Spin transport using optically injected spin electrons

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Dilute Magnetic SC
Advantages: No conductivity mismatch, high spin injection efficiency has been demonstrated
Drawbacks: Low Curie temperatures and/or high magnetic fields required

FM metals
Advantages: well-known Materials, operation at room temperature and low magnetic fields possible, low resistance
Drawbacks: Spin injection and detection efficiencies observed so far are small


1. Can the electron spin be preserved upon transport across the FM/SC interface at RT.?

2. How important are the details (morphology, composition, defects, etc) of the interface structure?

3. Can FM metals act as efficient spin injectors/detectors (conductivity mismatch)?

Injected electron spin polarisation $S$ is determined from the circular polarisation of the electroluminescent light.

Schottky Barrier

$S \sim 2\%$ for Fe/GaAs at RT

$S \sim 32\%$ for Fe/AlGaAs at 4.5 K

Artificial Tunnel Barrier

$S \sim 9\%$ for CoFe/AlO$_x$/AlGaAs at 80K

$S \sim 55\%$ for CoFe/MgO/AlGaAs at 100K
Optical Spin injection using circularly polarized light

The transition selection rule
$$\Delta m_j = \pm 1$$

- For $h\nu > E_g + \Delta$, $P$ decreases due to the mixture of $P_{3/2}$ states with $P_{1/2}$ states, which have an opposite sign of polarization to $P_{3/2}$ states.

- Although the maximum polarization is expected to be 50% in theory, the maximum is experimentally observed to be $\sim 40\%$ at the threshold.

Identifying the True Spin Filtering Signal in FM/GaAs Schottky Barrier Structures

- True spin filtering signal $\Delta I_{SF} = \Delta I - \alpha I_{ph}$
- Bias and GaAs doping density dependence of $\Delta I_{SF}$ suggest that electron tunneling is the relevant spin dependent transport process

### Future works

**Study of tunneling polarisation through optical injection**

- High efficiency of spin-polarised electron transport into the MTJ structure; *systematic investigation of tunneling process & relaxation mechanism*

- Observation of Quantum-Well states in FM layer

**Resonant tunneling through optical injection**

- Quantum oscillation along the voltage change

- Comparison (QW in FM & NM layer)
Future works

**Direct measurement of true spin filtered current in window type samples**

- True spin filtered photocurrents from window type sample; *estimate of MCD factor, real spin device*
Cavendish-KAIST Symposium, Spintronics, Daejeon 2006

Room temperature spin detection in ferromagnetic metal/$\text{Al}_2\text{O}_3$/GaAs heterostructures


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Different charge transport mechanisms contribute to the net measured photocurrent, depending on the applied bias.

Magnetic circular dichroism (MCD) in the FM layer could obscure or even mimic any real spin filtering effect.
Spin Polarized Electron Transmission in Schottky vs Artificial Tunnel Barrier Structures

For n-type SC with $V \geq 0$, there is transmission.

For p-type SC, there is no transmission.
The Tunnel device of NiFe/Al₂O₃/p-typeGaAs Structure

- Well defined interface control and high efficient spin transport
- Micro-fabrication process
- He-Ne laser energy: 1.96 eV
- Energy gap of GaAs: 1.43 eV
- Tunnel barrier height: ~1.2 eV
Optical Spin Injection and Electrical Detection Set Up
Interface characteristics in NiFe/Al₂O₃/p-type GaAs Structures

- Well defined interface due to Al₂O₃ tunnel barrier
- The contribution of the electron and hole current generated by photoexcitation
- The electron transport mechanism change from tunneling process to thermionic emission with applied forward bias (with respect to NiFe layer)
Spin filtering in NiFe/Al$_2$O$_3$/p-type GaAs Structures

$\Delta I = p(i^+-i^-)$ under circularly polarized light

- $\Delta I$ is proportional to the magnetisation of NiFe layer
- Saturated $\Delta I$ due to thermionic emission under high applied forward bias.

$W = \sqrt{\frac{2eS}{qN_D}(V_{bi} - V)},$
Evaluation of MCD and True Spin filtering in NiFe/Al₂O₃/p-type GaAs Structures

$$\Delta I_{SF} = \Delta I - \Delta I_{MCD}$$

$$\Delta I_{MCD} = \alpha I_{ph}$$

- $\Delta I_{SF}$ peak heights around 0.55 V due to the optimised electron tunneling process.

- MCD factor $\alpha$ and $\Delta I_{SF}$ curves reveal that tunneling effect is strongly dependent on the magnetisation of NiFe layer.

- the obstacle to develop a real spin device
Summary and Outlook

Spin filtering of electrons transmitted across the NiFe/Al₂O₃/p-type GaAs interface is observed at forward bias at room temperature.

Only tunneling electrons show significant spin dependent transmission as in earlier experiments on n-type GaAs → in the structure based on p-type GaAs the depletion region should be modulated to realize high efficiency of spin tunneling.

Critical issues for the exploitation of the observed effect in spintronic devices are

- a deeper understanding of the underlying theory
- control of the FM/SC interface properties (incl. barrier layer)
- optimisation of the details of the SC structure
- new structure to exclude MCD from measured helicity dependent photocurrent
Spin Filtering in FM/AlGaAs Barrier/GaAs Structures

$\Delta I$ (nA) vs. Bias (V)

- $T = 320$ K: $\alpha = 0.112\%$, $P_{\text{eff}} = 0.019\%$
- $T = 240$ K: $\alpha = 0.149\%$, $P_{\text{eff}} = 0.070\%$
- $T = 160$ K: $\alpha = 0.171\%$, $P_{\text{eff}} = 0.086\%$
- $T = 80$ K: $\alpha = 0.185\%$, $P_{\text{eff}} = 0.107\%$

$i^+ \& i^-$ due to the spin split DOS in the FM

- Electron tunneling is the spin dependent transport process at the FM/GaAs interface