THE EFFECT OF SAMPLE PREPARATION PARAMETERS ON MAGNETORESISTANCE RATIOS (MR%) IN CO/CU NANOSTRUCTURES

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To my family. Without their continual support and encouragement this work would not have been possible.

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ABSTRACT

The research reported in this thesis is primarily aimed at establishing the fundamental understanding of magnetoresistance (MR) phenomena occurring in layered magnetic nanostructures of Co/Cu system fabricated using sputtering and electron beam method. Emphasis is given on the studies of magnetoresistance ratios (MR%) as functions of Co layer thickness, working pressure, annealing time and temperature, number of bilayer, direction of magnetic fields, and the application of buffer layer. The Co/Cu/Co sandwiches in this study were fabricated on corning glass substrates. The electrical resistance of samples was measured using the four point Van der Pauw method when magnetic fields of ± 2500 gauss were applied. It was observed that, the MR% attained almost 10% between 2 - 6 nm of the Co layer thickness. By varying the working pressure, a maximum MR% of 11.4% was obtained at a working pressure of 2.6 x 10^{-3} torr. In the other hand, the MR% also increases with the increasing of annealing temperature and time. In the bilayers number, *n* various MR% was revealed by the existence of up-down fluctuations with the MR's peak and valley occurring at n = 5 and n = 8, respectively. It was also observed that, the magnetic field applied in plane to the samples with and without chromium buffer layer produced higher value MR% of compared to those applied perpendicularly. Thus, the results indicate the dependent of MR% on various preparation parameters.

ABSTRAK

Laporan penyelidikan dalam tesis ini bermatlamat untuk menghasilkan pemahaman asas mengenai fenomena *magnetoresistance* (MR) dalam struktur Co/Cu yang dihasilkan melalui kaedah *sputtering* dan *electron beam*. Penekanan diberikan terhadap faktor-faktor ketebalan lapisan Co, tekanan semasa proses pemendapan, masa dan suhu pemanasan, bilangan lapisan saput tipis, arah pembekalan medan magnet, dan lapisan *buffer* yang mempengaruhi nilai-nilai nisbah magnetoresistance (MR%). Lapisan Co/Cu/Co dalam pengajian ini dimendapkan ke atas kaca *corning*. Rintangan sampel diukur dengan menggunakan kaedah *Van der Pauw* apabila medan magnet berjumlah ± 2500 gauss dikenakan. MR% didapati meningkat ke hampir 10% apabila ketebalan lapisan Co berada di antara 2-6 nm. Dengan mengubah tekanan semasa proses pemendapan, nilai maksimum MR% berjumlah 11.4% telah dihasilkan pada tekanan 2.6 x 10^{-3} torr. Selain daripada kesan ketebalan Co dan tekanan semasa pemendapan, proses pemanasan juga turut meningkatkan nilai MR%. Kesan bilangan lapisan sampel telah menghasilkan bentuk turun naik dengan puncak dan lembah MR% masing–masing muncul semasa n = 5 dan n = 8. Disamping itu, MR% yang lebih tinggi dapat dihasilkan dengan mengenakan medan magnet dalam arah mendatar kepada sampel, sama ada terdapat lapisan buffer atau tidak. Oleh itu, hasil penyelidikan ini menunjukkan bahawa MR% adalah dipengaruhi oleh pelbagai cara penyediaan sample.

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LIST OF SYMBOLS

GMR	Gaint Magnetoresistance
MR	Magnetoresistance
MR%	Magnetoresistance ratios
SSF	Surface Spin-Flop
H	Magnetic field
M	Magnetization
μ_0	Permeability of free space
β	Bohr magnetron
B	Magnetic induction
χ	Susceptibility
T_N	*Neel temperature*
E_F	Fermi Energy
n	Number of multilayers
ρ	Resistivity
R_{min}	Resistance in maximum external magnetic field
R_{max}	Resistance in zero field
R_{total}	Total resistance
ΔR	Distance between R_{max} and R_{min}
t	Thickness
t_{Co}	Thickness of Co layers
RF	Radio frequency
e-beam	electron beam

HVC	High Vacuum Coater
Auto 306	Edwards Auto 306 Evaporation Systems
Sccm	Standard cubic centimeter per minute
FTM	Film Thickness Monitor
Z value	Acoustic impedance
$DEKTAK^3$	$Dektak^3$ Surface Profiler
LVDT	Linear Variable Differential Transformer
RAM	Random access memory
MRAM	Magnetic RAM
FM-layers	Ferromagnetic layers
NM-layers	Non-magnetic spacer layers
P	Paramagnetic
F-mode	Ferromagnetic mod
AF-mode	Anti-ferromagnetic mode
α	Direction of magnetic field
Co	Cobalt
Cu	Copper
Cr	Chromium
Fe	Iron
Ni	Nickel
NiFe	Nickel Iron
GaAs	Gallium Arsenide

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CHAPTER 1

INTRODUCTION

1.1 Literature Review

The capacity of magnetic disk systems is growing rapidly year by year with the advancement in the information-oriented society. From a statistical survey, the density of magnetic recording is increased by 60% every year (Sato, 1998). Magnetic thin films have been of great interest recently due to their technological application in magnetic sensors and magnetic random access memory (MRAM) modules (Timothy, 2001; and Yamada *et al*., 2002).

The issue of sensitivity has drawn a lot of attention in giant magnetoresistance (GMR) materials for applications in sensors, high-density read-out heads and other magnetic storage technology in this decade. Thus, the study of GMR effect was essential to investigate the thin film condition, which can produce higher GMR values while decreasing the size of the magnetic fields required to produce the effect.

The phenomenon of magnetoresistance (MR) was first observed by Lord Kelvin in 1956 (Philip, 2000), where 0.033% rise of electrical resistance was recorded in a piece of iron subjected to a magnetic fields. However, it only becomes important when the electrical resistance of permalloy thin film magnetic sensor changed by up to 2% when its magnetization direction was changed (Mahdi *et al*., 2003).

Generally, MR sensors are made from ferromagnetic thin films. There are two major advantages of ferromagnetic thin film over bulk material. These include the high resistance and the anisotropic characteristic of ferromagnetic thin film, which can be made uniaxial (Timothy, 2001). According to David (1991), the anisotropy phenomenon ferromagnetic layers behaves like a single domain. It has one distinguish direction of magnetization in its plane, called the easy axis.

Barna and Grunberg (1992) reported that, for a given thickness of the non-magnetic chromium layer in three-layer Fe/Cr/Fe structure, the magnetizations of Fe layers pointed in the opposite directions. According to Ping (2001), the interlayer coupling responsible for this anti-alignment is called “antiferromagnetic”. Antiferromagnetism is a phenomenon in which atomic magnetic moments point in opposite directions in materials.

In 1988, Baibich *et al*. observed a similar phenomenon occurring in the antiferromagnetically coupled Fe/Cr superlattice. However, a considerable drop in the resistance occurred when a sufficiently high magnetic field of approximately 2T was applied. This effect is now known as GMR.

GMR sandwich structures were then introduced with capabilities of producing a higher GMR ratio up to 50% (Mahdi, *et al*. 2003). Generally, GMR structures consist of an ultra thin metallic non-magnetic layer of Cu or Ag (≈10 nm) sandwiched between two ferromagnetic metals, such as cobalt and iron. Several theoretical studies have been carried out to account for the various mechanisms occurring in GMR multilayer film (Valet, *et al.* 1996; Johnson, *et al.* 1991; and Barthelemy, *et al*. 1991)

The novel magnetic alignments were the other interesting aspects in magnetic thin films. It has been investigated for the academic interest and application in micro devices (Jiang and Bader, 2002; Matteo *et al.,* 2000; and Crew *et al.,* 2001). Magnetic multilayers were also proved to be a model system for investigating the magnetization reversal process, where a transition of surface spin-flop (SSF) was obtained in an ideal antiferromagnet (Luthi and Hock, 1983; and Rohrer, 1977). According to Timothy (2001), SSF only occurs when the direction of the top surface magnetization is antiparallel to the bottom surface magnetization. GMR is a new and developing field. Thus, much more work was needed to explore and make use of the GMR.

1.2 Research Objectives

It is well known that GMR is very sensitive to the microstructure of the sample (Ratzke *et al*., 1999; Herker *et al.,* 2002; and Dinia *et al*., 2000). Thus, the main interest of this study is to determine the highest GMR effect that can be obtained in Co/Cu nanostructures. Although study of GMR effect in Co/Cu nanostructures have been reported previously, not much work was done in studying the optimum conditions of thin film, which can produce the highest GMR effect. This information is important to the computer manufactures to produce read-out heads with higher density. Thus, the objectives of this research are as follow:

1) To prepare Co/Cu nanostructures.
2) To measure and study the MR% of Co/Cu nanostructures.
3) To determine the highest MR% obtain in the Co/Cu nanostructures.

1.3 Research Scope

The scope of this research involves the preparation of Co/Cu nanostructures by two different methods, namely the RF sputtering and electron beam (e-beam) method. Emphasis is given on the studies of magnetoresistance ratios (MR%) as functions of Co layer thickness, working pressure, annealing time and temperature, number of bilayer, direction of magnetic fields, and the application of buffer layer in order to obtain the optimum condition for the highest MR%. The resistance of samples in this study was measured using the four-point Van der Pauw method.

The following materials (Table 1.1) were chosen in order to achieve the aims of the study.

Table 1.1: Material and their function in the system

	Material	Function
1.	Cobalt (Co)	Ferromagnetic material
2.	Copper (Cu)	Non-magnetic but a good conductor
3.	Chromium (Cr)	Buffer layer

Co was chosen as the ferromagnetic material because it is one of the elements with ferromagnetic characteristic at room temperature (Anderson *et al.*; 1985 and David, 1991). Apart from that, the Curie temperature of Co is higher than other ferromagnetic materials, for example Ni and Fe. Curie temperature is the transition temperature from ferromagnetic to paramagnetic behavior. Thus, Co was chosen as ferromagnetic material, since a high temperature is needed to transform into paramagnetic behavior. Meanwhile Cu, the most common good conducting material is chosen as a non-magnetic material.

The Cr was used as a buffer layer in the system. This is due to its ability to enhance the MR% of system (Shen, *et al.*, 1999). Besides, it is easily deposited by sputtering and electron beam method (e-beam).

1.4 Thesis Plan

This thesis contains 6 chapters. Chapter I is the introductory section on the development of the research. It reviewed the problem statement and previous work done by other researchers. This chapter also specified the aim of studies, choice of system, and outline of the thesis plan.

Meanwhile, Chapter II deals with the background of this study, which covers the theoretical aspects of the magnetic material; i.e. ferromagnetic and antiferromagnetic material, band structures, thin film deposition and method such as radio frequency (RF) sputtering and electron beam (e-beam) method, thickness measurement and GMR.

The details of the sample preparation, design of the experiment, methods of measurement of the various physical parameters such as thickness and resistivity of samples, calculation of MR% are described in Chapter III.

Chapter IV discusses all the experimental results obtained from the investigation on the effects of thin film layers thickness, working pressure, bilayers of sample, annealing process, buffer layer, direction of external magnetic fields, and different methods of sample preparation.

Chapter V summarized the findings mentioned and the condition of sample that can produce highest MR%. Finally, suggestions on future work will also be mentioned.

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