**UNIVERSITI PUTRA MALAYSIA**

# ANNEALING EFFECTS ON THE MAGNETORESISTANCE CHARACTERISTICS- OF SPUTTERED FeNi-Cr GRANULAR MAGNETIC THIN FILMS

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# ANNEALING EFFECTS ON THE MAGNETORESISTANCE CHARACTERISTICS OF SPUTTERED FeNi-Cr GRANULAR MAGNETIC THIN FILMS

By

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# LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| $R_0$ | The resistance in the zero field |
| $R_H$ | The resistance in the magnetic field |
| $\Delta R$ | The difference between $R_0$ and $R_H$ |
| U(r) | Coulomb potential |
| $\varepsilon$ | Relative dielectric constant |
| R | Radius |
| q | Charged particle |
| x | FeNi composition |
| $\varepsilon_I$ | The energy of ions bombarding the walls |
| V | Potential |
| $V_a$ | Anode fall |
| $V_c$ | Cathode fall |
| X | Electric field strength |
| $\rho$ | Space charge densities |
| j | Current densities |
| $\Phi$ | Electric potential |
| $T_e$ | Temperature of electron |
| e | elementary charge |
| m | Mass of electron |
| M | Mass of ion |
| E | Electric field |

| | |
|---|---|
| $\Phi(x)$ | Potential profile |
| $r_{ce}$ | The gyration radius |
| $r_1, r_2$ | Radii of magnetic field line |
| $\theta$ | Scattering angle |
| w | Ring width |
| s | Sheath width |
| $\Delta 2\theta$ | The width of the peak |
| $V_p$ | Plasma potential |
| r | Radius |
| RF | Radio frequency |
| RT | Room temperature |
| $LN_2$ | Liquid nitrogen |
| Ar | Argon |
| W | Tungsten |
| Mo | Molybdenum |
| Ta | Tantalum |
| $\rho(\uparrow)$ | Spin-up resistivity |
| $\rho(\downarrow)$ | Spin-down resistivity |
| M | Magnetic layer |
| NM | Non-magnetic Layer |

| | |
|---|---|
| $H_c$ | Coercive field |
| $\lambda_s$ | Mean-free path |
| $f(V_\alpha)$ | Distribution function for the size of the granules magnetic moments of the granules |
| $\rho$ | Conductivity |
| n | The number of conduction electron per unit volume |
| CPP | Current perpendicular to the plane of the layers |
| c | The concentration of the granules |
| $a_0$ | The lattice constant of the granules |
| $\Delta^\sigma$ | Imaginary part of the self-energy of the conduction electrons due to impurity scattering |
| $M_\alpha$ | Magnetic moments of the granules |
| $H_a$ | Anisotropic field |

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# ANNEALING EFFECTS ON THE MAGNETORESISTANCE CHARACTERISTICS OF SPUTTERED FeNi-Cr GRANULAR MAGNETIC THIN FILMS

By

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**Faculty : Science and Environmental Studies**

The effect of the magnetic field and annealings on the magnetoresistance (MR) of two series of FeNi-Cr granular magnetic thin films deposited by radio frequency magnetron sputtering system in vacuum on a glass substrate is discussed. The first series consist of $(FeNi)_{40}Cr_{60}$, $(FeNi)_{42}Cr_{58}$ $(FeNi)_{52}Cr_{48}$, $(FeNi)_{55}Cr_{45}$ and $(FeNi)_{57}Cr_{43}$ whereas the second series consist of FeNi-Cr granular magnetic thin films prepared at various radio frequency power (40W, 50W and 60W). The first series of samples were annealed at 400°C and 450°C for one hour. These films were annealed again at 390°C for two hours to obtain larger MR values. The films of the second series of the samples were annealed at 400°C only. The structure, microstructure and percentage of composition of the films were characterized by using x-ray diffraction (XRD), Scanning Electron Microscopy (SEM), Energy Dispersive Analysis (EDAX) while the MR of the samples under the influence of the magnetic field was studied by a standard four point probe technique.

The structure of all the samples has been characterized by x-ray diffraction. The as-deposited and first annealed samples appear to be metastable where the halo pattern is prominent in all the graphs. After the second annealing, some prominent peaks are observed for certain samples. For the samples that have undergone two stages of annealings, after two annealings at 450°C for 1 hour and at 390°C for 2 hours, the peak of Ni [200] shifted to Ni [111] and Fe [110] at higher concentration of FeNi, resulting in further increase of MR .

However the MR does not saturate at 1 Tesla, the maximum field available in the laboratory, for all samples. When the FeNi concentration is increased, the MR is also increased. The maximum of MR, -0.63%, has been observed in the film with 57% FeNi after two annealings at 450°C for 1 hour and at 390°C for 2 hours.

The magnitude of MR is affected by the size and density of the magnetic entities which can be controlled by varying the composition and the preparation conditions. For application such as for the MR heads, a large MR ratio of about 2% due to a small applied field is desirable.

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# KESAN SEPUHLINDAPAN PADA CIRI-CIRI MAGNETORINTANGAN BAGI SAPUT TIPIS "GRANULAR" MAGNET FeNi-Cr DISEDIAKAN SECARA PERCIKAN

Oleh

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Kesan medan magnet dan sepuhlindapan pada magnetorintangan (MR) bagi dua siri saput tipis "granular" magnet FeNi-Cr , yang dimendapkan pada substrat kaca di dalam vakum dengan menggunakan sistem magnetron frekuensi radio dibincangkan. Siri pertama sampel itu terdiri daripada $(FeNi)_{40}Cr_{60}$, $(FeNi)_{42}Cr_{58}$, $(FeNi)_{52}Cr_{48}$, $(FeNi)_{55}Cr_{45}$ dan $(FeNi)_{57}Cr_{43}$, sedangkan siri kedua sampel itu terdiri daripada FeNi-Cr saput tipis "granular" magnet yang disediakan pada kuasa frekuansi radio yang berlainan (40W, 50W dan 60W). Siri pertama sampel disepuhlindap pada 400°C dan 450°C untuk satu jam. Selepas itu, saput tipis-saput tipis ini disepuhlindap sekali lagi pada 390°C untuk dua jam supaya memperolehi nilai-nilai MR yang lebih besar. Sementara, saput tipis siri kedua disepuhlindap pada 400°C sahaja. Struktur, mikrostruktur dan peratus komposisi saput tipis dicirikan dengan menggunakan pembelauan sinar-x (XRD), mikroskopi imbasan elektron (SEM) dan analisis serakan tenaga (EDAX) manakala MR sampel itu di bawah pengaruh kesan medan magnet, dikaji dengan menggunakan teknik penduga empat titik.

Struktur untuk semua sampel telah dicirikan dengan menggunakan serakan sinar-x. Sampel yang tersedia mendap dan yang telah melalui sepuhlindapan yang pertama, saput tipis-saput tipis "granular" itu adalah metastabil di mana corak "halo" adalah menonjol untuk semua graf. Selepas sepuhlindapan yang kedua, terdapat puncak- puncak yang menonjol untuk sampel-sampel yang tertentu. Bagi sampel-sampel yang melalui dua peringkat sepuhlindapan, iaitu selepas sepuhlindapan pada 450°C untuk satu jam dan 390°C untuk dua jam, puncak Ni[200] beralih ke Ni[111] dan Fe[110] pada komposisi FeNi yang lebih tinggi, seterusnya menyebabkan penambahan MR.

Walau bagaimanapun, untuk semua sampel, MR adalah tidak tepu pada 1 Tesla, iaitu medan magnet maksimum yang diperolehi di makmal. Apabila komposisi FeNi meningkat, MR juga bertambah. Bagi filem dengan 57% FeNi yang melalui dua sepuhlindapan, iaitu pada 450°C untuk satu jam dan 390°C untuk dua jam, MR yang maksimum adalah -0.63%.

Magnitud MR dipengaruhi oleh saiz dan ketumpatan entiti magneti yang boleh dikawal dengan membezakan komposisi dan keadaan penyediaan. Untuk penggunaan seperti penduga MR, MR yang besar sebanyak 2%, di bawah kesan medan magnet yang kecil adalah diperlukan.

# CHAPTER I

# INTRODUCTION

## Magnetic Thin Film

### Introduction to Thin Films

A thin film is a structure whose dimensions are such that it has a substantially large surface-to-volume ratio. For example, while the structure may be macroscopically large in length and width, it may have a thickness that is only on the order of a micron or less. Thin films do not have to be planar. The properties of such thin film structures are strongly influenced by the surface properties and may be very different from that of the same material in bulk form. The thin film may consist of a pure material, or a composite or a layered structure, and several of the thin films may be present in a more complex device (W. Kiyotaka, 1992).

### Multilayered Magnetic Thin Film

Giant magnetoresistance (GMR) was first observed in transition metal multilayers, in which antiferromagnetically coupled ferromagnetic layers are separated by non-magnetic interlayers (A. Tsoukatos, 1993). Theoretically the