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PREVIEW

DIRECT LASER INTERFERENCE PATTERNING OF MAGNETIC THIN FILMS

by

Aliekber Akgag

A DISSERTATION

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Major: Physics & Astronomy

Under the Supervision of Professor Roger D. Kirby

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DISSERTATION TITLE  
DIRECT LASER INTERFERENCE PATTERNING OF

MAGNETIC THIN FILMS

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Nebraska UNIVERSITY OF GRADUATE COLLEGE

# DIRECT LASER INTERFERENCE PATTERNING OF MAGNETIC THIN FILMS

Aliekber Ahtag, Ph.D.

University of Nebraska, 2004

Advisor: Roger D. Kirby

Recently, patterned magnetic thin films have attracted much attention for a variety of applications such as high density magnetic recording, magnetoresistive sensing, and magnetic random access memories. In the case of magnetic recording, one scheme calls for the films to be patterned into single domain “dots”, where every dot represents a thermally stable bit.

In this thesis, we extended a technique called direct laser interference patterning (DLIP), originally developed by Polushkin and co-workers, to pattern and locally modify the materials properties of magnetic thin films. In this technique, a high-intensity Nd:YAG pulse laser beam was split into two, three, or four beams, which are then recombined to interfere on a sample surface. The interference intensity maxima can modify the local materials properties of the film through local “annealing” or, more drastically, by ablation.

We carried out some preliminary investigations of the DLIP process in several films including co-sputtered Co-C, amorphous Dy/Co:SiO<sub>2</sub> multilayers, and Co/SiO<sub>2</sub> multilayers in order to refine our techniques. We successfully produced regular arrays of lines, dots, or antidots formed by ablation of the thin film. The preliminary studies also showed that, in the regime of more modest pulse energies, it is possible to modify the magnetic properties of the films without noticeably changing the film topography. We

then prepared perpendicular magnetic anisotropy Co/Pt multilayers with a SiO<sub>x</sub> passivation layer and applied DLIP at fairly modest intensities to pattern the film. We then studied the structural and magnetic changes that occurred in some detail. X-ray diffraction scans showed the Co/Pt:SiO<sub>x</sub> multilayer films to be nanocrystalline before and after patterning. Atomic force microscopy images showed no evidence for topographic changes of the Co/Pt:SiO<sub>x</sub> during patterning. In contrast, magnetic force microscopy showed regular periodic dot arrays, indicating that the local magnetic properties were significantly affected by the patterning process. Alternating-gradient-force magnetometry and magneto-optic measurements also showed that the magnetic properties were markedly changed by the DLIP process. Our results offer strong evidence that local heating causes the moments to change from perpendicular to in-plane, with the consequent formation of an “anisotropy lattice”: dots of in-plane magnetization within a matrix of perpendicular magnetization.

We also carried out some optical interference calculations to predict the light intensity distributions for two, three, and four interfering beams of light. We found that the patterns could be controlled by varying the angles of incidence, the polarizations of the beams, and the wavelength and intensity of the beams, and that a wide variety of patterns are possible. The predicted patterns were in quite good agreement with those observed experimentally.

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PREVIEW

## List of figures

Fig. 2.1 Simulation of a low-angle  $2\theta$  XRD pattern for a perfect  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})]_{\times 11}$  multilayer thin film

Fig. 2.2 High-angle XRD pattern of  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})]_{\times 11}$  multilayer film

Fig. 2.3 Schematic AFM Force-distance curve

Fig. 2.4 MFM LiftMode Principles (taken from Digital Instrument Dimensions, manual, Support Note No. 229, Rev. B (1996)).

Fig. 2.5 A typical polar Kerr Effect measurement of Co/Pt multilayer film

Fig. 2.6 Schematic diagram of magneto-optical, polar Kerr effect measurement system

Fig. 2.7 Schematic diagram of the AGFM

Fig. 3.1 A schematic representation of direct laser interference patterning (DLIP) system

Fig. 3.2 Lens controlled intensity

Fig. 3.3 The intensities ratio  $I/I_0$  (on the left) and the areas ratio  $A/A_0$  (on the right) vs.  $x$  ( $f = 50$  cm).

Fig. 3.4 The elongation of a circular beam on the sample

Fig. 4.1 Schematic representation of four linearly p-polarized beams interfering on the xy-plane

Fig. 4.2 Interference of four p-polarized beams for  $\theta_1 = \theta_2 = \theta_3 = \theta_4 = 35^\circ$ . The intensity profile (top) and the intensity distribution (bottom) on xy-plane are shown.

Fig. 4.3 Interference of four p-polarized beams  $\theta_1 = \theta_2 = \theta_3 = \theta_4 = 60^\circ$ . The intensity profile (top) and the intensity distribution (bottom) on the xy-plane are shown.

Fig. 4.4 Schematic representation of four linearly s-polarized beams interfering on the xy-plane

Fig. 4.5 Interference of four s-polarized beams at  $\theta_1 = \theta_2 = \theta_3 = \theta_4 = 60^\circ$ . The intensity profile (top) and the intensity distribution (bottom) on xy-plane are shown.

Fig. 4.6 Schematic representation of two p-polarized beams in the xz-plane, and two s-polarized beams in the yz-plane interfering on the xy-plane

Fig. 4.7 Interference of two p-polarized and two s-polarized beams for  $\theta_1 = \theta_2 = 60^\circ$  (2p),  $\theta_3 = \theta_4 = 60^\circ$  (2s).

Fig. 4.8 Interference on the xy plane of two p-polarized and two s-polarized beams for  $\theta_1 = \theta_2 = 20^\circ$  (2p),  $\theta_3 = \theta_4 = 45^\circ$  (2s).

Fig. 4.9 Interference in the xy plane of two p-polarized and two s-polarized beams for  $\theta_1 = \theta_2 = 35^\circ$  (2p),  $\theta_3 = \theta_4 = 35^\circ$  (2s).

Fig. 4.10 A simulation (left) for  $3^\circ$  misalignment and an experimental optical microscopy topography pattern (Co-C) (right) of probably  $5^\circ$  misalignment of the four beam interference.

Fig. 4.11 Three-beam interference pattern for  $\theta_1 = \theta_2 = 25^\circ$  (2p) and  $\theta_3 = 25^\circ$  (s) in the xy-plane

Fig. 4.12 Three-beam interference pattern for  $\theta_1 = \theta_2 = 25^\circ$  (2p) and  $\theta_3 = 45^\circ$  (s) in the xy-plane.

Fig. 4.13 Two beam interference patterns for (s, s) and (p, p) polarizations in the xy-plane.

Fig. 5.1 Typical reflectance for a linearly polarized (s, p) radiation incident on an absorbing, metallic material where  $\Phi_B$  is the pseudo-Brewster's angle where p-polarized light is relatively weakly reflected.

Fig. 5.2 3D-AFM (topographic) image of the laser patterned Co-C (100 nm) film.

Fig. 5.3 AFM (right), MFM (left) scan images of Co-C (100 nm) film patterned by two pulse "crossed" two beam interference pattern.

Fig. 5.4 2D and 3D-close views of MFM (left images) and AFM (right images) patterns of the Co-C (100 nm) film.

Fig. 5.5 Polar Kerr rotation hysteresis loop of as deposited amorphous  $[\text{Dy}(8.25\text{\AA})/\text{Co}(5\text{\AA})] \times 38$  multilayer film

- Fig. 5.6 Polar Kerr rotation hysteresis loop of patterned amorphous  $[\text{Dy}(8.25\text{\AA})/\text{Co}(5\text{\AA})]_{\times 38}$  multilayer film
- Fig. 5.7 As-sputtered state MFM (on the left) and AFM (on the right) views of  $[\text{Dy}(8.25\text{\AA})/\text{Co}(5\text{\AA})]_{\times 38}$  multilayer film
- Fig. 5.8 Remanence state MFM (on the left) and AFM (on the right) topographic views of  $[\text{Dy}(8.25\text{\AA})/\text{Co}(5\text{\AA})]_{\times 38}$  multilayer film
- Fig. 5.9 MFM (on the left) and AFM (on the right) topographic views  $[\text{Dy}(8.25\text{\AA})/\text{Co}(5\text{\AA})]_{\times 38}$  multilayer film
- Fig. 5.10 MFM (on the left) and AFM (on the right) topographic views of  $\text{Co}/\text{SiO}_2$  multilayer film patterned with three polarized (2p-1s) beams.
- Fig. 5.11 Profile (AFM) views of patterned  $\text{Co}/\text{SiO}_2$  multilayer film
- Fig. 5.12 3D-Topographic (AFM) views of patterned  $\text{Co}/\text{SiO}_2$  multilayer film
- Fig. 5.13 3D-Topographic (AFM) views of patterned  $\text{Co}/\text{SiO}_2$  multilayer film in several scales.
- Fig. 5.14 Profile (AFM) views of one dot of  $\text{Co}/\text{SiO}_2$  multilayer film
- Fig. 6.1 High-angle XRD pattern of as-deposited  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})]_{\times 11}$  multilayer film.
- Fig. 6.2 High-angle XRD pattern of patterned  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})]_{\times 11}$  multilayer film.
- Fig. 6.3 Low-angle XRD reflection pattern of as-deposited  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})]_{\times 11}$  multilayer film.
- Fig. 6.4 Low-angle XRD reflection pattern of a patterned  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})]_{\times 11}$  multilayer film.
- Fig. 6.5 Polar Kerr rotation hysteresis loop of as-deposited  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})]_{\times 7}$  multilayer film.
- Fig. 6.6 Polar Kerr rotation hysteresis loop of patterned  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})]_{\times 7}$  multilayer film.
- Fig. 6.7 Longitudinal Kerr rotation hysteresis loop of as-deposited  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})]_{\times 7}$  multilayer film.

Fig. 6.8 Longitudinal Kerr rotation hysteresis loop of as patterned  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})] \times 7$  multilayer film.

Fig. 6.9 Perpendicular hysteresis loop obtained by AGFM for the as-deposited  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})] \times 7$  multilayer film.

Fig. 6.10 Perpendicular AGFM hysteresis loop for the patterned  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})] \times 7$  multilayer film.

Fig. 6.11 In-plane AGFM hysteresis loop for the as-deposited  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})] \times 7$  multilayer film.

Fig. 6.12 In-plane AGFM hysteresis loop for the patterned  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})] \times 7$  multilayer film.

Fig. 6.13 Schematic diagram of focused beam magneto-optical, polar Kerr effect measurement system.

Fig. 6.14 Schematic representation of some of the possible states that the focused beam (red circles) may sit on and yield a polar Kerr effect measurement.

Figure 6.15 The polar Kerr hysteresis loops from four different regions of the sample:

(a) unpatterned region; (b-d) representative loops taken in the patterned region.

Fig. 6.16 A patterned MFM (on the left) and AFM (on the right) image of  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})] \times 7$  multilayer film with a *negative* (into the sample's surface) field of 793 Oe applied.

Fig. 6.17 A simulation "dot" pattern for  $25^\circ$  (2p) and  $35^\circ$  (1s) angles of incidence

Fig. 6.18 A simulation "elongated dot" pattern for  $25^\circ$  (p),  $28^\circ$  (p) and  $35^\circ$  (s) angles of incidence

Fig. 6.19 the remanence state (a), in 183 Oe (b), 277 Oe (c), 416 Oe (d), 793 Oe (e) and 1576 (f) Oe of positive (out of the sample's surface) fields were applied.

Fig. 6.20 the remanence state (g), in 183 Oe (h), 279 Oe (i), 416 Oe (j), 793 Oe (k) and 1570 (l) Oe of *negative* (into the sample's surface) fields were applied.

Fig. 6.21 MFM scans on  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})] \times 7$  in the remanent state (m), and in positive fields (from left to right) of 85 Oe (n), 267 Oe (o), 1034 Oe (p), 2320 Oe (q) and 3010 (r) Oe.

Fig. 6.22 MFM scans on  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})] \times 7$  in the remanent state (s), and in in-plane negative (left to right in the images) fields of 143 Oe (t), 251 Oe (u), 760 Oe (v), 1,018 Oe (w) and 2,990 (x) Oe.

Fig. 6.23 Close view of 3D-MFM, Stray magnetic field strength respond of the patterned  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})] \times 7$  multilayer film. During the scan a field of 793 Oe was applied in the out of plane direction.

Fig. 6.24 Schematic representation of magnetic moment orientations in and out of box for magnetic field calculations of the model.

Fig. 6.25 The stray magnetic field at height 0.025 above the magnetic film surface.

Fig. 6.26 z-gradient of the stray magnetic field at a height 0.025 above the magnetic surface.

Fig. 6.27 Second derivative with respect to z of the stray magnetic field at a height 0.025 above the magnetic surface.

Fig. 6.28 Profile analysis of patterned  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})] \times 7$  multilayer film on 416 Oe field, applied perpendicular into the plane of the film.

Figure A.1 Sectional pattern of a right handed elliptically polarized monochromatic light.

Figure A.2 Snapshot patterns of a beam of monochromatic light traveling along z direction (a) linearly polarized horizontally, (b) linearly polarized vertically.

Figure A.3 Schematic representation of two linearly polarized interfering beams on the surface S.

Figure A.4 Schematic representation of four linearly *p*-polarized beams interfering on the xy-plane.

Figure A.5 Schematic representation of four linearly *s*-polarized beams interfering on the xy-plane.

Figure A.6 Schematic representation of two *p*-polarized beams in the xz-plane, and two *s*-polarized beams in the yz-plane interfering on the xy-plane.

## Contents

Chapter 1. Introduction.....	1
Chapter 2. Thin Film Preparation and Characterization.....	5
2.1. <i>Thin film preparation</i> .....	5
2.2. <i>Thin film structural characterization</i> .....	7
2.2.1 X-ray diffraction.....	7
2.2.2 Atomic force microscopy.....	10
2.3. <i>Magnetic characterizations</i> .....	11
2.3.1 Magnetic Force Microscopy (MFM).....	12
2.3.2 Magneto-Optic Kerr Effect Measurements.....	15
2.3.3 Alternating gradient force magnetometry.....	21
Chapter 3. Direct Laser Interference Patterning (DLIP) Technique.....	23
3.1 <i>The DLIP system</i> .....	23
Chapter 4. The Interference Theory of Linearly Polarized Light.....	30
4.1. <i>Interference of four p-polarized beams</i> .....	31
4.2 <i>Interference of four s-polarized beams</i> .....	39
4.3 <i>Interference of four (2p, 2s) polarized beams</i> .....	41
4.4 <i>Interference of three (2p, s) polarized beams</i> .....	44
4.5 <i>Interference of two (s-s or p-p) polarized beams</i> .....	46
Chapter 5. Survey of DLIP Experiments in Several Systems.....	48
5.1 <i>Radiation-Matter Interactions</i> .....	48
5.1.1 Reflection and Refraction of Radiation at an Interface.....	49

5.1.2	Classical (Linear) Absorption.....	51
5.2	<i>Topographic and intrinsic modifications of magnetic thin films by DLIP.....</i>	52
5.3	<i>MFM measurements of stray magnetic fields.....</i>	53
5.4	<i>Studies of patterned films.....</i>	54
5.4.1	Co-C Films.....	54
5.4.2	Dy/Co:SiO <sub>2</sub> multilayers – magneto optical measurements.....	57
5.4.3	Dy/Co:SiO <sub>2</sub> multilayers – AFM and MFM measurements.....	61
5.5	<i>Co/SiO<sub>2</sub> multilayers.....</i>	64
5.5.1	AFM/MFM, topographic/stray magnetic field patterns.....	64
Chapter 6.	Results and Discussion.....	69
6.1	<i>XRD results for Co/Pt:SiO<sub>x</sub> multilayers.....</i>	69
6.2.	<i>MOKE measurements on Co/Pt:SiO<sub>x</sub>.....</i>	75
6.2.1	Polar Kerr rotation hysteresis loops of Co/Pt:SiO <sub>x</sub> multilayer films.....	78
6.2.2	Longitudinal Kerr rotation hysteresis loops of Co/Pt:SiO <sub>x</sub> multilayer films.....	80
6.3	<i>AGFM hysteresis loop measurements on [Co(4Å)/Pt(10Å)] x 7.....</i>	82
6.4	<i>Focused beam polar Kerr hysteresis loop measurements on [Co(4Å)/Pt(10Å)] x7.....</i>	88
6.5	<i>MFM and AFM studies of [Co(4Å)/Pt(10Å)] x 7.....</i>	93
6.5.1	MFM on [Co(4Å)/Pt(10Å)] x 7 with perpendicular field applied.....	96



6.5.2	MFM measurements on [Co(4Å)/Pt(10Å)] x 7 with in-plane field applied.....	101
6.6	<i>A simple model for MFM stray magnetic field scans.....</i>	106
Chapter 7. Summary and Conclusions.....		115
7.1	<i>Overview.....</i>	115
7.2	<i>Primary Results.....</i>	116
7.3	<i>Future DLIP Applications.....</i>	120
References.....		122
Appendix A	The Interference Theory of Linearly Polarized Beams.....	127
A.1	<i>Polarized Light.....</i>	127
A.2	<i>Mathematical Expression of a Polarized Wave Train.....</i>	128
A.3	<i>Interference of Two Coherent Linearly Polarized Beams.....</i>	129
A.4	<i>Interference of Four Linearly p-Polarized Beams.....</i>	131
A.5	<i>Interference of Four Linearly s-Polarized Beams.....</i>	135
A.6	<i>Interference of Four (Two s-Polarized and Two p-Polarized) Beams... </i>	136
Appendix B	Maple code for intensity expressions and profiles of linearly Polarized lights.....	138
Appendix C	Labview g-language MOKE Hysteresis loop measurements program code.....	143

## Chapter 1. Introduction

The length scale of magnetic information storage technology is rapidly approaching the ten nanometer range, storage densities are projected to increase to a terabit per square inch in the next decade and most of the recent explosive growth in magnetic data storage has been due to new material discoveries and fabrication techniques and better understanding of the magnetic and electronic properties of complex magnetic thin film systems. These systems are used in a large variety of applications including magnetic media, magnetic recording heads, magnetic random access memory, sensors, and actuators [1.1, 1.2].

Development of many new magnetic materials with exciting and novel properties is in progress in laboratories around the world. A detailed knowledge of the physical and magnetic microstructure is important if the properties of modern magnetic materials are to be understood and subsequently improved. Many important properties of materials displaying an ordered magnetic phase depend on the magnetic domain configuration present within the material. Many such desirable magnetic properties are induced by a particular film growth or fabrication procedure, rather than being intrinsic to the material itself. Thus optimization of the macroscopic magnetic properties is only likely to be achieved if the magnetic nanostructure can be determined and its dependence on the physical nanostructure investigated.

Study of regularly-shaped magnetic thin film elements whose in plane dimensions vary in sub-micron range, as compared to larger structures, allows the influence of

particle shape and size to be studied more thoroughly in that surface effects are more important in smaller structures.

The term “ordered patterned media” is used to refer to thin films which consist of arrays of discrete elements, each of which can store one bit of data. In the simplest scheme, the magnetic elements could have only a single axis of magnetization. The direction of magnetization is interpreted as a binary 1 or 0. Ideally, the storage density is then equal to the surface density of the elements. In many patterned media, each discrete element is exchangeably isolated from other elements, but inside each element polycrystalline grains are strongly exchange-coupled and behave collectively like a larger single magnetic grain. The problem with patterned media is that there have been no cheap and mass-production-compatible manufacturing methods capable of making them, as their surface density implies that both the linear bit density (bits per inch) and the track density (tracks per inch) must be in the deep sub-micrometer range. Conventional lithographic methods either are too time-consuming or do not handle the small structure sizes needed [1.3, 1.4].

For a successful application of the concept of ordered patterned media the development of a suitable patterning technique is one of the crucial items. The requirement of patterning large areas with regularly spaced uniform dots with small spacing puts strong demands on the patterning technology. However, our goal in this work was to prepare patterned magnetic thin films and study their relevant magnetic properties rather than to design a patterning technology for the manufacture of patterned magnetic thin films.

In the last decade, several lithography techniques were developed to fabricate regular-ordered patterned surfaces, including nanoimprint lithography [1.5], electron beam lithography and electroplating [1.6], laser interference lithography [1.7], synchrotron radiation based X-ray lithography [1.8] and scanning tunneling microscope lithography [1.9]. However, these techniques are time consuming and often need multi-step processes such as mask preparation, resist spinning, exposure, developing, etching and resist removal.

We have extended a direct laser interference patterning (DLIP) technique originally developed by Polushkin and co-workers [1.10]. Using this technique, one can modify the topography and intrinsic material properties and create a regular patterned arrays. Specifically, this technique allows thin films to be patterned directly, without the need for an intermediary photoresist mask or hard mask. The purpose of this thesis work is to utilize the DLIP to pattern and locally change the topographic and/or magnetic properties of magnetic thin films and multilayers including Co/Pt:SiO<sub>2</sub>, amorphous Dy/Co:SiO<sub>2</sub> and co-sputtered Co-C. Results on these films will be presented, and we will offer evidence that such patterns can form an “anisotropy lattice”, where “dots” of in plane magnetization are formed in a background matrix of perpendicular magnetization.

The DLIP technique is based on the pattern produced by two, three or four interfering laser beams of a given wavelength. The standing wave interference pattern produces alternating light and dark regions with a spacing determined by the wavelength and the angles at which the beams intersect. For a Nd:YAG laser operating at the second harmonic wavelength (532 nm), lines, dots down to 300 nanometers in diameter can be

fabricated, With a single pulse exposure, many patterns such as lines, elongated lines, dots, and anti-dots, can be formed and fabricated.

In Chapter 2 of the thesis details of film preparation, including the sputtering process and the mass calibration is introduced. Then the magnetic and structural measurement methods are briefly discussed and described. These include: X-ray diffraction (XRD) to detect the structure changes, Atomic Force Microscopy (AFM) to measure the topographic changes, and Magnetic Force Microscopy (MFM) to study magnetic domains. In addition, magneto-optic Kerr effect (MOKE) and an alternating gradient field magnetometer (AGFM) were used for magnetic property measurements of the various films at room temperature before and after DLIP. In Chapter 3, the experimental details and principles of the direct laser interference patterning (DLIP) technique are described. In Chapter 4, the classical theory of electromagnetic radiation is used to derive expressions to calculate interference intensity distributions for two to four beams of linearly polarized light. These expressions are evaluated numerically using the symbolic algebra program, “Maple” for several different situations, and graphical simulation results are presented. In Chapter 5, in addition to a brief discussion on the laser-matter interaction, the properties of Co-C, amorphous Dy/Co:SiO<sub>2</sub>, and Co/SiO<sub>2</sub> magnetic thin films, patterned and modified by DLIP, are presented. In Chapter 6, the film characterization (XRD), magnetic (AGFM, MFM) and magneto-optic properties (MOKE) measurements and the magnetic modifications (AFM/MFM) made by DLIP, on Co/Pt:SiO<sub>x</sub> multilayer thin films are presented. The results are given and discussed in more detail. Finally, in Chapter 7, a summary of the results and the conclusions is given.

## Chapter 2. Thin Film Preparation and Characterization

Co/Pt: SiO<sub>x</sub>, amorphous Dy/Co: SiO<sub>2</sub>, Co/SiO<sub>2</sub>, and Co-C multilayer thin films were prepared in a three-gun magnetron sputtering system. In this chapter, the thin film preparation process, structural and magnetic characterization methods are described.

### 2.1. *Thin film preparation*

For all prepared films Si(100) was used as substrate. Before the substrates were placed into the sputtering chamber they were ultrasonically cleaned in acetone to remove dust and grease. The films were deposited in a homemade three-gun (1-RF and 2-DC) magnetron sputtering (Dale) system with a computer-controlled, water-cooled rotating substrate holder. To minimize contamination, the chamber was evacuated to a good vacuum by a diffusion pump and a base pressure of  $5 \times 10^{-7}$  torr was reached prior to sputtering. Sputtering was carried out at 5 mtorr of pressure in argon environment. The multilayer films were prepared by alternately positioning the substrates above different targets for different time durations. The sputtering rates were adjusted and controlled by varying the power to the sputtering guns. The deposition rate of a particular material was calibrated by measuring the mass of the material deposited for various sputtering powers and a fixed period of time. After calibration, the layer thickness of each component of the multilayer film was controlled by the time that the substrate remained above the gun. Total film thickness and the sequential depositions of multilayer components were controlled by a standard computer program. 99.99% pure Co, Pt, Dy and C target

materials were used as sputtering sources. The DC sputtering guns were used for multilayer depositions of Co, Pt, Dy and C target materials, and the RF gun was used for SiO<sub>x</sub> or SiO<sub>2</sub> as an insulating overcoat material to passivate the film surfaces after removal from the sputtering chamber.

Sputtering rate calibrations for the materials used in the sputtering processes were done as follows: For each target, usually four 2 x 2 cm aluminum foils were cut and ultrasonically cleaned in acetone or ethyl alcohol, and then their weights were measured twice using a very sensitive digital balance and averaged. The nominal accuracy of the balance was 10<sup>-3</sup> mg. The foils were mounted in the sputtering chamber. Depending on the material to be sputtered and the particular sputtering gun, gun powers and periods of time were increased or decreased in stepwise manner and recorded. After sputtering, the foils were again weighed twice and averaged. The change in weight due to sputtering determines the amount of mass deposited in the aluminum foil at certain power and period of time. Using the expression of the rate, R, for a certain power,

$$R = \Delta M / (\rho A t) \quad (2.1)$$

was calculated for a particular material (Co, Pt, Dy, C, SiO and SiO<sub>2</sub>). In the expression  $\Delta M$  is the weight difference,  $\rho$  is the mass density, A is the sputtered area and t is the period of time. Finally, from the plot of the sputtering rate versus power, which is a straight line for most of the materials, the desired sputtering rate could be chosen.

## 2.2 Thin film structural characterization

### 2.2.1 X-ray diffraction

The structures of the films were investigated before and after direct laser interference patterning (DLIP) processes using a Rigaku X-ray diffractometer with a Cu source. The  $2\theta$  X-ray diffraction (XRD) patterns were used to analyze the crystal structure. The  $2\theta$  XRD profile is divided into two regions: low-angle ( $<15^\circ$ ) and high-angle ( $> 15^\circ$ ). Diffraction due to the chemical modulation of the layers appears in the low-angle XRD region and is used to determine the bilayer thickness. The position of the peaks are determined by [2.1]

$$\sin^2 \theta = \left( \frac{n\lambda}{2\Lambda} \right)^2 + 2\delta_s, \quad (2.2)$$

where  $\lambda$  is the X-ray wavelength,  $n$  is the order of the reflection,  $\Lambda$  is the bilayer thickness of the multilayer, and  $\delta_s$  is the correction of the refraction index due to the small incident angle. The typical value for  $\delta_s$  is  $\sim 3 \times 10^{-5}$  which only leads to significant deviations from Bragg's law when  $2\theta < 3^\circ$  for Cu radiation. Thus, it was ignored in this work. As an example, Fig. 2.1 shows a simulation of a low-angle  $2\theta$  XRD pattern for a perfect multilayer of  $[\text{Co}(4\text{\AA})/\text{Pt}(10\text{\AA})] \times 11$  thin film [2.2].