UNIVERSITI PUTRA MALAYSIA

STUDIES OF THE PROPERTIES OF SPUTTERED CoAg AND CoNiAg GRANULAR MAGNETIC THIN FILMS

HUDA ABDULLAH

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By

HUDA ABDULLAH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

May 2002

UPM

DEDICATION

Special dedication to:

My beloved family

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

STUDIES OF THE PROPERTIES OF SPUTTERED CoAg AND CoNiAg GRANULAR MAGNETIC THIN FILMS

By

HUDA ABDULLAH

May 2002

Chairman: Professor Abdul Halim Shaari, Ph.D.
Faculty: Science and Environmental Studies

The observation of the magnetoresistance effect has been focussed on the studies of the giant magnetoresistance (GMR) effect, throughout the world, by researchers and scientists after its discovery from magnetic multilayer. It has later been observed in granular alloys in which nanometer-sized magnetic granules such as Co, Ni, Fe, are embedded in an immiscible metallic matrix (Ag, Cu, Au, etc.). These magnetic alloys having GMR effect find potential applications in magnetic field sensor and read heads.

In this work, granular thin films of CoAg and CoNiAg alloys have been prepared using Radio frequency (RF) Magnetron sputtering technique. A split target composed of high purity (99.99%) Co, Ni and Ag metals have been bombarded with argon atoms to form plasma, which condensed onto the glass substrate to form thin films of various thicknesses depending on the deposition time and RF power. The

characteristics and magnetotransport properties of GMR materials based on the CoAg and CoNiAg have been investigated. Magnetoresistance (MR) is usually expressed as the fractional change in resistance of a specimen produced by an applied field, GMR = $\Delta R/R$. For non-magnetic films MR is quite small, however the presence of magnetic entities in the non-magnetic matrix, increases its MR and hence it is termed as GMR.

The surface morphology and the structure of the films had been examined using a scanning electron microscope (SEM). It has been observed that the surface morphology was smooth and homogeneous with little contamination on the films surfaces, due to oil spots and time debris throughout the deposition process and sample preparation for various measurements. The composition and the element percentage for each series were determined through EDX microanalyser installed in the SEM unit. The optimum percentage for this ferromagnetic element of Co is about 23.32%. At this composition of Co, sample has the highest value of MR. The structures of samples were analyzed by using PHILIPS X-ray diffractometer. The X-ray diffraction indicates a uniform fcc structure and set of <111>, <200>, <220> and <311> peaks were observed. The <111> peak shows higher intensity indicated that the growth of <111> Ag structure is dominant. It was observed that <111> peaks are broad and hence could be deduced that these granular films are well distributed with small grain size. As the peak of <111> is broad, the value of MR is increase.

The MR effect had been measured using a standard four-point probe technique and the measurements extended from room temperature to 100 K by using liquid nitrogen cryostat. The increase of maximum MR for as-deposited samples

from 1.83% at room temperature to 2.83% at 100 K were observed in $Co_{23.32}Ag_{76.68}$ (Co5Ag (d.t.50°C)) film deposited for 70 minutes. The value of MR depends on the density and the size distribution of ferromagnetic entities. The results also show that the GMR values have not achieved saturation condition at an applied field of 1 Tesla at any temperature. This could be due to the small clusters in the film that need higher external field to totally align the magnetic moment along the field axis. This is also supported by the broadening of XRD peaks.

The highest MR for the annealed sample of $Co_{29.63}Ag_{70.37}$ (Co6Ag (d.t.50°C)) deposited for 80 minutes is approximately to 2.95%. This sample is almost saturated at 1 Tesla when the sample was annealed at 350°C for 30 minutes. The increase in the GMR values following the heat treatment is believed to be mainly due to particle growth that depends on both the size and the density of magnetic grains.

Abstrak tesis yang kemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

KAJIAN CIRI-CIRI KEMAGNETORINTANGAN BAGI FILEM-FILEM NIPIS CoAg DAN CoNiAg

Oleh

HUDA BINTI ABDULLAH

Mei 2002

Pengerusi: Profesor Abdul Halim Shaari, Ph.D.
Fakulti: Sains dan Pengajian Alam Sekitar

Pemerhatian kesan magnetorintangan adalah lebih menarik telah difokuskan dalam satu kajian tentang kesan magnetorintangan gergasi (MRG) di seluruh dunia, dengan penyelidikan-penyelidikan dan ahli-ahli sains setelah ianya dijumpai daripada berbilang lapisan magnetik. Kemudian, ianya telah diperhatikan dalam berpepasir aloi-aloi di mana butiran magnetik bersaiz nanometer seperti Co, Ni, Fe, adalah terbenam dalam matriks metalik tak tercampurkan (Ag, Cu, Au, sbg.). Aloi-aloi magnetik ini yang mempunyai kesan MRG menjumpai keupayaan aplikasi dalam pengesan medan magnet dan *read head*.

Dalam penyelidikan ini, butiran saput tipis daripada aloi-aloi CoAg dan CoNiAg telah disediakan dalam teknik percikan RF Magnetron. Sasaran pisahan mempunyai ketulenan tinggi (99.99%) logam Co dan Ag telah ditembak secara bertalu-talu dengan atom-atom argon kepada bentuk plasma, di mana akan berubah menjadi cecair ke atas substrak kaca kepada bentuk filem nipis dengan pelbagai

ketebalan yang bergantung kepada masa pemendapan dan kuasa R.F. Ciri-ciri dan sifat-sifat magnetoangkutan daripada bahan-bahan magnetorintangan gergasi berdasarkan kepada CoAg telah diselidiki. magnetorintangan (MR) biasanya dinyatakankan sebagai perubahan berperingkat suatu specimen kerintangan dihasilkan oleh medan yang dikenakan, MRG = $\Delta R/R$. Untuk filem bukan magnetik nilai MR adalah terlalu kecil, walau bagaimanapun, dengan kewujudan entiti magnetik dalam matrik bukan magnetic akan meningkatkan MR, sebagai takrifan bagi MRG.

Morfologi dan struktur permukaan bagi filem-filem telah diperiksa menggunakan mikroskop electron pengimbasan (SEM). Ia telah diperhatikan bahawa morfologi permukaan adalah licin dan homogen, dan terdapat sedikit sahaja kontaminasi pada permukaan-permukaan filem ini. Ia boleh disebabkan oleh bintik-bintik minyak dan kesan tapak jari seluruh proses pemendapan dan penyediaan sampel untuk pelbagai pengukuran. Komposisi dan peratusan unsure-unsur untuk setiap siri telah ditentukan menggunakan penganalisis penyebaran tenaga sinaran-X (EDX) tersedia dalam unit SEM. Peratusan optima untuk unsur ferromagnetic ini, Co adalah kira-kira 23.32%. Pada komposisi cobalt ini, sample mempunyai nilai MR yang paling tinggi. Walau bagaimanapun, struktur sampel dianalisis dengan menggunakan Pembelauan sinar-X PHILIPS. Pembelauan sinar-X menunjukkan satu bentuk struktur fcc dengan nyata komposisi bergantung kepada parameter kekisi. Spektra XRD menunjukkan set puncak-puncak <111>, <200>, <220> dan <311> telah diperhatikan. Puncak <111> Ag menunjukan keamatan yang tinggi yang menunjukan struktur <111> Ag yang dominan. Ia telah diperhatikan bahawa puncak <111> Ag adalah lebar dan boleh disimpulkan bahawa granular filem-filem

ini bertaburan rapi dengan saiz butiran kecil. Puncak <111> Ag melebar, maka nilai MR akan meningkat.

Kesan magnetorintangan telah diukur dengan menggunakan teknik penduga empat-panggal piawai dan pengukuran dilakukan dari suhu bilik hingga ke 100 K dengan menggunakan cecair nitrogen cryostat. Peningkatan maksimum MR untuk sampel disimpan dari 1.83% pada suhu bilik ke 2.83% pada 100 K diperoleh dari $Co_{23.32}Ag_{76.68}$ (suhu pemendapan.50°C) dimendap selama 70 minit. Nilai MR bergantung kepada ketumpatan dan taburan saiz entiti ferromagnetic. Lengkungan-lengkungan MRG juga menunjukkan bahawa nilai MRG tidak mencapai keadaan ketepuan ketika medan yang dikenakan 1 Tesla pada mana-mana suhu. Ini boleh disebabkan oleh kelompok-kelompok kecil dalam filem yang memerlukan medan luaran yang tinggi untuk menjajarkan momen magnetic sepanjang paksi medan. Ini juga telah disokong oleh kelebaran puncak XRD.

Nilai tertinggi MR untuk sampel sepuh lindap diperolehi oleh $Co_{29.63}Ag_{70.37}$ (suhu pemendapan 50°C) dimendap selama 80 minit adalah menghampiri 2.95%. Sampel ini hampir tepu pada 1 tesla apabila sample disepuh-lindapkan pada 350°C selama 30 minit. Peningkatan nilai MRG berikutan dengan rawatan pemanasan yang dipercayai menjadi punca utama yang menyebabkan pertumbuhan zarah-zarah yang bergantung kepada kedua-dua saiz dan ketumpatan butiran-butiran magnetik.

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I certify that an Examination Committee met on 20th May 2002 to conduct the final examination of Huda Abdullah on her Master of Science thesis entitled "Studies the Properties of Sputtered CoAg and CoNiAg Granular Magnetic Thin Films" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are a follows:

ZAIDAN ABD. WA AB, Ph.D.
Faculty of Science and Environmental Studies,
Universiti Putra Malaysia
(Chairman)

ABDUL ALIM S AA I, Ph.D.
Professor
Faculty of Science and Environmental Studies,
Universiti Putra Malaysia
(Member)

W. MAHMOOD MAT YUNUS, Ph.D.
Associate Professor
Faculty of Science and Environmental Studies,
Universiti Putra Malaysia
(Member)

ELIAS BIN SAION, Ph.D.
Associate Professor
Faculty of Science and Environmental Studies,
Universiti Putra Malaysia
(Member)

SHAMSHER MO AMAD AMADILI, Ph.D.
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 21 JUN 2002

This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science.

AINI IDERIS, Ph.D.
Professor/Dean,
School of Graduate Studies,
Universiti Putra Malaysia

Date: 08 AUG 2002

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

HUDA BINTI ABDULLAH
Date: 21/6/2012

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LIST OF ABBREVIATIONS AND GLOSSARY OF TERMS

Abbrev/Gloss	Description
A, β, γ	Phase designations
θ	Bragg diffraction angle
°C	Degree Celsius
$\rho\uparrow$	Spin-up resistivity
$\rho\downarrow$	Spin-down resistivity
ρ_F	Ferromagnetic resistivity
ρ_N	Non Ferromagnetic resistivity
ρ_{II}	Parallel resistivity
ρ_T	Transverse resistivity
$\rho_\perp$	Perpendicular resistivity
ρ_0	Resistivity due to impurity
ρ_H	Resistivity at applied magnetic field H
ρ_{ave}	Average resistivity
ρ_m	Magnetic resistivity
$\Delta\rho_{AMR}$	Resistivity variation of Anisotropic magnetoresistance
$\Delta\rho$	Resistivity variation
ΔR	Resistance variation
ρ_{tot}	Total resistivity
σ	Conductivity
Λ_s	Interface spin-scattering length

λ_1	Mean free path
γ	Secondary electron emission coefficient
ω	angular velocity
AMR	Anisotropic magnetoresistance
AP	Antiparallel
AF	Antiferromagnetic
at%	Atomic percent
B	Magnetic induction
CIP	Current in Plane
CPP	Current Perpendicular to the Plane
CMR	Colossal Magnetoresistance
CVD	Chemical Vapor Deposition
c_1	Mean velocity of sputtered atoms
d	Lattice spacing
Δd	Variation in lattice spacing
d_{bulk}	Bulk lattice spacing
DC	Direct current
d.t.	Deposited temperature
e	Electron
EDX	Energy dispersive X-ray
E	Electric field
F	Ferromagnetism
GMR	Giant Magnetoresistance
H	Magnetic field
HBT	High electron mobility transistor

HEMET	Hetrojunction bipolar transistor
H_{max}	maximum field
H_s	Saturation field
I	Current
j	Current density
k	Boltzman's constant
K	Kelvin
keV	Kilo-electron volt
kV	Kilo volt
L	Electrode spacing
LSI	Large Scale Integration
L_{SF}	Spin-diffusion length
m	Mass
M	Magnetisation
MBE	Molecular beam epitaxy
MESFET	Metal semiconductor field effect transistor
MHz	Megahertz
M_S	Saturation magnetization
MOCVD	Metalorganic chemical vapour deposition
MR	Magnetoresistance
MRAM	magnetic RAM
n_2	Density of the discharge gas molecules
OMR	Ordinary magnetoresistance
Oe	oersted
P	pressure