Spin Effects in Organic Semiconductors

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Magnetism and Spintronics study at WPL

- Preparation of bulk and thin film samples
- Structural characterization – XRD, AFM
- Magnetic Measurements (also under light and electric field)
- Transport and Magneto-transport Measurements
- Fabrication of Spintronic components (in collaboration with ÅA and MIT)
- Characterization of Spintronic components
Spintronics

Spin Valve Open
Current High

Spin Valve Close
Current Low

Ferromagnet 1
Spacer layer
Ferromagnet 2

Spin up spin down
one type of carrier scattered, low resistance

spin up spin down
both types of carrier scattered, high resistance
Spin injection, transport and detection

- Spin polarized Injection

- Spin polarized transport

- Spin polarized detection
Spin injection – Half metals

- **Advantages:**
  - Half metals (LSMO) have very high net spin polarization ~ 100%
  - Stable oxides
  - Lesser conductivity mismatch

- **Disadvantages:**
  - Lower Tc and loss of spin polarization at the surface
  - Surface roughness

- **Solutions:**
  - Higher Tc half metals (SFMO)
  - Reducing surface roughness by optimization of thin film growth parameters
  - Protecting the surface

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Spin transporter

- Spin-flips mainly due to –
  - Spin-Orbit interaction: Interaction between electron spin magnetic moment and orbital angular momentum.
  - Hyperfine interaction: Interaction between electron spin and nuclear spin.

Both effects are stronger for heavier atoms

Organic molecules: Lighter atoms, better alternative
Organic Semiconductors

- Advantages - chemical tuning of electronic functionality.
- Easy structural modification.
- Ability of self assembly.
- Mechanical flexibility.
- Large Area and low cost electronic applications.
- Thin film technology does not require high temperatures and lattice matching.

- Challenges – unstable in air
- Highly resistive
- Reproducibility
Hybrid spintronics – best of both world

- Half metallic spin injectors – La$_{0.7}$Sr$_{0.3}$MnO$_3$, Sr$_2$FeMoO$_6$

- Better spin transporting materials – organic semiconductor small molecules, Polymer, Graphene, Carbon nanotubes

- Different spintronic components – spin valves, magnetic tunnel junctions, magnetic sensors, spin LEDs, spin transistors and ....
Organic Spintronics

- Organic spin valves
- Organic magnetic tunnel junctions
- Organic magneto resistance in OLED
Organic Spin-valves

Organic Spin-valves

Polymeric Spin-valves

- Room temperature operation of Organic spin valves.

Spin injection in Organics

• To achieve significant spin-current injection, the OS must be driven far out of local thermal equilibrium by an electric current.
• If the injecting contact has metallic conductivity, its electron distribution cannot be driven far from thermal equilibrium by practical current densities.
• Quasi-equilibration between the conjugated OS and the metallic contact must be suppressed to achieve effective spin injection.
• This requires a spin-dependent barrier to electrical injection that may be either due to tunneling through the depletion region of a large Schottky barrier or due to tunneling through a thin, insulating, interface layer.

The FM-Organic interface

The FM- Organic interface

- Introduction of Alq3 on LSMO creates a strong interface dipole of 0.9 eV.

- Energy level shift of Alq3 with respect to the vacuum level makes electron injection into Alq3 more favorable than hole injection.

- Interface of Alq3/Co on the detector side of the SV show a shift of about 1 eV.

Irrespective of the spin injecting electrode, the SV response with increased temperature decreased substantially.

Spin polarization is lost at the LSMO/OS interface.

Loss of injection with temperature

- OS Small molecules also showed similar temperature dependence of SV response.
- Spin polarization is lost at the LSMO/OS interface.
Spin transport and relaxation

- SP carriers injected into the OS, travel by drift and diffusion under the influence of an electric field.

- During transport, the SP carriers interact with their environment (trapping, spin precession around a local hyperfine field) and their initial spin direction is lost.

- Different spin relaxation length in OS is reported.

- The effect of disorder and impurity of the OS can play a major role.

Effect of impurity on spin transport

Spin detection

- Depending on top electrode penetration in OS, MR response changed substantially.
- Two spin transport channels were detected.
- For improved performance it is essential to have a well-defined interface.

Sizable Room-temperature TMR response was observed.

SP tunneling transport measurement showed more than 35% spin polarization of the Py/OS interface and spin injection in OS.

13 nm spin relaxation length in OS small molecule Rubrene was measured.

LSMO based organic MTJs

- LSMO/Alq$_3$/Co nano MTJ
  - 300% TMR with high bias and temp. dependence
  - TMR vanishes beyond 50 mV and 150K
  - Reproducibility - 65% working samples
- Among those, 20% showed measurable magnetoresistance from 10 to 300%.

C. Barraud et al., Nature Phys.6, 615 (2010)
LSMO based organic MTJs

- **LSMO/Rubrene/V(TCNE)$_x$**
  - ~2 % TMR at 100 K with high bias and temp. dependence
  - Below 100K, too high junction resistance
  - ~1% TMR reported till 150K

- **LSMO/LaO/Rubrene/Fe**
  - ~10 % TMR with high bias and temp. dependence at 10 K
  - Above 200 K, TMR vanished

*(J-W.Yoo et al., Nature Mat. 9, 638 (2010))

*(J-W.Yoo et al., Synth Mat. 160, 216 (2010))
LSMO based organic MTJs

- LSMO/Rubrene/Co MTJ
- ~8 - 14% TMR observed at low temperature
- Bias dependence is not consistent from device to device
- Measurable TMR was observed at least until 150 K
- LSMO thickness plays a big role in the TMR response of the MTJs

(Majumdar et al., Unpublished)
MR without FM electrodes - OMAR

Conclusions and future research

Due to small spin orbit coupling and hyperfine interaction OS are promising as spin transporting materials.

Spin injection and transport have been successfully demonstrated in organic spintronic devices.

Any defect in the OS layer can modify the spin transport properties significantly.

Search is ON for higher spin injecting electrode and better spin transporter like carbon nanotubes and graphene.
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Thank You