Ferromagnets on semiconductors

Electrodeposited Ni, Co, Fe on GaAs(011), GaAs(001)

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Made use of NSF MRSEC DMR-98-09423
Spin-dependent transport materials

- Spin valve
- Magn. tunnel junction
- GMR multilayer
- CIP
- CPP
- Domain wall resistance
- Spin transistor
Electrodeposited Ni, Co, Fe on GaAs

Experimental

Galvanostat

MeSO₄ 0.1 M, pH 2.5 - 4

Growth
- n-GaAs (001), (011) -10¹⁷ cm⁻³ Te
- Back contact: Ga/In eutectic
- Graphite counter electrode
- EG&G 273A Galvanostat
- Room Temperature
High angle XRD spectra

- Samples were tilted by 0.2° -0.4° to reduce GaAs peaks from the substrate.
- Rocking curve width 2.6° -3.2°

- Diffraction peaks corresponding to bcc Fe (epitaxial or textured) were observed.
Glancing angle XRD – $\Phi$ scan

**Four-fold symmetry**

- Epitaxial relationship
  - Fe(001)[100] // GaAs(001)[100]
  - Fe(011)[100] // GaAs(011)[100]

**Two-fold symmetry**

- Minor peaks at 60° intervals indicate possible twinning
FMR measurement (Y. Ding and C. Alexander Jr.)

<table>
<thead>
<tr>
<th>n-GaAs orientation</th>
<th>Electrolyte (0.1 M)</th>
<th>K_u/M_s (Oe)</th>
<th>K_L/M_s (Oe)</th>
<th>4πM_s + 2K_p/M_s (Oe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(001)</td>
<td>FeSO_4</td>
<td>136 ± 4</td>
<td>4 ± 3</td>
<td>20740 ± 40</td>
</tr>
<tr>
<td>(001)</td>
<td>FeCl_2</td>
<td>46 ± 5</td>
<td>7 ± 5</td>
<td>19830 ± 60</td>
</tr>
<tr>
<td>(011)</td>
<td>FeSO_4</td>
<td>151 ± 4</td>
<td>29 ± 3</td>
<td>20500 ± 30</td>
</tr>
<tr>
<td>(011)</td>
<td>FeCl_2</td>
<td>100 ± 4</td>
<td>33 ± 4</td>
<td>20110 ± 30</td>
</tr>
</tbody>
</table>

- Fe/GaAs(001) : mostly magnetocrystalline anisotropy.
- Fe/GaAs(011) : magnetocrystalline anisotropy + uniaxial anisotropy.
- magnetocrystalline anisotropy: FeSO_4 > FeCl_2

THE UNIVERSITY OF ALABAMA
Center For Materials For Information Technology
An NSF Materials Research Science and Engineering Center


Electrodeposited Ni, Co, Fe on GaAs

Interface intermixing: XPS analysis

- No Ga, As at the surface
- No or little diffusion at interface

GaAs

Ni

mfp @370eV (Ga 2p) 0.75nm
mfp @1444eV (As 3d) 1.9nm

Ga 2p

6nm 0°

As 3d

6nm 0°

6nm 40°

14nm 0°

binding energy (eV)

intensity (arb. units)

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Electrical and magnetic measurements

Fuchs model:
\[
\rho(T) = \rho_\infty + \frac{(3/8)(1-p)(\rho_\infty \times l_\infty)}{T}
\]
with the bulk resistivity \(\rho_\infty\), the bulk mean free path \(l_\infty\), the “reflectivity” coefficient \(p\)

\(\rho_\infty = 12.8 \, \mu\Omega \text{cm}\)

No or little intermixing at the interface
1. Interface XPS analysis (As, Ga diffusion)
2. Resistivity measurement ($\phi_{e0}$, n)

Repeat procedure after annealing sample at 100°C, 200°C, 250°C,…

**Schottky I-V Characteristics**

- I-V characteristic:

\[
J = A * * T^2 e^{-q(\phi_{e0})/k_BT} e^{qV/nk_BT} \left[1 - e^{-qV/k_BT}\right]
\]

- Fit data $\phi_{e0}$, n (assuming **thermionic** emission only)

\[
\ln[J/[1-\exp(-qV/k_BT)]] = C_1(\Phi_{e0}) + C_2(n)V
\]
\[ \ln\left[\frac{J}{1-\exp\left(-\frac{qV}{k_B T}\right)}\right] = C_1(\Phi_{e0}) + C_2(n)V \]
Electrical and magnetic measurements
Schottky barrier

Correlation between interface interdiffusion and Schottky barrier height
Photo-induced electrodeposition

Principle:

- $e^-$ are photo-excited from V.B to C.B and contribute to the conduction process.

Electroless deposition of Cu occurs only where laser shines on p-Si. w/ or w/o the mirror.
Light induced ECD of Cu on p-Si

Bulk + Surface charge carrier diffusion

Laser focus spot size 1 – 2 µm
Photo-induced electrodeposition

Structure size given by electron diffusion in the semiconductor

Structure size reduced by:
- shorter wavelength
- lower intensity
- $e^-$ mfp and carrier lifetime in semiconductor
Electrodeposited Ni, Co, Fe on SC

Self-aligned patterning

→ Selective deposition on n-type GaAs and Si
Electrodeposited Ni, Co, Fe on SC
Self-aligned patterning on p/n-GaAs

direct lithography through: local doping
Electrodeposited Ni, Co, Fe on SC Co nanowire on cleaved n-Si
Future work:

- Electric characterization of interfaces
  Spin injection, Schottky barrier

- Preparation and analysis of electroplated nanostructures
  Decrease dimensions of side plated wire
  Electrical characterization