Magnetotransport Properties of Co/Au Multilayers

Conrad Rizal
Department of Electrical and Computer Engineering,
University of British Columbia, Vancouver, BC, V6T 1Z4, Canada
Outline

- Introduction
- Experimental Methods
- Results and Discussions
- Conclusions
- Future Prospects
Introduction

- Research Background
  - Periodic Table
  - Electrical Resistivity and Magnetism

- Magnetoresistance (MR) Effects
  - Normal MR Effect
  - Anisotropic MR Effects
  - Giant MR Effects

- Mechanism MR Effects
  - Mechanism of AMR
  - Mechanism of GMR

- Magnetic Anisotropy Types
  - Natural Magnetic Anisotropy
  - Artificial Generation
Periodic Table

Eight elements are ferromagnetic, four at RT
Twelve are antiferromagnetic, one at RT
Electronic Configurations

Fe

\[1s^22s^22p^63s^23p^63d^64s^2\]

Co

\[1s^22s^22p^63s^23p^63d^74s^2\]

Ni

\[1s^22s^22p^63s^23p^63d^84s^2\]
Electrical Resistivity and Magnetism

Group 10
Pd [Kr] d^{10}
Ni [Ar] 4S^{2}d^{8}

Magnetoresistance (MR) Effect

A change in electrical resistance of the material due to an external magnetic field

- Normal magnetoresistance (NMR) effect
- Anisotropic magnetoresistance (AMR)
- Giant magnetoresistance (GMR)
  
  etc.
Anisotropic Magnetoresistance (AMR) Effects

Features: Magnetoresistance effect as a function of the direction of applied magnetic field and current.

\[ \rho = \rho_0 + \Delta \rho \cos^2 \theta \]

\[
AMR\% = \left[ \frac{R_\parallel(H) - R_\perp(H)}{R_\parallel(H) + R_\perp(H)} \right] \times 100
\]

<table>
<thead>
<tr>
<th>AMR</th>
<th>4s electron of the Ferromagnetic layers</th>
<th>Conduction Electrons</th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>H = 0</td>
<td>3d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H ≠ 0</td>
<td>4s</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Giant Magnetoresistance (GMR) Effects

GMR is exhibited mainly by multilayers, alloys and nanoparticles

\[ \%MR = \frac{R_H - R_0}{R_0} \times 100 \]

Features:
- Large MR as compared with AMR
- Independent of direction of magnetic field
- Independent of direction of current

<table>
<thead>
<tr>
<th>Conduction Electrons</th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMR</td>
<td>H = 0</td>
</tr>
<tr>
<td></td>
<td>H ≠ 0</td>
</tr>
<tr>
<td>4s electron of the non-magnetic layers</td>
<td>Ferro</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Magnetic Anisotropy

Direction dependence of magnetization

Diagram showing the direction dependence of magnetization with magnetic fields parallel (H // e.a.) and perpendicular (H ⊥ e.a.) to the easy axis (e.a.).
Natural Magnetic Anisotropy

Material Characteristics

- Crystal Magnetic Anisotropy
- Shape Anisotropy

Graphs and diagrams illustrating magnetic properties of Fe and Co, showing magnetic moments and crystal structures.
Artificial Generation of Magnetic Anisotropy

Artificial Generation

- Oblique Incidence Deposition
- Magnetic Annealing
- Application of High Magnetic Field
- Application of Strain on Film

Electromagnets

Heater  H  Sample
Applications

✓ In Computers-
  ✓ Read head sensors; significantly improved storage density.

✓ In magnetic field sensing
  ✓ Detection of magnetic field-
    Measurement of field strength

✓ In Automobile sector
  ✓ Automation Control, e.g., detection of incremental increase of vehicle speed.

✓ In medical science
  ✓ Registering cardio-respiratory activity
  ✓ Biosensor-magnetic nanoparticles for detection of biomolecules based on magnetic resonance effects.

✓ To be explored.....
Objectives

- To induce magnetic anisotropy by changing incident angle of evaporation and magnetic annealing
- To compare giant magnetoresistance (GMR) effects of isotropic (randomly oriented) and anisotropic (uniaxially oriented) multilayer films.
Sample Preparation and Measurement

- **Sample Preparation**: E-beam
- **Substrate**: Glass
- **Substrate Temp.**: Room
- **Film Thickness**: Crystal oscillator
- **Vacuum Pressure**: $1 \times 10^{-6}$ [Torr.]
- **Deposition Speed**: $1\,[Å/\text{sec.}]
- **Deposition Angle**: $0,\,45°$
- **Annealing Temp.**: $250\,[\text{℃}]$
- **Magnetic Field**: $3 \,[\text{kOe}]$

- **Composition**: Energy Dispersive Micro-probe Analysis
- **Magnetoresistance**: DC four Probe Method (0-21 kOe)
- **Microstructure**: X-ray Diffractometer
- **Magnetic Properties**: Vibrating Sample and Torque Magnetometer

A torque meter

DC four Probe Method

Measurement in various configurations
Magnetization Curves

\[ \theta = 0 \]

\[ \theta = 45^\circ \]

Magnetic Fields (kOe)

Substrate

vapor
Magnetic Anisotropy from Torque Measurement

\[ E_A = K_u \sin^2 \theta \]

\[ T = -\frac{\partial E_A}{\partial \theta} = -K_u \sin 2\theta \]

- A torque magnetometer was designed to measure magnetic anisotropy.
- A sample in the form of a disc was suspended in the magnetic field.
- A torque curve as a function of the measurement angle was derived.
- Torque \( T \), which is a derivative of the anisotropy energy, corresponding to the easy axis (EA) energy, \( E.A. = K_u \sin(2\theta) \) is given by, \( T = -\delta E_A/\delta \theta = -K_u \sin(2\theta) \).
- This measurement validates the anisotropic behavior of these multilayer films.
Film Periodicity Analysis

\[ 2D \sin \theta = n \lambda \]

\[ D = 3.7 \text{ nm} \]

\[ 2\theta = 2.86 \]

Bragg’s law

Graph showing intensity (Arb.) vs. 2\( \theta \) (deg) for Au and Co layers with a peak at 2\( \theta = 2.86 \) degrees.
Thickness Dependence of MR Ratio

Au layer dependence of MR ratio for:
(a) Isotropic Samples
(b) Anisotropic Samples

Field dependence of MR ratio for:
(a) Isotropic Samples
(b) Anisotropic Samples
AMR and GMR Contributions

Field dependence of MR ratio

AMR and GMR contributions

Conclusions

- Uniaxial magnetic anisotropy is induced due to the effect of oblique incidence evaporation and magnetic annealing.

- Co/Au multilayer films exhibited GMR effect and the value is up to 2 % at room temperature.

- The observed value of the coercive force, $H_c$, is in the range of 0.2 Oe.

- The multilayers have been considered useful for potential application as magnetic sensors in anti-lock brake system, magnetic field and electric current measurement, bioassay and testing.
A scheme of electronics using spins degrees of freedom, a new superior device can be fabricated.

Possible outcome of the research project can vary one or many of the followings as:

a. GMR Sensor with high sensitivity
b. High magnetic moment nanoparticles
c. Nano wires for nano-electronic device applications
d. Integration of (a) GMR sensor (b) and high moment nanoparticles with the human cells to detect symptoms of chronic diseases at their early stage.
Acknowledgements

Department of Information and Electronic Engineering, Kyushu University

Faculty of Applied Science, University of British Columbia
Thank you.

Any Questions?