange bias in a compound magnetic thin film. Exchange bias causes a shift in the hysteresis loop of a FM film (Fig. 1). This shift causes the "pinning" effect in a magnetic tunneling junction (MTJ) or a spin-valve based on giant magnetoresistance effect (GMR). The establishment of exchange bias allows one FM layer in a junction to respond to an external field while keeping the other's magnetization intact. This is an invaluable technique for creating MTJ and GMR magnetic sensors widely used in read-write heads in hard disk drives.

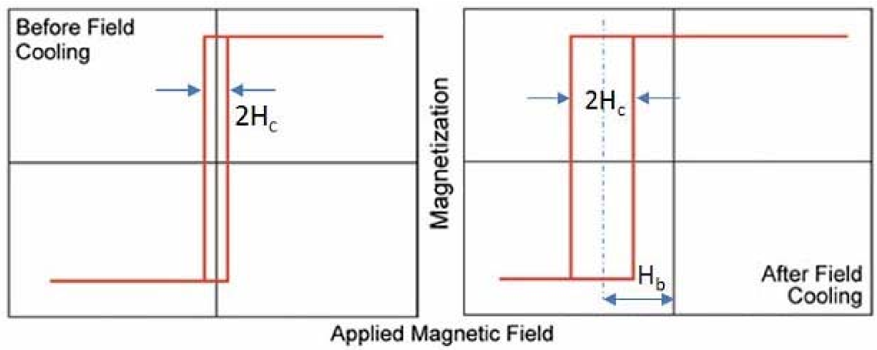


Fig. 1: Hysteresis loops demonstrating the appearance of exchange bias after magnetic thermal annealing

Exchange bias works by placing an AFM (Fig. 2) directly adjacent to an FM layer. When annealed in an external field, the FM layer has its easy axis set parallel to the magnetic field direction. As the bilayer is cooled to below the magnetic ordering temperature called Neel temperature of an AFM, the spin structure in the AFM aligns itself to the ferromagnet such that the topmost layer of spin is parallel to the FM's magnetization. Since it must adopt the configuration in Fig. 2, the AFM's symmetry axis becomes parallel to the FM's easy axis. The effect of the ARM/FM junction is an effective pinning of the FM magnetization parallel to the topmost layer of the AFM, giving rise to the exchange bias phenomenon. At room temperature, the topmost layer of the AFM exerts an internal effective magnetic field (also called molecular field). This internal field is called exchange biasing field and is responsible for the exchange biasing phenomena.

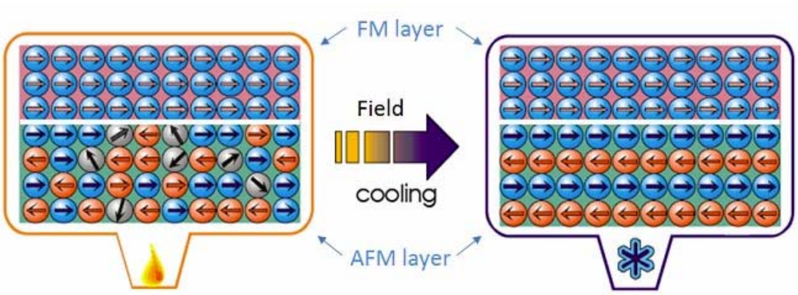


Fig. 2: After magnetic thermal annealing, an antiferromagnet becomes much more ordered and pins the adjacent ferromagnetic layer

Application Notes

Setting up synthetic antiferromagnetic coupling

The simplest way to create exchange bias is by having an AFM adjacent to the layer to be pinned. However, using a synthetic antiferromagnet (SAF) is another method that causes a stronger pinning as well. SAF has the advantage of reducing stray magnetic field effect due to magnetic poles at the edges of ferromagnetic thin films.

The SAF works similar in principle to the AFM. The structure is a trilayer consisting of two FM layers separated by a nonmagnetic metallic layer. The FM layers are anti-aligned due to magnetic exchange coupling through the metallic layer. In order to anti-align the two FM layers in a SAF, both layers need to be annealed in a high magnetic field, aligning their easy axes parallel to each other. Since one layer has slightly different anisotropy, it will flip direction once the field has been removed.

Magnetic thermal annealing significantly improves magnetic structures inside SAF films. The antiparallelly aligned FM films will not generate external magnetic fields because their opposite poles are very close to each other. Also in SAF, both FM layers are in the single domain state, which will enhance magnetic performance in various magnetic devices.

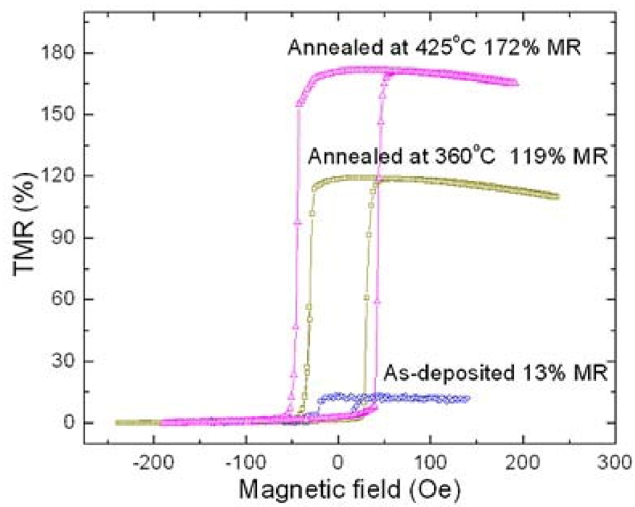


Fig. 3: The easy axis of a magnetic thin film is reoriented and strengthened after magnetic thermal annealing treatment using SpinTherm-1000, allowing for much higher magnetization in a magnetic field.

Enhancing giant magnetoresistance in magnetic devices

In modern processing of MTJ and GMR magnetic devices, magnetic thermal annealing will increase the magnetoresistance substantially (Fig. 3). During thin film deposition, the crystalline and magnetic structures of the thin film devices may possess high degrees of disorder. Post deposition thermal magnetic annealing can remove these disorders, and yield the optimal magnetic performance of the devices. Often, with proper magnetic annealing processes, the magnetoresistance of an MTJ or GMR device can see its magnetoresistance increase by more than a factor of ten, as shown in Figure 3.