Chiral-based simple spin devices

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Quantum Nano Engineering Lab

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Lecture Synopsis

- Quantum effects at room temperature?
- Chiral induced spin selectivity effect (CISS)
- CISS based devices
Toward RT Quantum Machines

• Implementation of room temperatures quantum devices
• Room temperature quantum coherence
• Very hard to achieve but we can use a mix of quantum and classical approach

Meeting between Top-down to Bottom-up

Controlled Coupling
The Tool Box

Controlled quantum engineering
Nano crystals (NC) and/or NV Centers in Nanodiamonds

NV - Energy levels are independent of nanodiamonds’ sizes

NV- No charge transport

(ZPL=zero phonon line)

NC – controlled charge and energy transfer

NC – Size distribution influence strongly the energy spectrum

Fedor Jelezko, Alex Retzker

Banin and MK nano
Controlled Coupling

[Diagram showing controlled coupling between different materials]
Self Assembly Monolayer/ Multi-layers

Molecules can be adsorbed on different substrates.

The molecules consist of a *Head Group* and a *Tail Group*.

At the initial step fast adsorption occurs.

At the second step the monolayer organizes slowly.
Selective Adsorption

(a) 

(b) 

500 nm 

5 µm 

500 nm 

200 nm
Hybrid based spintronics
Spin Electronics
Electrons have charge and spin 1/2

• Conventional electronic devices ignore the spin property and rely strictly on the transport of the electrical charge of electrons

• Adding the spin degree of freedom provides new effects, new capabilities and new functionalities
Why Spin?

• Energy and heat - For Spintronics, less energy

• Quantum effects - It may be a way for introducing the spin properties to our tool arsenal.
Spintronics Devices

The 2007 Nobel Prize in Physics was awarded to: Albert Fert and Peter Grünberg for the discovery of GMR.
Chiral based spintronics
What do we have to contribute

• Simple and easy to process

  Small  Cheep  Si compatible

From industrial point of view lets take existing magnetic devices and improve them with our CISS effect
The CISS effect

Spin Selectivity in Electron Transmission Through Self-Assembled Monolayers of Double-Stranded DNA

Spin-dependent electron transmission through bacteriorhodopsin embedded in purple membrane

Spin-selective transport through helical molecular systems

SOC is the main cause for CISS
The CISS effect

The CISS effect - Chiral induced Spin Selectivity.
Chirality Induced Spin-selectivity (CISS) effect
Spin dependent transport through double stranded DNA

Chiral Induced Spin Selectivity - CISS

Zuoti Xie, Tal Markus, Sidney Cohen, Zeev Vager, Rafael Gutierrez, Ron Naaman
Magnetic Memory WO Magnet Embedded/MRAM
Memory devices

Fast but need constant power

**DRAM** - Dynamic random-access memory
refreshed periodically

**SRAM** - Static random-access memory
Does not need to be periodically refreshed

Slow last for 10 years

**Flesh memory**

All existing memory technologies challenged when critical size is smaller than 45 nm

**We want:**

*No constant power, long lived, fast, standard technology*
The Charily Molecular based Universal memory

- Fast
- Dense
- Non-Volatile
- Power efficient

The industry needs are met without compromising in cost, compatibility to standard Si process & complexity of design.
Embedded Memory

Embedded memory is integrated on-chip memory that supports the logic core to accomplish intended functions.

Why is it good??? high-speed and wide bus-width capability, which eliminates inter-chip communication.
The Memristor

Fundamental circuit element, forming a non-linear relationship between electric charge and magnetic flux linkage

The missing memristor found
Dmitri B. Strukov, Gregory S. Snider, Duncan R. Stewart & R. Stanley Williams; HP Labs Nature 453, 80-83 (1 May 2008)
Reading

1 cell

0 cell

Ferromagnetic layer

Spin filter

Hi resistance

Low resistance

+Low V
+Low V
Erase

Filter effect disappears at hi current

Hi current

+Hi V

1 cell

0 cell

Ferromagnetic layer
Method

Sample Preparation

Pre-adsorption
- Optical lithography

Adsorption
- 1/5/10mM on 40x50 um² adsorption areas

Post-adsorption
- Al₂O₃ is evaporated in two sessions: 4-5nm followed by 2nm →
  - reduces pinholes
  - Evaporation of Ni 30nm
Si based CISS devices

Low-power silicon based spintronic transistors with chiral molecular spin filter

Potential difficulty- pin-holes in the organic monolayer.
The problem was solved by evaporating thin layer (3-5 nm) of AlOx on top of the organic monolayer.

*Nature Communications* 4, 2256 DOI: 10.1038 (2013).
Memory writing at low temperatures

*Nature Communications* 4, 2256
DOI: 10.1038 (2013).

Highlighted in Nature
"Nanotechnology: A memory device with a twist" 7.8.2013
http://www.natureasia.com/en/research/highlight/8613

*Magnetization of the device at 2K*
Dual direction writing
Spin filter not spin polarizer?
Memory effect on a Real Device

Memory effect. Writing the at -15V reading at lower voltage. For the same direction of current the resistance is high and low for the opposite direction of current

Breakthrough in memory technologies could bring faster computing, smaller memory device


*Nature Communications 4, 2256 DOI: 10.1038 (2013).*

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http://www.natureasia.com/en/research/highlight/8613
Light induced device
Methods

Optically induced charge transfer device

Ni-based Hall effect device (anomalous HE)

532nm Circular Polarized Beam

CdSe QD (610nm) 
α-Helix L-Polyalanine 36C
Calibration

\[ n = \frac{B_z I_x}{V_{xy} t e} \]

\[ \Rightarrow n_{\text{experiment}} \sim 10^{27} \text{ electrons / Meter}^3 \]

\[ n_{\text{theory}} \sim 5 \cdot 10^{26} \text{ electrons / Meter}^3 \]
Optical CISS

- Comparing the right hand circular polarization and left hand circular polarization with the same linear polarization.

One order of magnitude difference – Spin detector
Results

Nano letters 14 6042 (2014).

\[ \Delta \rho_{xy}(\text{RCP-LCP}) \text{ [p}\Omega\text{cm}] \]

- \( \alpha \)-Helix Polyalanine
- MPS

T = 50K
Results

Nano letters 14 6042 (2014).

Methods

Highly localized magnetization device •
(measured with MFM)

532nm Circular Polarized Beam

CdSe QD (610nm)
α-Helix L-Polyalanine 36C

5nm Au
1.5nm Co

Optically induced charge transfer device

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Results

Nano letters 2014

Topography

Illuminated area in illuminated sample

Unilluminated area in illuminated sample

Illuminated area in reference sample (no Molecules & no NC)

Magnetism
Magnetic Nano Memristor
Spin Based Memristor

![Graph and images related to Spin Based Memristor]
Additional related work

Local charge separation - 532 nm room temperature

Vertical injection to spin torque transfer devices

Chiral based surface superconductivity
CISS Future Applications

- Magnetic memory
- Spin transistors
- 3D spin logic
- Charge separation
- Local EMR
Changing the world of memory device as we know