Patterned Nano Magneticstructures

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Abstract— Most magnetic devices marketed nowadays still use bulk or thin film materials, this is soon to change with the advent of nano-fabrication technologies [1]. Proper scaling requires that the magnetic particle size decreases with the scaling factor at the same rate as all of the other dimensions. This is necessary in order to keep the number of particles in a bit cell constant (at a few hundred per cell) [2]. Magnetic nano-structures represents future miniaturization in magnetic recording devices, and detailed understanding of the formation of magnetic vortices in closely spaced ferromagnetic nanoparticles is important for the design of ultra-high-density magnetic devices. It is necessary to achieve ultra-high density in magnetic storage media so that the lateral size of the information bits be as small as possible, without the bit volume reaching the superparamagnetic limit beyond which the energy needed to switch the magnetization of a bit becomes less than the thermal energy, and nano-fabrication offers the technical ability to fabricate magnetic objects with nano scale precision having unique magnetic properties, which may be tailored by manipulating the size, the shape, or the composition of the nanostructures [3].

The magnetic nano-structures of have been formed by different rates of heavy ion irradiation of thin films. The fluence affects both anisotropy and spontaneous magnetization.

1. INTRODUCTION

Most recently, research interest in nanocrystalline soft magnetic alloys has dramatically increased. This is due, in part, to the properties common to both amorphous and crystalline materials and the ability of these alloys to compete with their amorphous and crystalline counterparts [4]. The magnetic properties of an ultra thin multilayer can be modified by controlled ion beam irradiation [5, 6]. Magnetic nanostructures are subjects of growing interest because of their potential applications in high density magnetic recording media and their original magnetic properties [7]. Multilayer thin films are well known for their high magnetic anisotropy, and the origin of this high magnetic anisotropy has been the subject of interest for many researchers [8].

2. BREAK THROUGH PHYSICAL LIMITS

The first hard disk recording has been based on a spinning magnetic disk with a longitudinal medium and an inductive write head. Over the past years significant developments have been made that increased the capacity, reduced the cost, and improved the performance and reliability of these magnetic storage devices. With each improved device the range and nature of the applications undertaken have expanded and, in turn, led to a need for further device improvement. The magnetic recording media industry will (also) benefit strongly from the advances in magnetic nanostructures.

Demands for the continuous increase in the data storage density bring the challenge to overcome physical limits for currently used magnetic recording media [9]. When the physical dimensions of a system become comparable to the interatomic spacing, strong modifications of the intrinsic magnetic properties (ordering temperature, magnetic anisotropy, spontaneous magnetization) are expected. Micromagnetic modeling of the behavior of a nanostructured film beautifully describes the magnetization process, but requires a high calculational effort and long computation times.

Furthermore, it is difficult to predict changes of the macroscopic physical behaviour due to variation of parameters. Phenomenological models, on the other hand, are very useful to simulate the behaviour of the magnetic material under the influence of varying parameters, especially when the parameters are based on physical constants.

2.1. Nano Magnetic Property Understanding

Patterned magnetic media could be a way of realizing ultra high density storage media. Recently, demonstrations of areal recording density over $60\,\mathrm{GB/in}^2$ in both longitudinal and perpendicular magnetic recordings have been successfully made [10]. Determining the properties of small magnetic structures is extremely important for the development of data storage devices [11]. Better understanding of the micromagnetic processes in magnetic recording media is essential for developing novel materials for future ultrahigh density recording [12]. Good understanding of the noise mechanism in magnetic recording is required for developing heads and media for future applications [13].

In perpendicular recording, the magnetization pattern corresponding to the bits is provided perpendicular to the plane of the medium. The information is being stored in vertical domains or other structures of uniform magnetization [14]. In magnetic materials two characteristic length scales have to be considered [15–17]:

1. At the atomic level, nearest neighbor exchange interaction is dominating.
2. At a mesoscopic level, the domain wall width is the characteristic length dominating the magnetization reversal.

3. CHANGING MAGNETIC PROPERTIES

The magnetic properties of an ultra thin multilayer can be patterned by controlled ion beam irradiation. The basic step in this technique is to control the changes in the magnetic properties induced by the irradiation process. Figure 1 shows ion beam irradiation with Ga^+ [9, 16, 17]. In several works light ion irradiation was used to induced ultra-high resolution magnetic patterns on the multi-layers. High aspect ratio silica masks on the produced Co/Pt multi-layers were obtained by e-beam lithography and reactive ion etching with feature sizes down to 30 nm for dots. Hence one of the proper method was through: the use He^+ ion irradiation of the magnetic layers through proper masks to pattern the magnetic properties, without significant changes in sample roughness or optical properties. In the irradiated regions, a strong decrease in magnetic anisotrophy, coercivity and Curie temperature can be controlled. After mask removal the obtained result was [18]: magnetic nano structures with high resolution and high density.

Magnetization reversal is one of the important key factors to describe the stability of the produced magnetic nano-structures. There are several studies to analyze the magnetization reversal processes with numerical simulations in magnetic patterns. It was found that this irradiation induced magnetic patterning technique is promising for both present magneto-optical storage devices and future near field recording [18].

3.1. Use of U heavy Ions for YCo_2 Sample Irradiation

An assembly of ferromagnetic nano-structures has been prepared by heavy ions irradiation of paramagnetic YCo_2 thin films on YCo_2 samples have shown that fluences in the order 10^{12} U ions/cm^2 cause changes in magnetic properties of. the samples Changes are reported to take place after the irradiation like [19, 20]:

1. Change of spontaneous magnetization, coercivity and initial susceptibility.

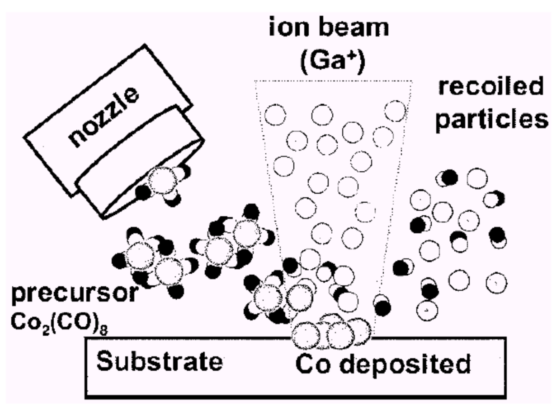

Figure 1: Cobalt dot arrays are fabricated by Ga^+ ion beam induced chemical vapor deposition with an objective to explore size limitations. Dots of about 100–150 nm in diameter are obtained as at islands [9].

Table 1: Macroscopic hysteresis features calculated for irradiated sample.

Φ	[ions/cm^2]	10^{12}	$5 \cdot 10^{12}$	$2 \cdot 10^{13}$
M_s	[kA/m]	20	40	60
H_c	[kA/m]	43.6	21.8	14.5
M_r/H_c	[ ]	0,46	1.83	4.13
α	[nm]	7.3	28.6	65.6

2. A distinct change of the anisotropy perpendicular to the film.

Hysteresis loops calculated for three YCo_2 thin film samples at $T = 10\,\mathrm{K}$ perpendicular and parallel to the film plane after U ion irradiation with different fluences [20].

3.2. Increase the Areal Recording

The ability to store a magnetic transition or a bit in the medium at a length as small as possible is one of the most interesting subjects to increase the areal recording density; other attempts to increase the areal recording density like low-noise thin film GMR head which consist of two ferromagnetic layers separated by a thin, non-magnetic conducting spacer, spacing between heads and media and signal processing technologies were successfully achieved [21–23]. To make the bit of information as small as possible it is important to consider the following equation [22]:

$$\alpha = \frac{M_r \delta}{2\pi H_c} \tag{1}$$

M_r [A/m] remanence magnetization of the material.
δ [m] thickness of the material.
H_c [m] coercivity of the material.
α [m] bit length.

The above equation relates important variables to each other to clarify the dependencies (to satisfy the demands) for smaller bit information. The bit length α directly depends on the thickness δ and remanence magnetization M_r of the material and is inversely proportional to the coercivity H_c of the material. Changes have to be made on the equations parameters for producing small bits.

This equation could be written for certain condition with magnetic noise (by assuming $M_r \Rightarrow M_s$ for (nano magnetic structure for ion irradiated material —)) using Equations (1), to find the dependencies as shown in the table.

4. NANO STRUCTURE PRODUCTION BY WAVE

Other method for nanostructure production are possible through different Wave, the angel and Wavelength.

Table 2: Nano pattern production with various λ.

λ Wave length	[nm]	10	12	13	14
θ Angle	[deg]	80	80	80	80
sin θ	[1]	0.9848	0.9848	0.9848	0.9848
Λ Period length	[nm]	5.0771	6.0925	6.6002	7.1079
θ Angle	[deg]	45	45	45	45
sin θ	[1]	0.7071	0.7071	0.7071	0.7071
Λ Period length	[nm]	7.0710	8.4852	9.1923	9.8994

The principle of interference lithography is simple; it uses the standing wave pattern (the interference of coherent light forms a standing wave pattern) formed between two interfering beams of light to expose a radiation sensitive material (recording on photo-resist) [24]. In traditional IL systems, the pattern is defined by the interference of spherical waves; hence the fringes produced by the spherical waves [25].

5. SUMMARY

In a conventional high density hard disk a bit with a sufficient signal to noise ratio consists of some hundred single-domain grains; the size of a grain is typically 10–30 nm. Grain size cannot be reduced liberally due to the superparamagnetic limit; a solution to that is to pattern the magnetic layer in a regular matrix of dots. Patterned media is the most prominent candidate for extremely high density magnetic recording media. Patterned media are being developed to form isolated tracks of single-domain magnetic islands. Lithography is a method for transferring a desired pattern into a thin film. Pattern transfer is achieved for example, by using light exposure to change the chemical properties of a photosensitive material, called resist, which has been deposited on top of the device layer (thin film) to be patterned. Advances in lithography have contributed significantly to the advancement of the integrated circuit technology. In using traditional interference lithography IL to pattern a grating, one splits a laser beam in two and spatially filters them to produce two spherical waves. The waves interfere and the resulting fringes are recorded in photo-resist. Conceptually, a grating is a simple pattern constituting periodic lines and spaces.

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