Chiral-based simple spin devices

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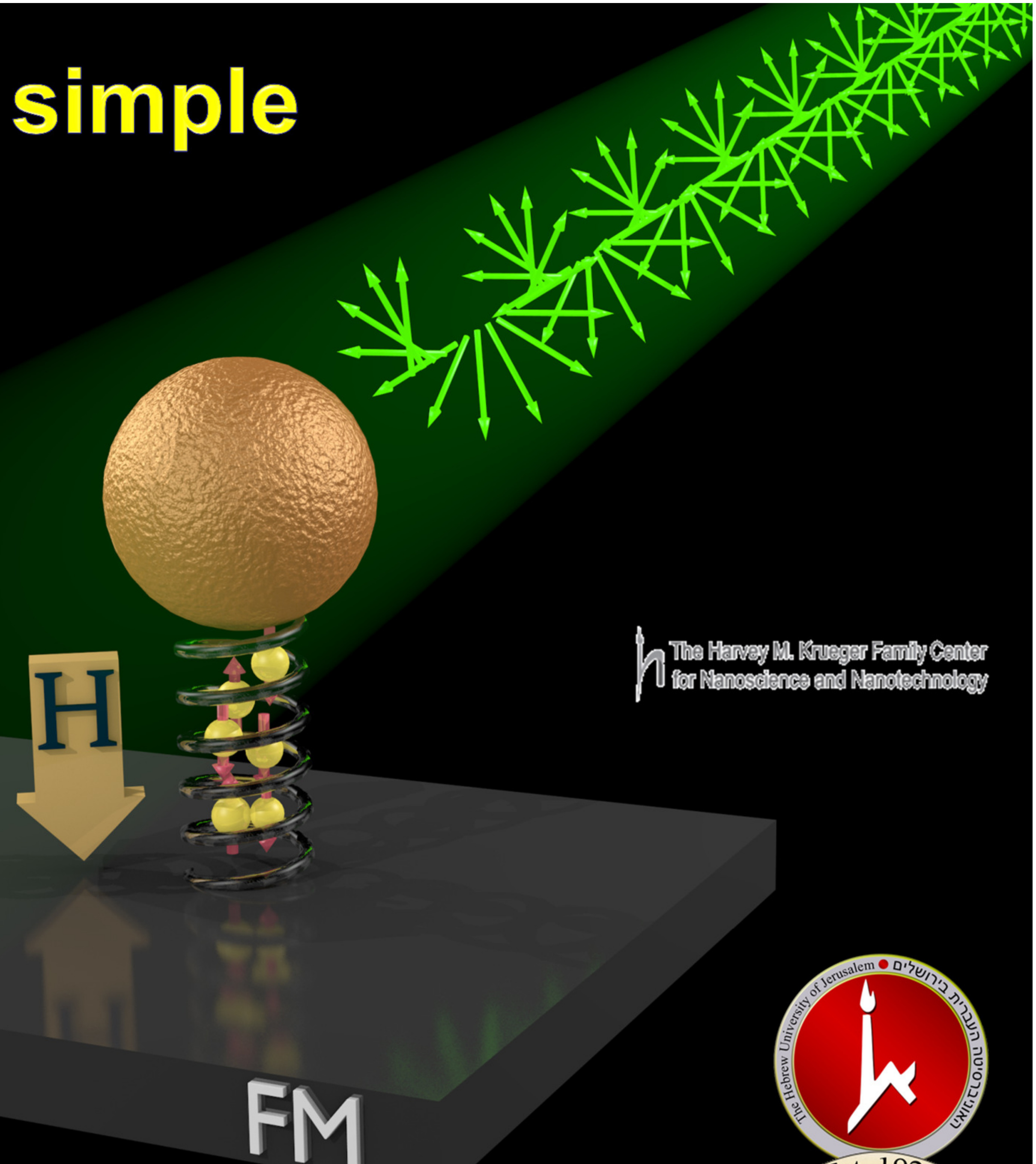
30.11.14



The Harvey M. Krueger Family Center for Nanoscience and Nanotechnology

QNE Lab

Quantum Nano-Engineering Lab

The Hebrew University of Jerusalem האוניברסיטה העברית בירושלים Est. 1925

Many thanks to

Our Group: Dr. Shira Yochelis, Eyal Cohen, Eran Katzir, Avner Neubauer, Guy Koplovitz, Oren Ben Dor, Ido Eisnberg, Ohad Westrich, Matan Galanty. Nir Peer, Chen Alpern; Amir Ziv, Aviya Perlman Illouz, Kuti Uliel

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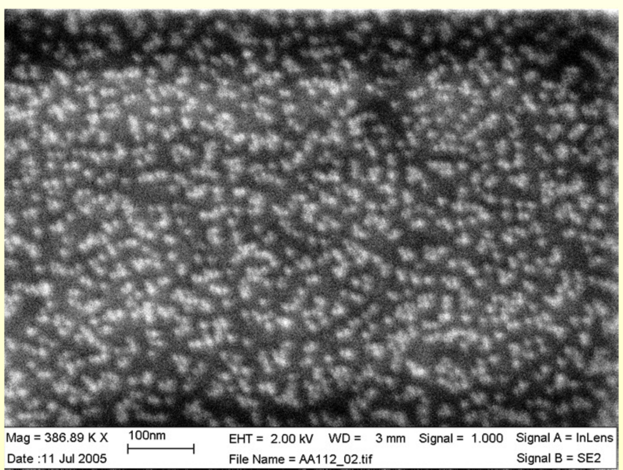
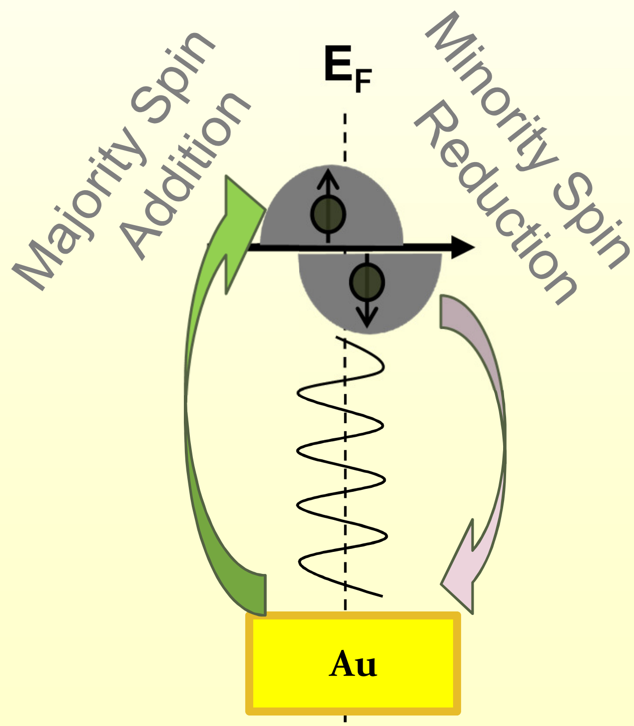
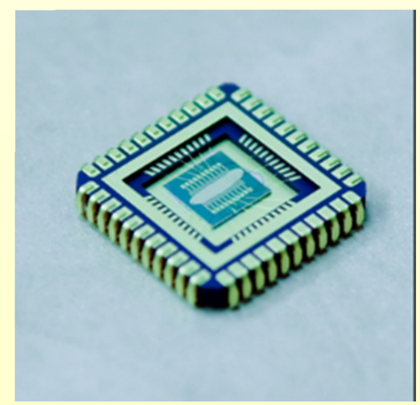
Financing:, ISF, ISF-BICORA, DARPA, MOD, Israel Taiwan, Magneton Capital Nature , FTA , Peter Brojde center, Volkswagen, Leverhulme

Lecture Synopsis

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



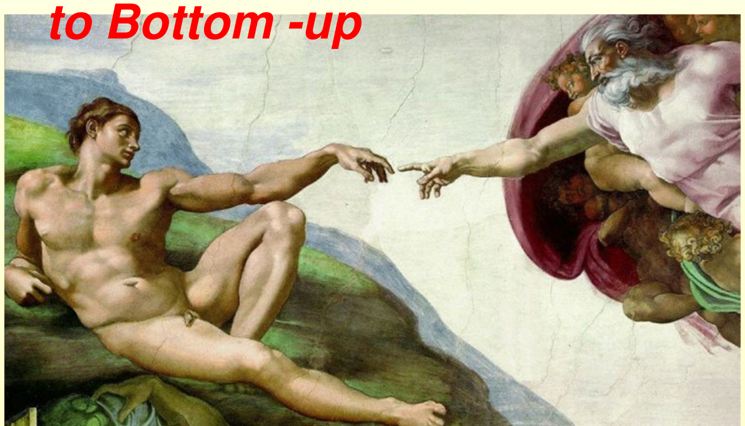




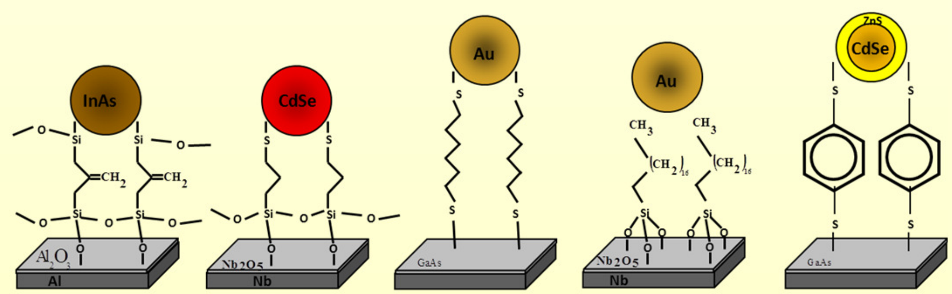
Toward RT Quantum Machines

- 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



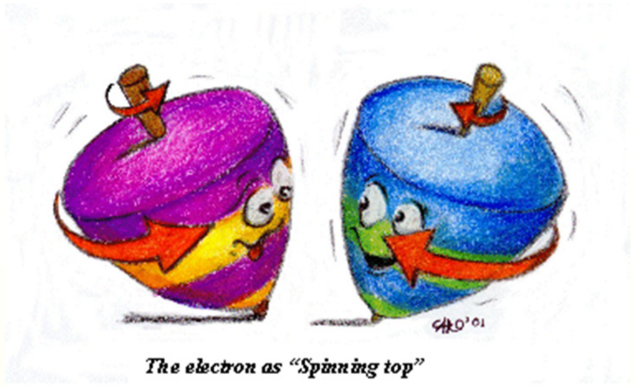
Spin Electronics

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

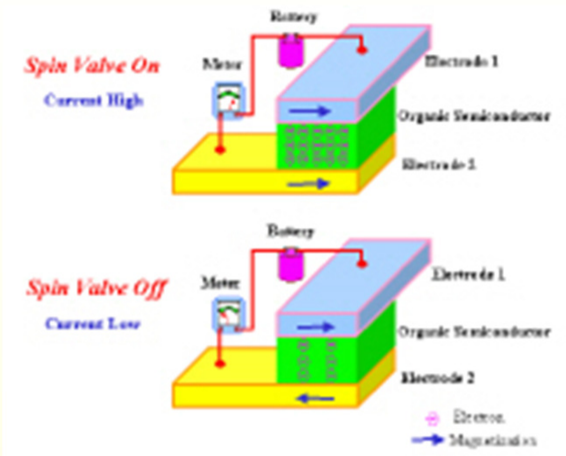
Why Spin?

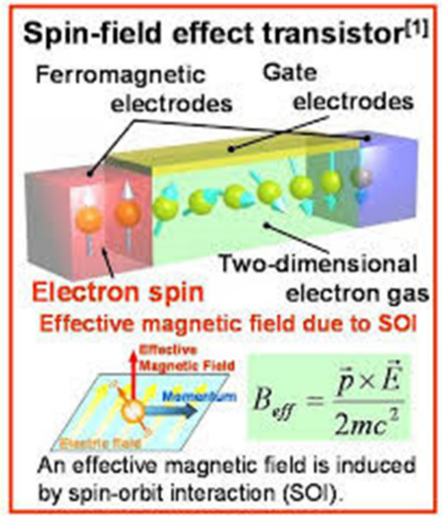


- **Energy and heat**- For Spintronics, less energy

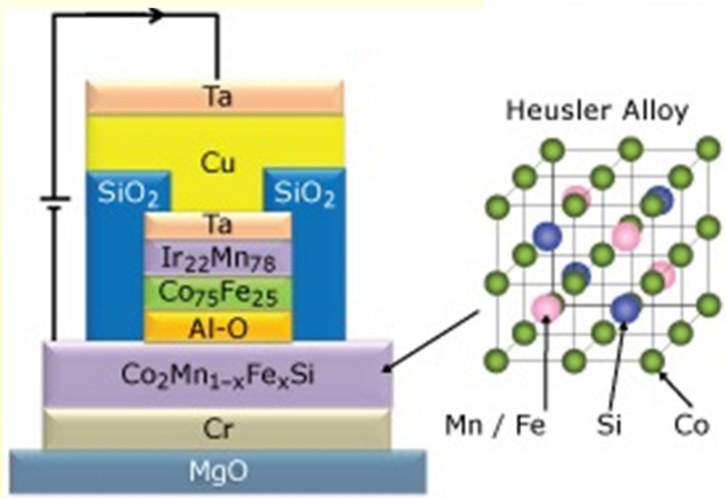
- **Quantum effects** -It may be a way for introducing the spin properties to our tool arsenal.

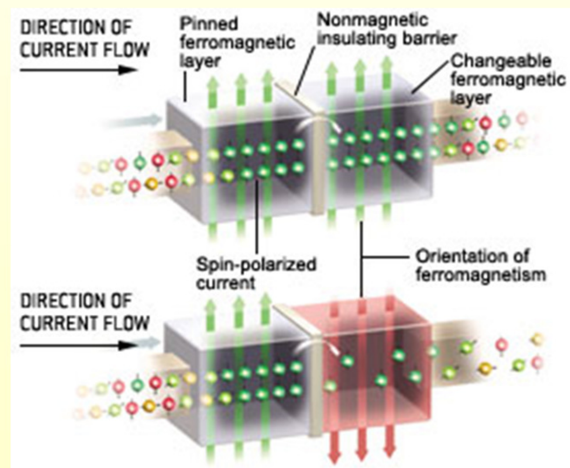
Spintronics Devices





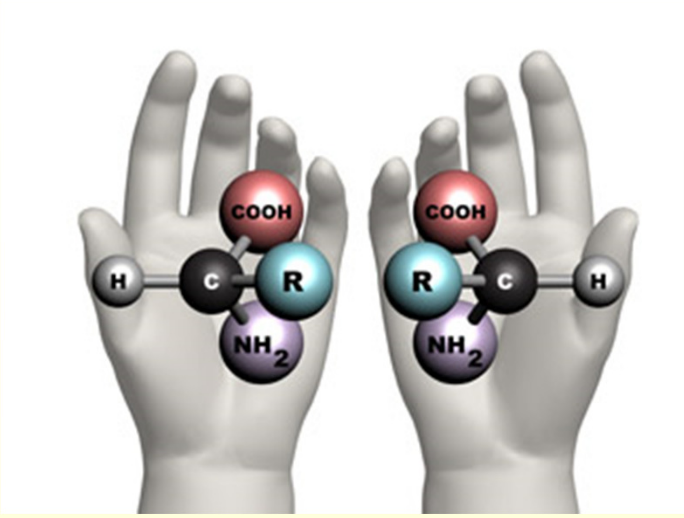
The 2007 Nobel Prize in Physics was awarded to :
Albert Fert and Peter Grünberg
for the discovery of GMR

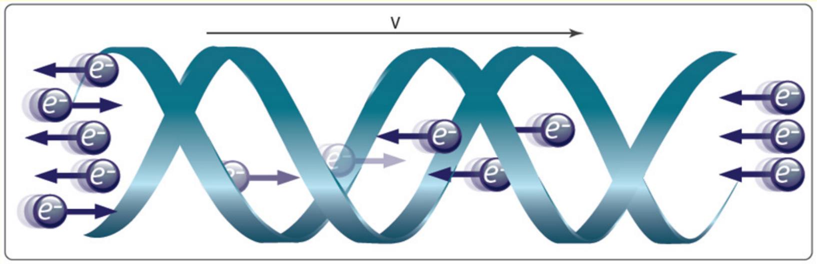




 Quantum Nano Engineering Lab 12/29/2014

Chiral based spintronics





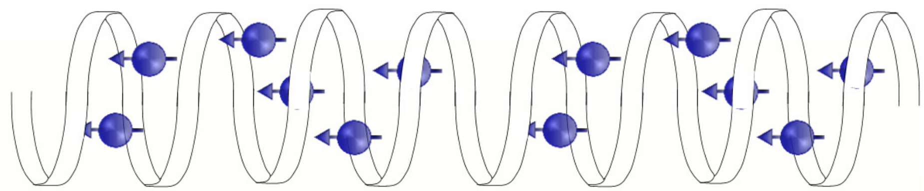
What do we have to contribute

- 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



Science AAAS

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

B. Göhler,[1] V. Hamelbeck,[1] T. Z. Markus,[2] M. Kettner,[1] G. F. Hanne,[1] Z. Vager,[3] R. Naaman,[2*] H. Zacharias[1]

In electron-transfer processes, spin effects normally are seen either in magnetic materials or in systems containing heavy atoms that facilitate spin-orbit coupling. We r…

NANO LETTERS LETTER pubs.acs.org/NanoLett

Spin Specific Electron Conduction through DNA Oligomers

Zouti Xie,[†] Tal Z. Markus,[†] Sidney R. Cohen,[‡] Zeev Vager,[§] Rafael Gutierrez,[∥] and Ron Naaman[*,†]

[†]Department of Chemical Physics, [‡]Chemical Research Support, and [§]Department of Partic…
Weizmann Institute of Science, Rehovot 76100, Israel
[∥]Institute for Materials Science, Dresden University of Techn…

THE JOURNAL OF CHEMICAL PHYSICS 131, 014707 (2009)

Chiral electron transport: Scattering through helical potentials

Sina Yeganeh,[1] Mark A. Ratner,[1,a)] Ernesto Medina,[2] and Vladimiro Mujica[1,3,b)]
[1]Department of Chemistry and Center for Nanofabrication and Molecular Self-Assembly, Northwestern University, Evanston, Illinois 60208-3113, USA
[2]Laboratorio de Física Estadística de Sistemas Desordenados, Centro de Física, IVIC, Apartado 21827, 1020A, Venezuela
…Center for Nanoscale Materials, Argonne, Illinois 60439-4831, USA

PNAS

Spin-dependent electron transmission through bacteriorhodopsin embedded in purple membrane

Debabrata Mishra[a,1], Tal Z. Markus[a,1], Ron Naaman[a,2], Matthias Kettner[b], Benjamin Göhler[b], Helmut Zacharias[b,2], Noga Friedman[c], Mordechai Sheves[c], and Claudio Fontanesi[d,2]

Departments of [a]Chemical Physics and [c]Organic Chemistry, Weizmann Institute, Rehovot 76100, Israel; [b]Physikalisches Institut, Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany; and [d]Department of Chemistry, University of Modena, 41100 Modena, Italy

Edited by Harry B. Gray, California Institute of Technology, Pasadena, CA, and approved August 2, 2013 (received for review June 17, 2013)

Spin-dependent photoelectron transmission and spin-dependent electrochemical studies were conducted on purple membrane …

most closely its natural structure (Fig. 1A). Electron conduction through these purple membranes was measured recently (9) in …

PHYSICAL REVIEW B 85, 081404(R) (2012)

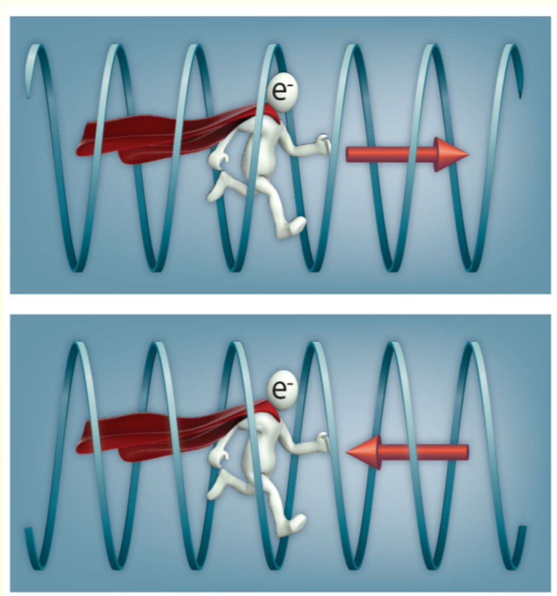
Spin-selective transport through helical molecular systems

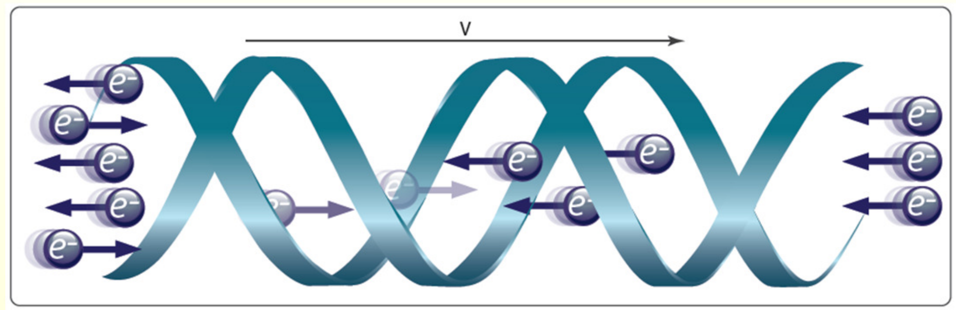
R. Gutierrez,[1] E. Díaz,[1,2] R. Naaman,[3] and G. Cuniberti[1,4]
[1]Institute for Materials Science, Dresden University of Technology, D-01062 Dresden, Germany
…erdisciplinar de Sistemas Complejos (GISC), Departamento de Física de Materiales, Universidad Co…
E-28040 Madrid, Spain
[3]Department of Chemical Physics, Weizmann Institute, 76100 Rehovot, Israel
…onvergence Engineering National Center for Nanomaterials Technology, Pohang University of Scienc…

SOC is the main cause for CISS

The CISS effect

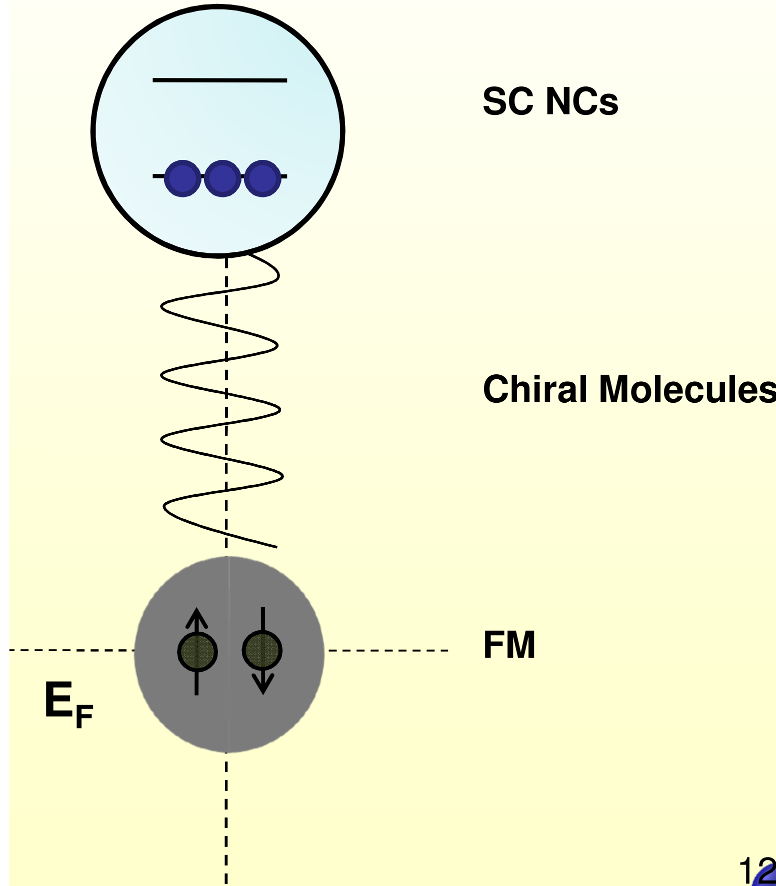
The CISS effect- Chiral induced Spin Selectivity.





Transport Vs Optics

- Chirality Induced Spin-selectivity (CISS) effect



Spin dependent transport through double stranded DNA

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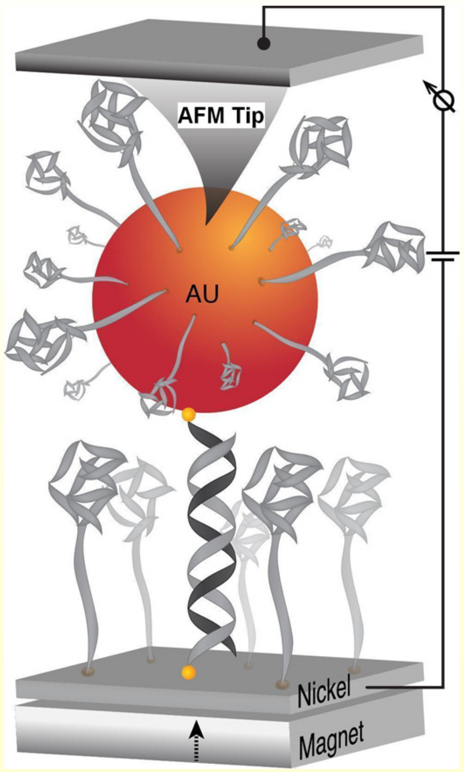
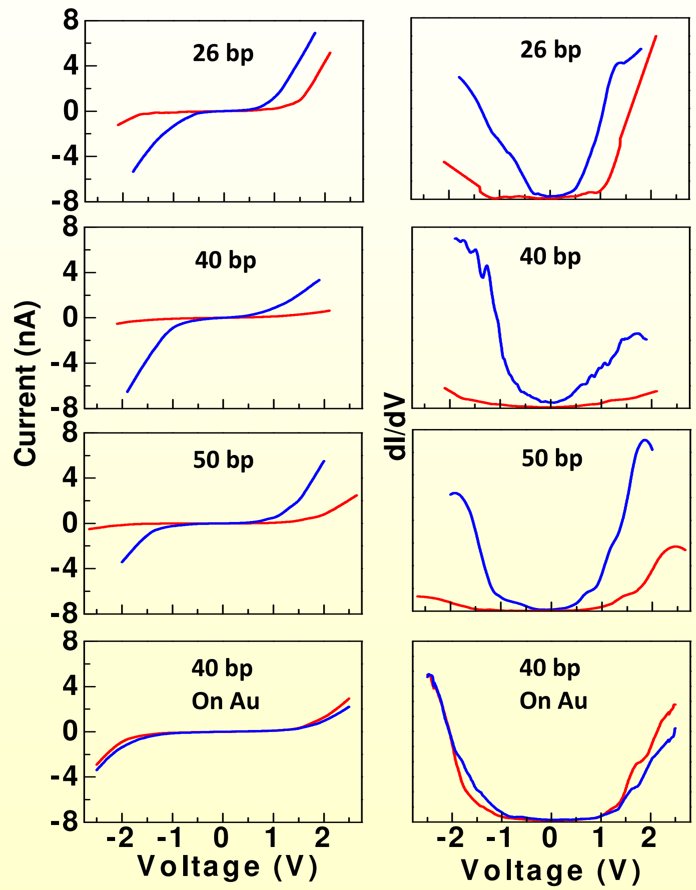
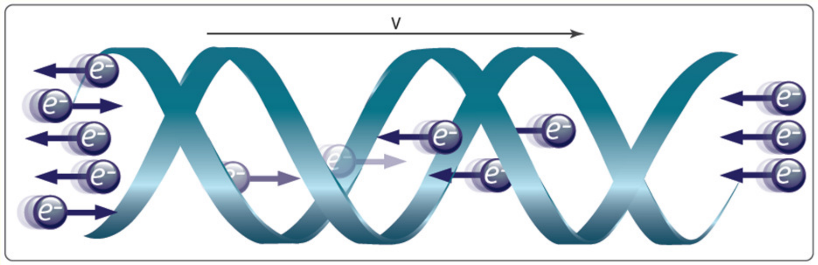
Chiral Induced Spin Selectivity - CISS

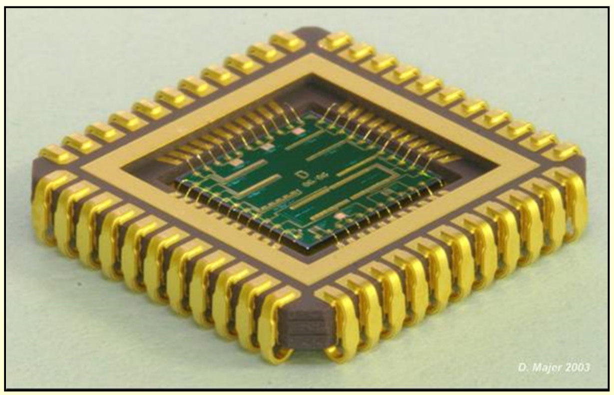




Zuoti Xie, Tal Markus, Sidney Cohen, Zeev Vager, Rafael Gutierrez, Nano Letters, **11**, 4652–4655 (2011).

Magnetic Memory without a Magnet



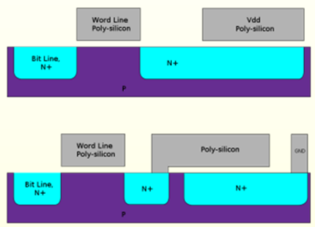


Memory devices

Fast but need constant power

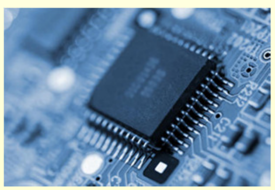
DRAM - Dynamic random-access memory

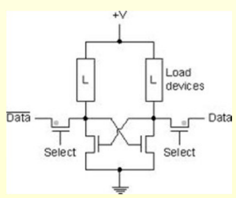
refreshed periodically



SRAM- Static random-access memory

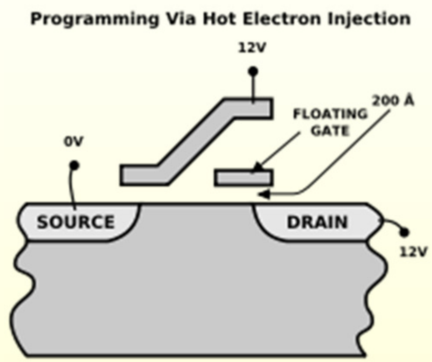
Does not need to be periodically refreshed





Slow last for 10 years

Flesh memory



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

We want:

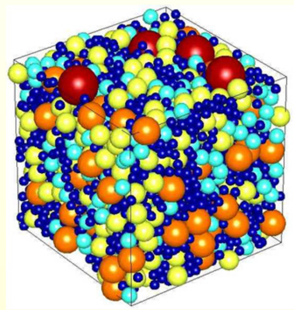
No constant power, long lived, fast, standard technology

The Charily Molecular based Universal memory

Fast

nm size transport

Dense



Unit size 10nm

Non-Volatile

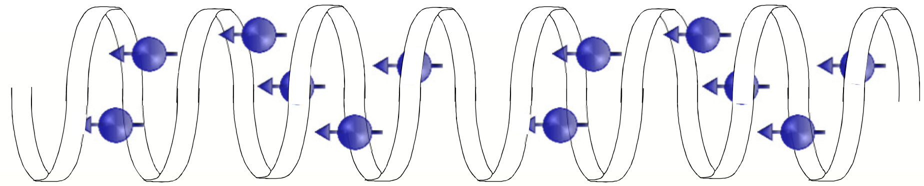
stable

Power efficient

No back scattering

The industry needs are met without compromising in <u>cost,</u> compatibility to <u>standard Si process</u> & complexity of <u>design</u>

Method



Sample Preparation

Pre-adsorption

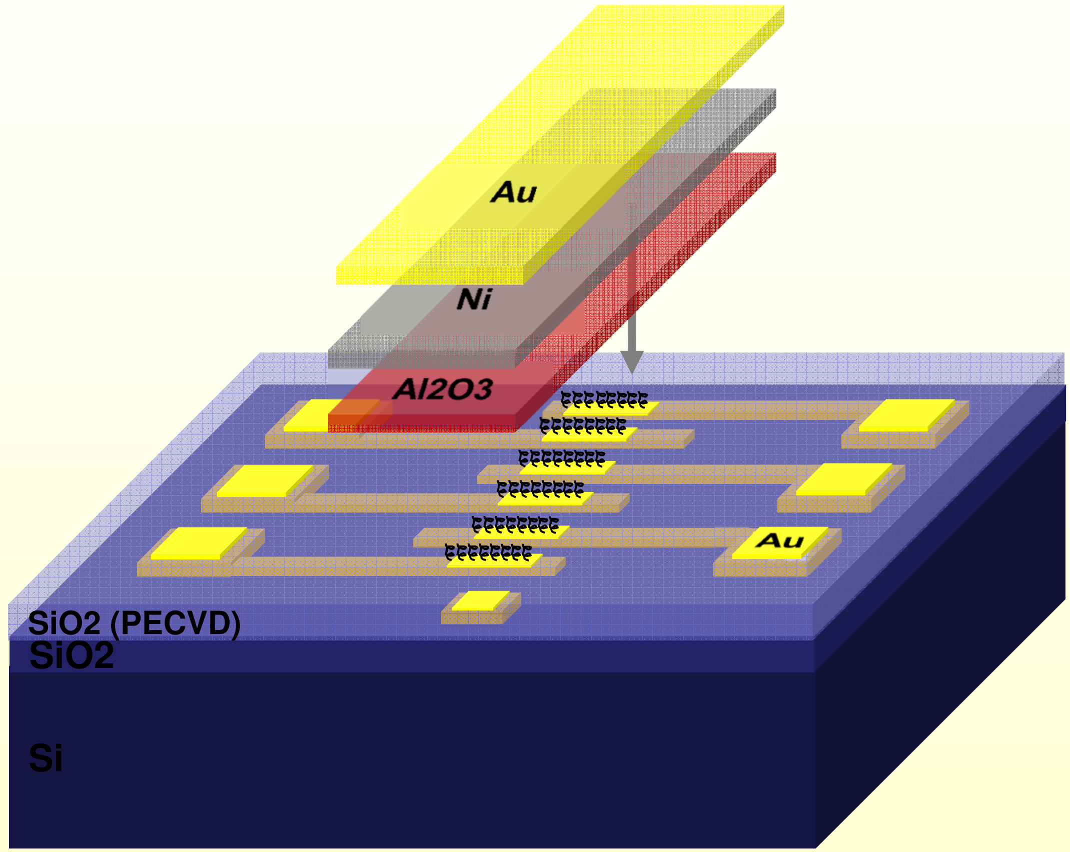
- Optical lithography

Adsorption

- 1/5/10mM on 40x50 um^2 adsorption areas

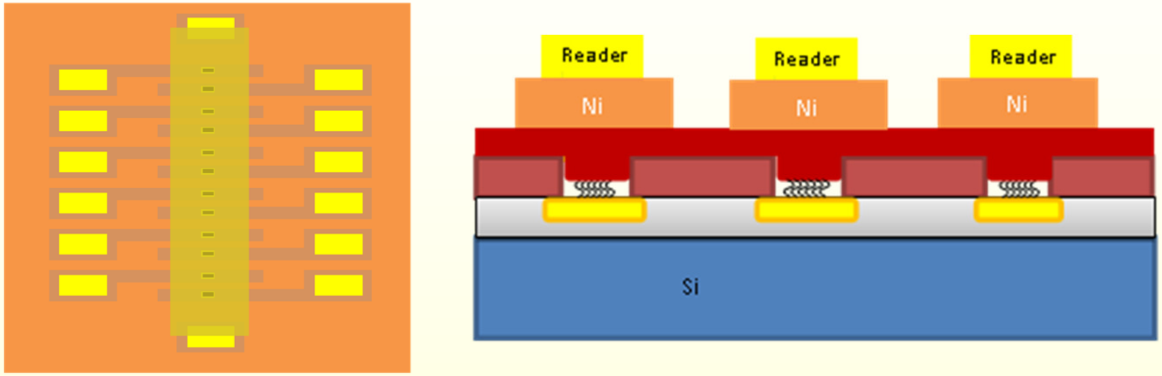
Post-adsorption

- Al_2O_3 is evaporated in two sessions: 4-5nm followed by 2nm →
- reduces pinholes
- Evaporation of Ni 30nm



Si based CISS devices

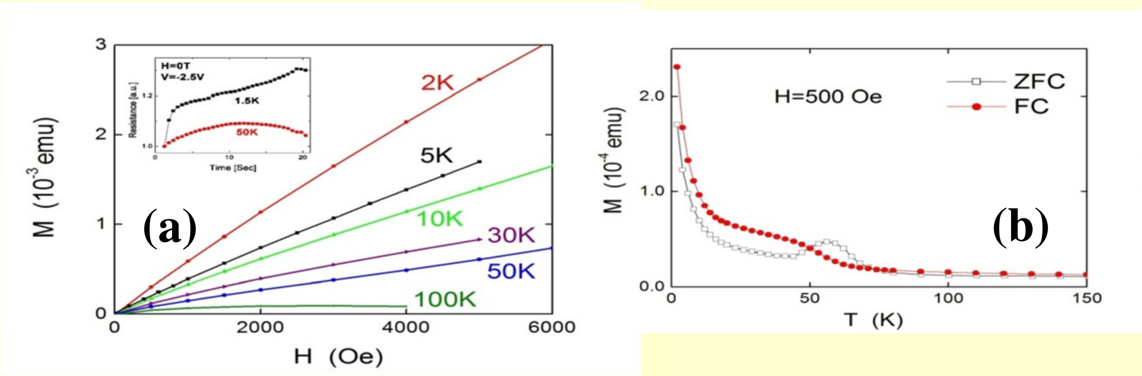
Low-power silicon based spintronic transistors with chiral molecular spin filter



Potential difficulty- pin-holes in the organic monolayer.

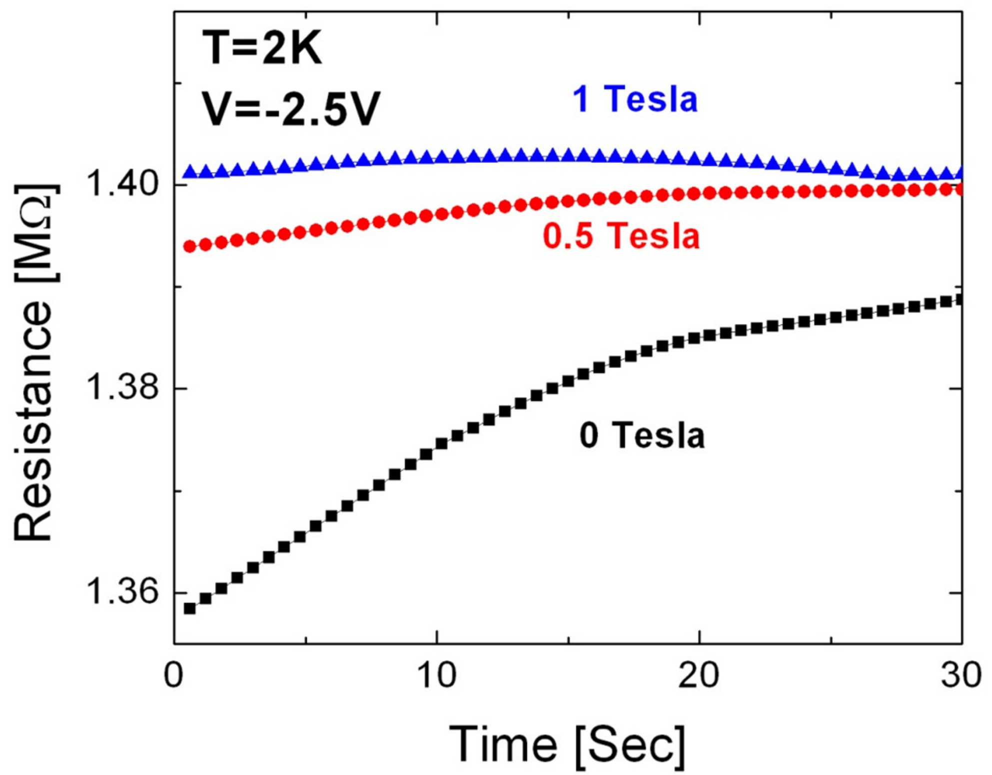
The problem was solved by evaporating thin layer (3-5 nm) of AlOx on top of the organic monolayer.

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



QNE Lab

Memory writing at low temperatures

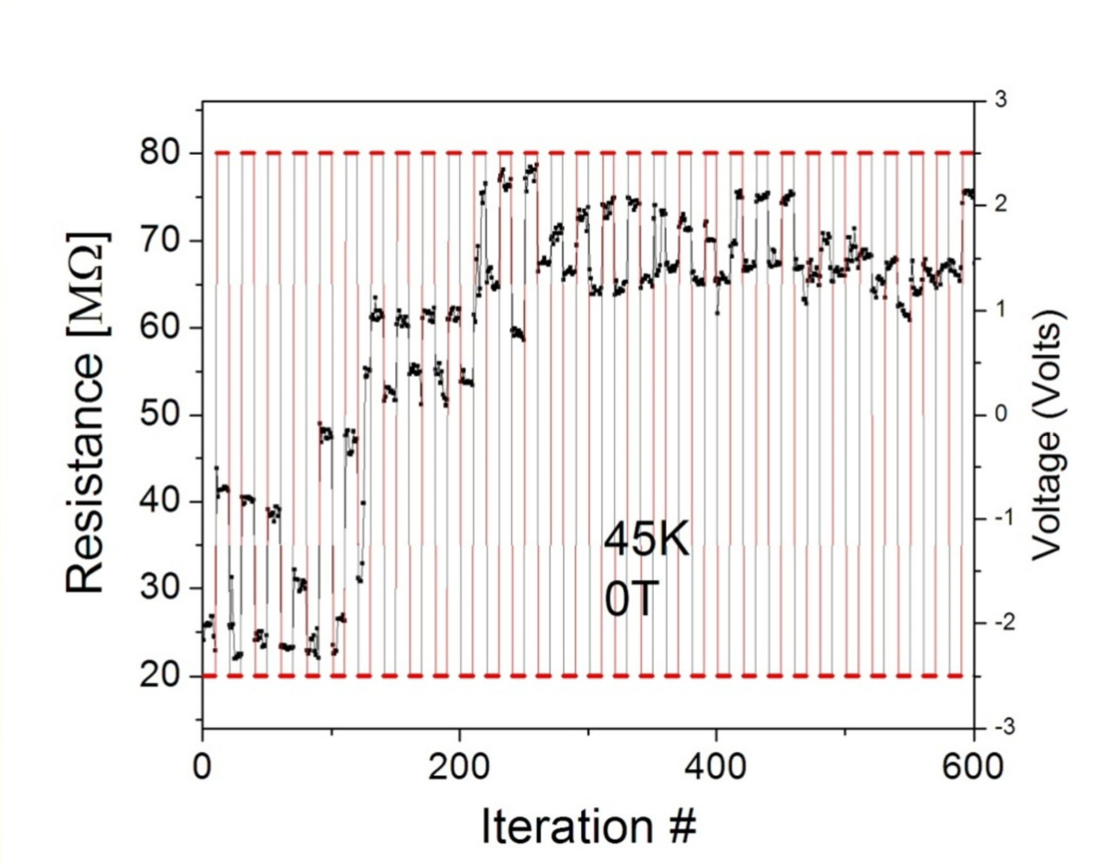


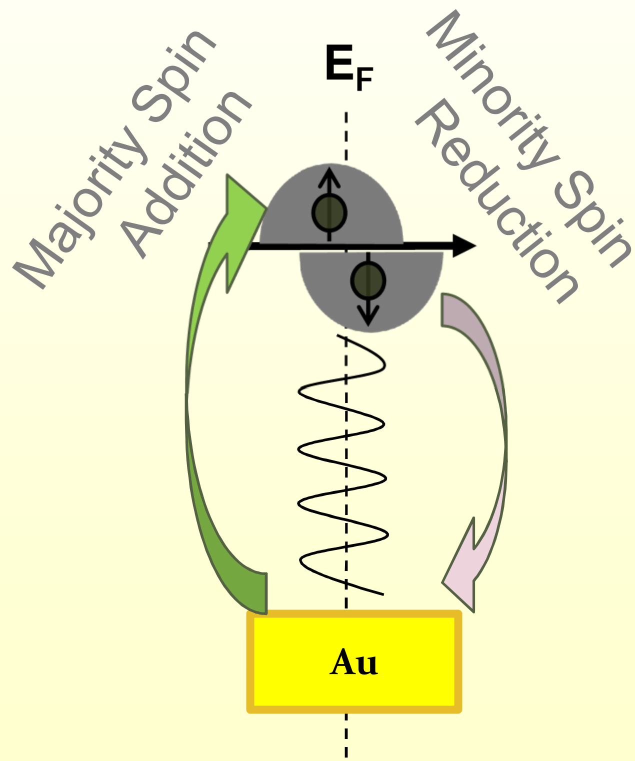
Magnetization of the device at 2K

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

Dual direction writing
Spin filter not spin polarizer?

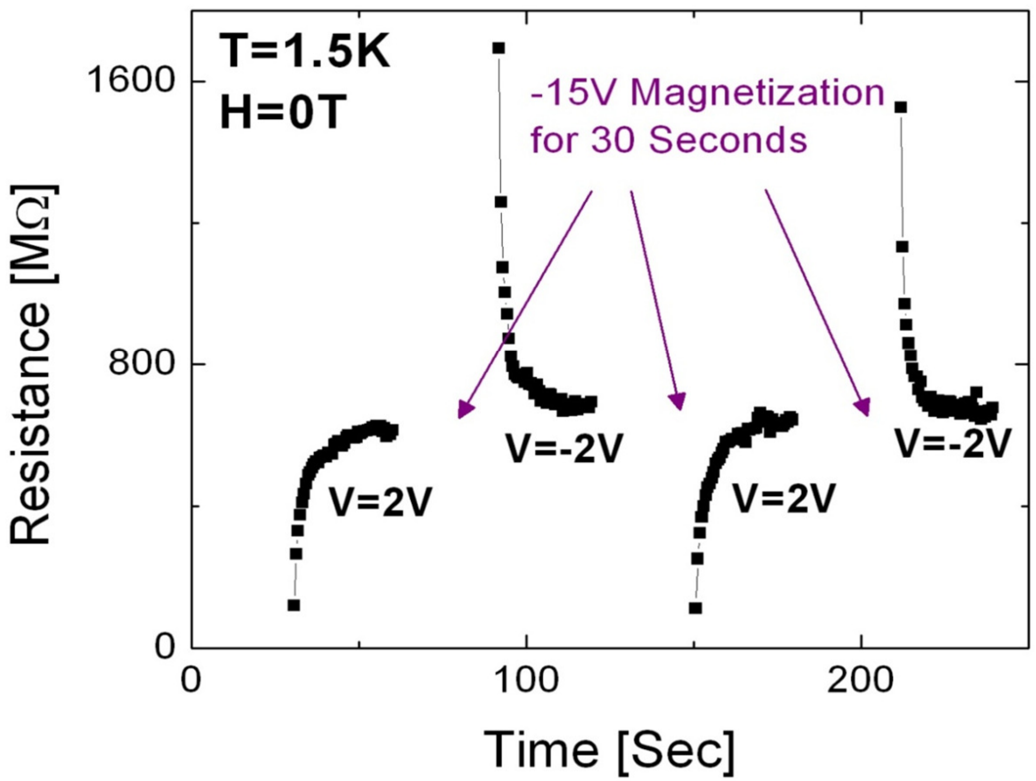




Quantum Nano Engineering Lab

12/29/2014

Memory effect on a Real Device

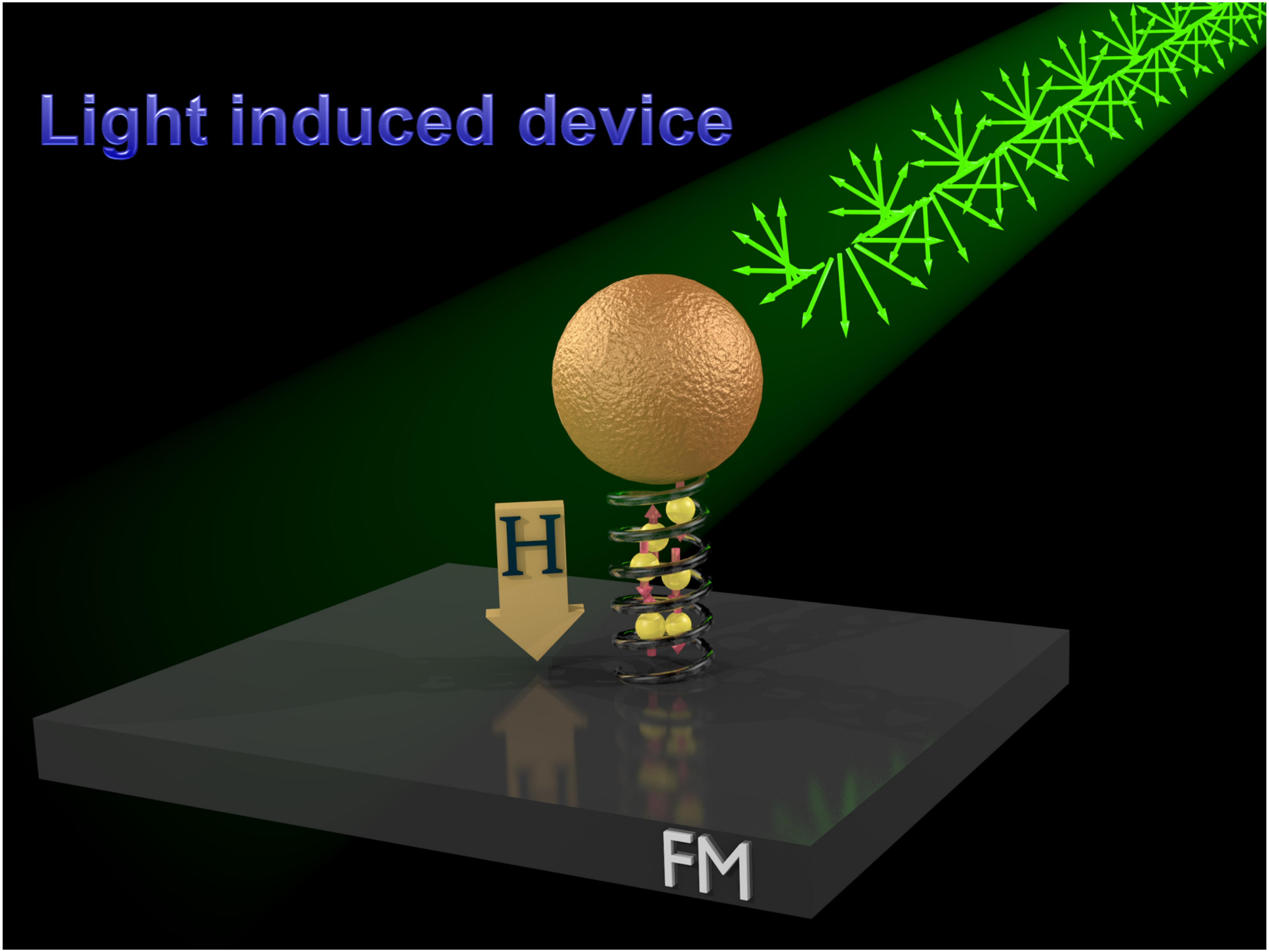


Nature Communications **4**, 2256
DOI: 10.1038 (2013).

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

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

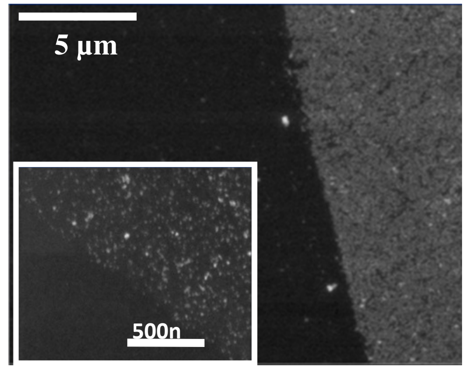
Breakthrough in memory technologies could bring faster computing, smaller memory device -http://phys.org/news/2013-08-breakthrough-memory-technologies-faster-smaller.html

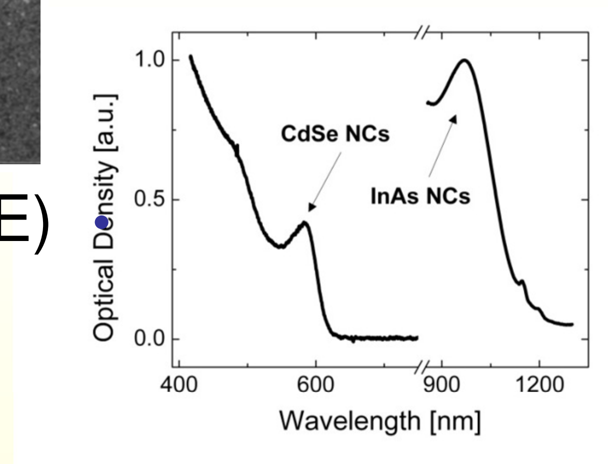

Light induced device
H
FM

Methods

Optically induced

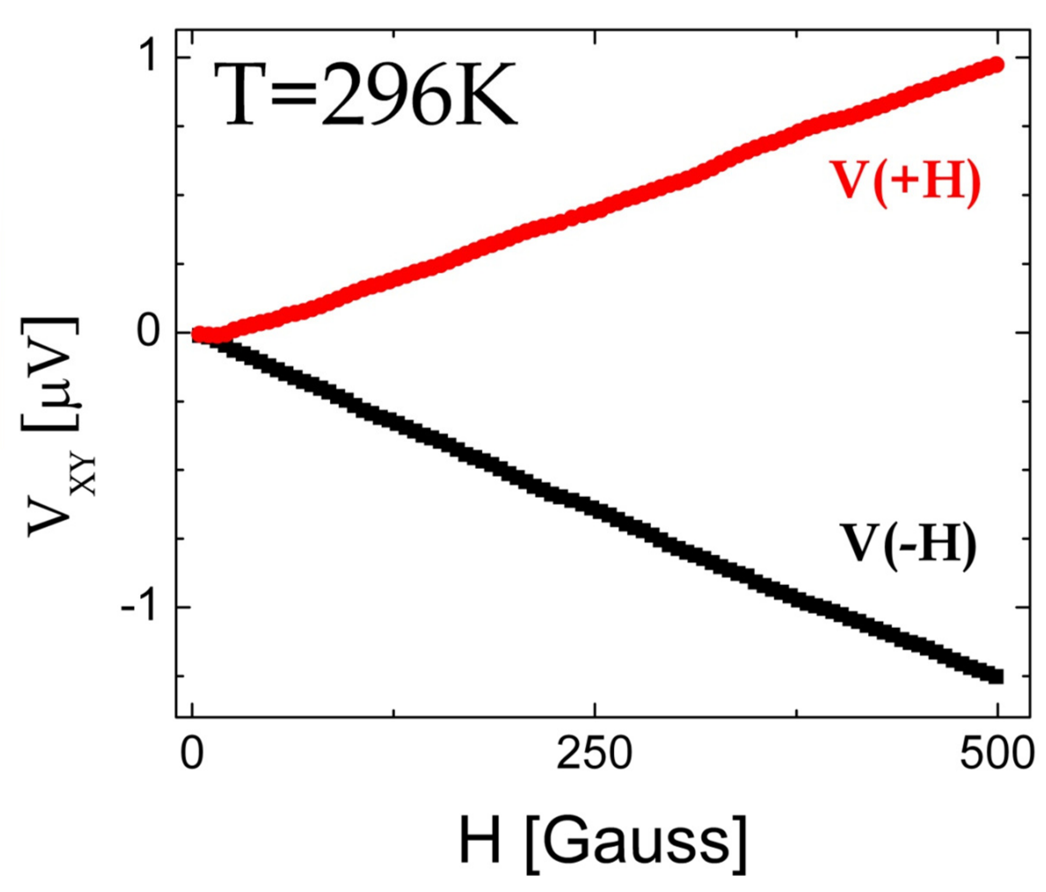
charge transfer device





Ni-based Hall effect device (anomalous HE)

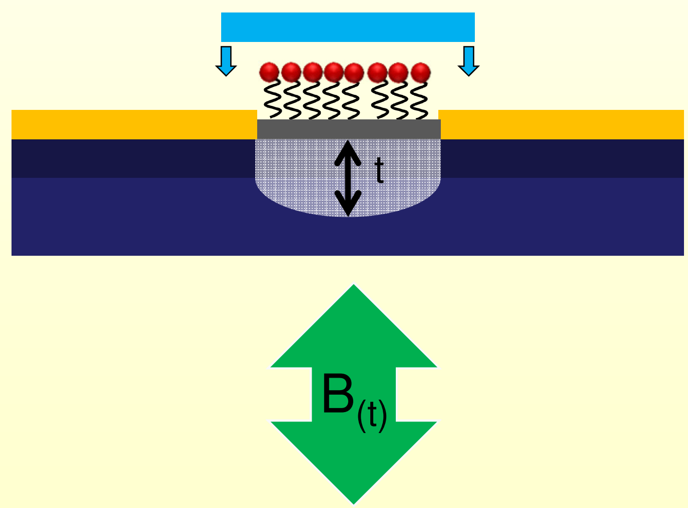
Calibration



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

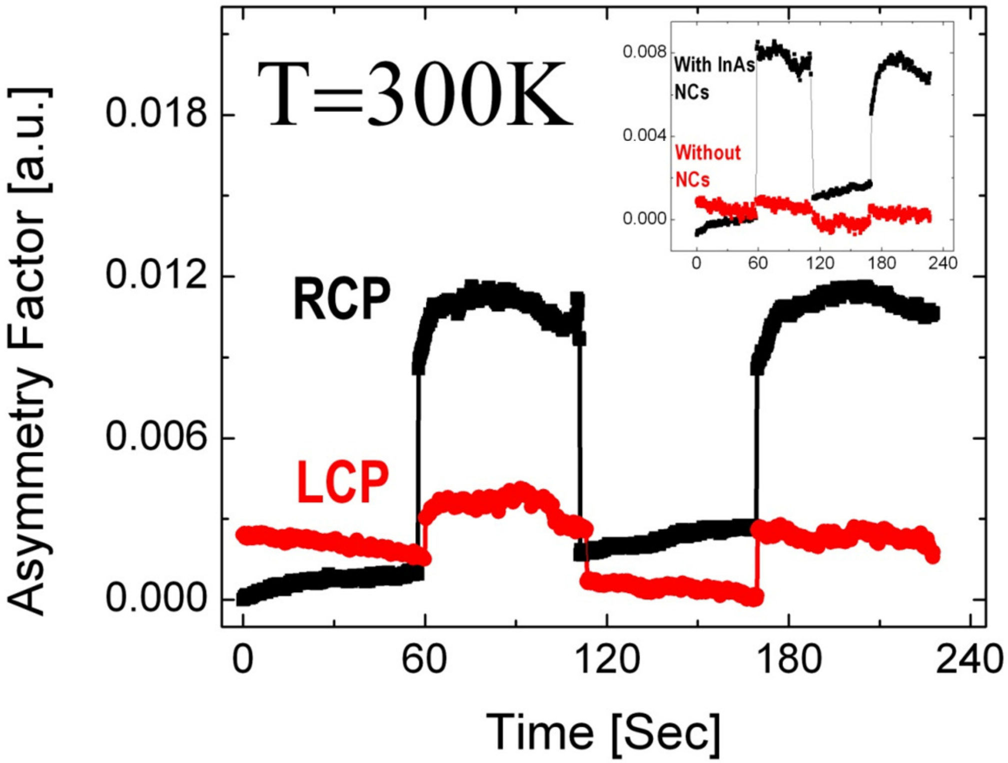
$$\Rightarrow \; n_{experiment} \sim 10^{27}\ electrons / Meter^3$$

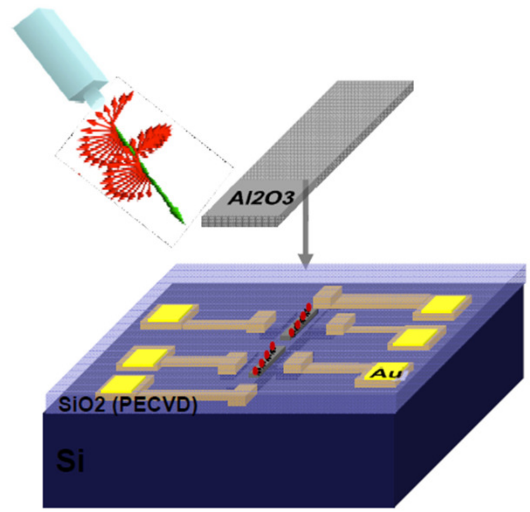
$$n_{theory} \sim 5 \cdot 10^{26}\ electrons / Meter^3$$



Optical CISS

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

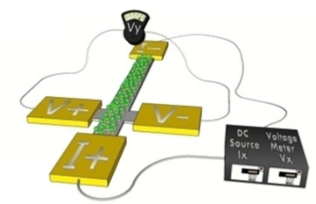


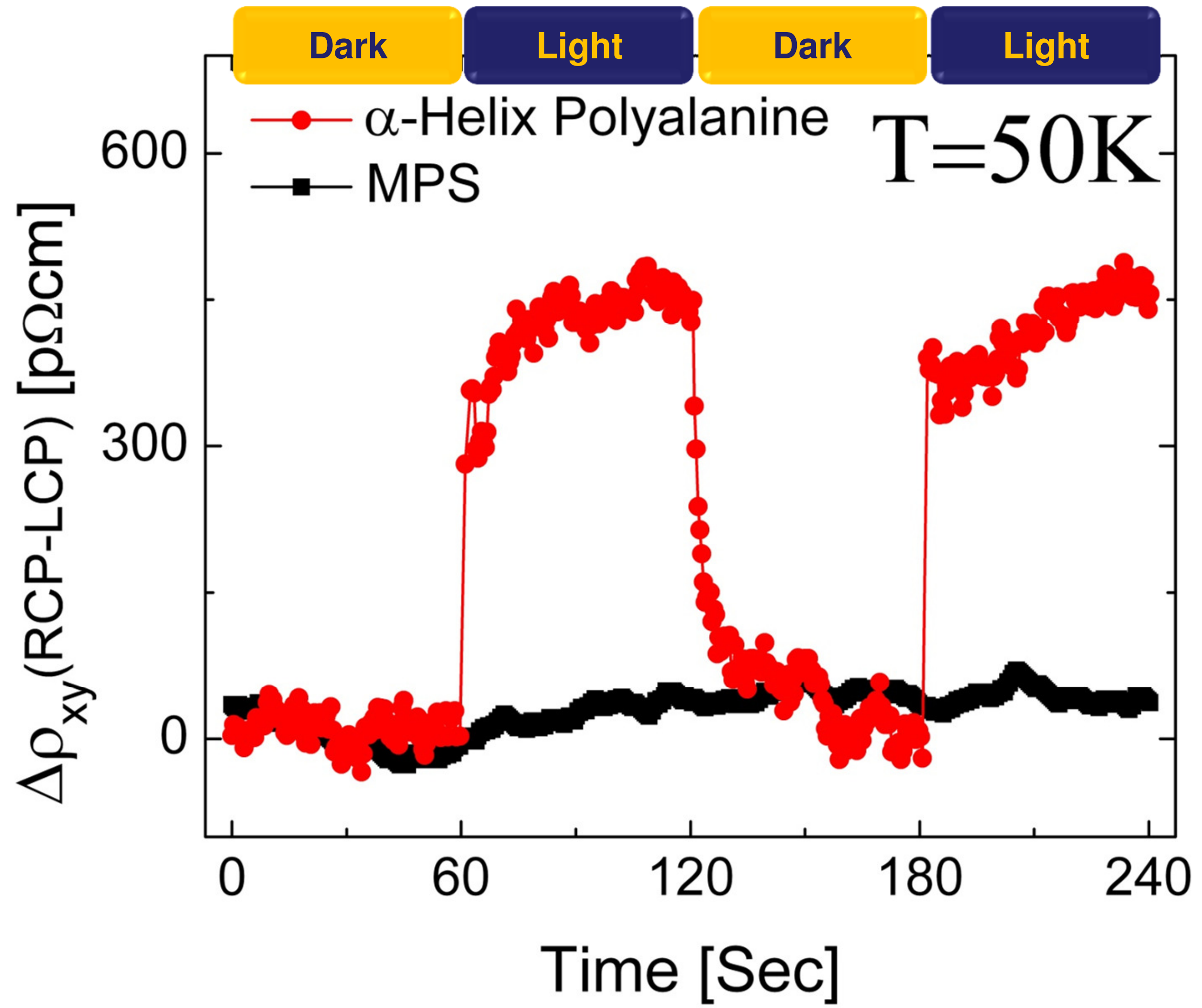


One order of magnitude difference – Spin detector

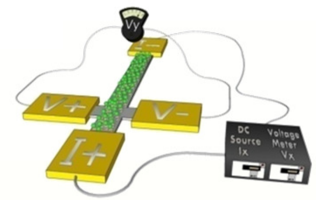
Results

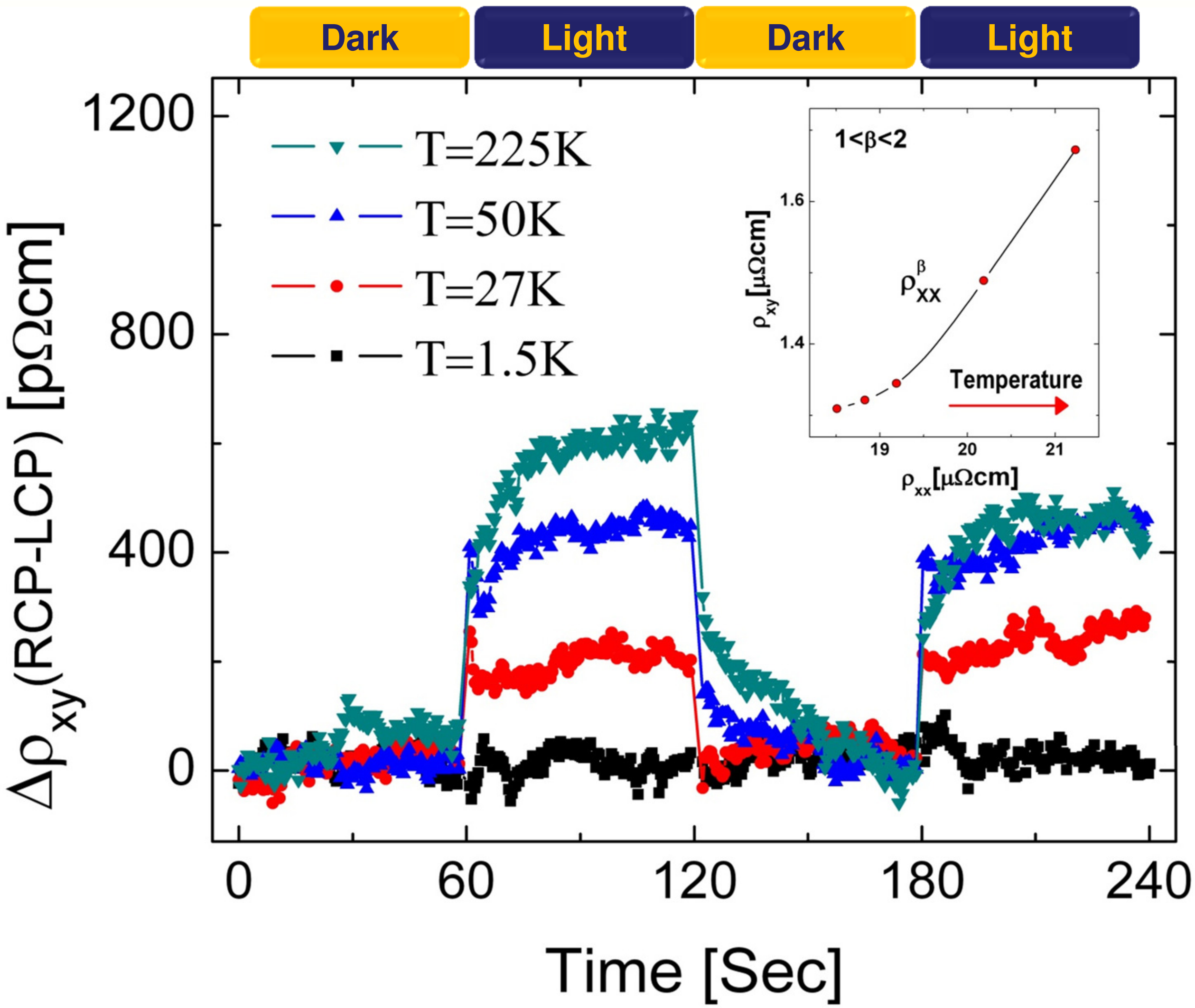
Nano letters 2014

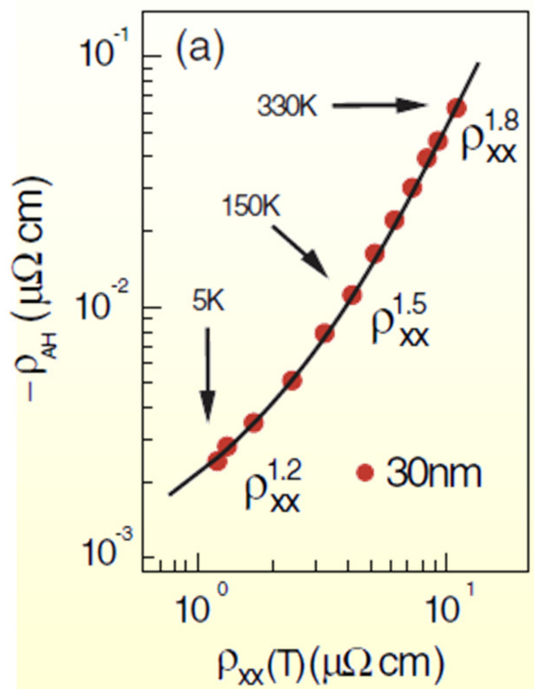




Results







Li Ye et al. Physical Review B 85, 240403(R) (2012)

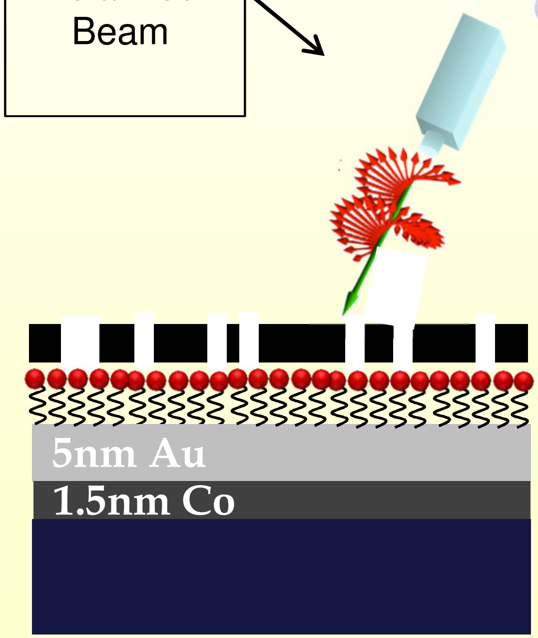
Methods

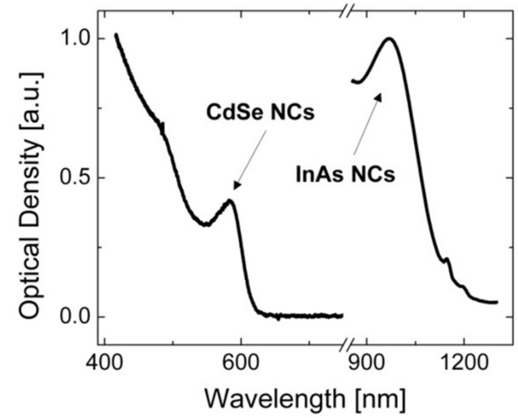
Optically induced charge transfer device

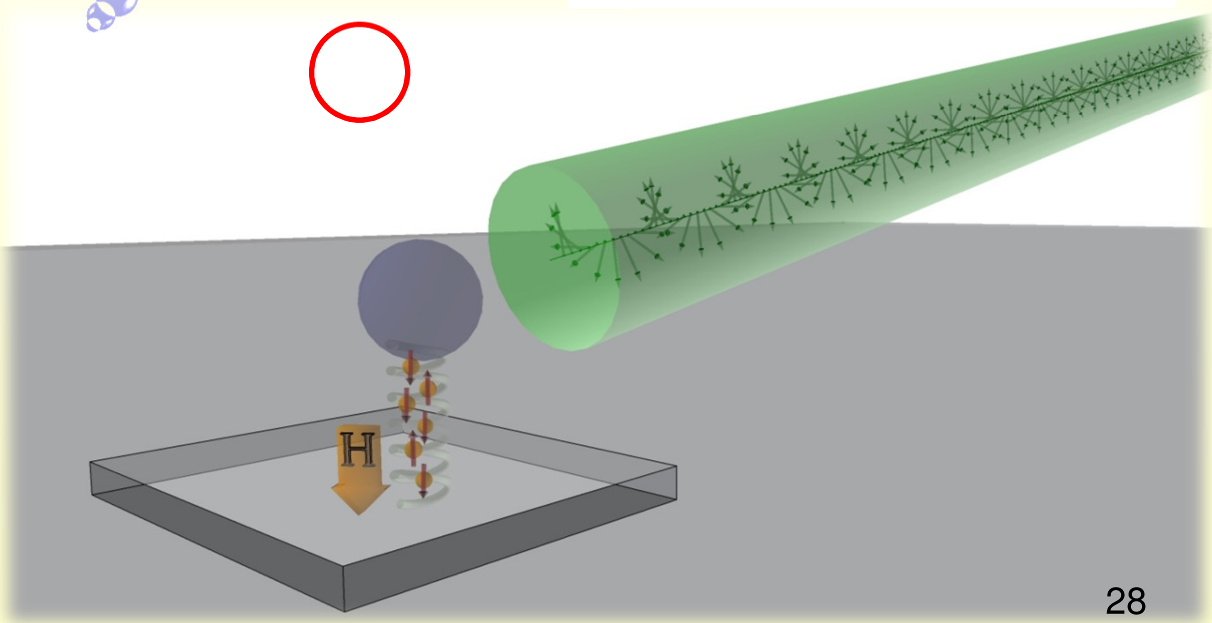
- Highly localized magnetization device (measured with MFM)

532nm Circular Polarized Beam

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

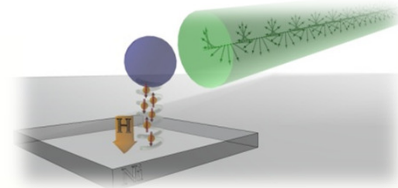






Results

Nano letters 2014

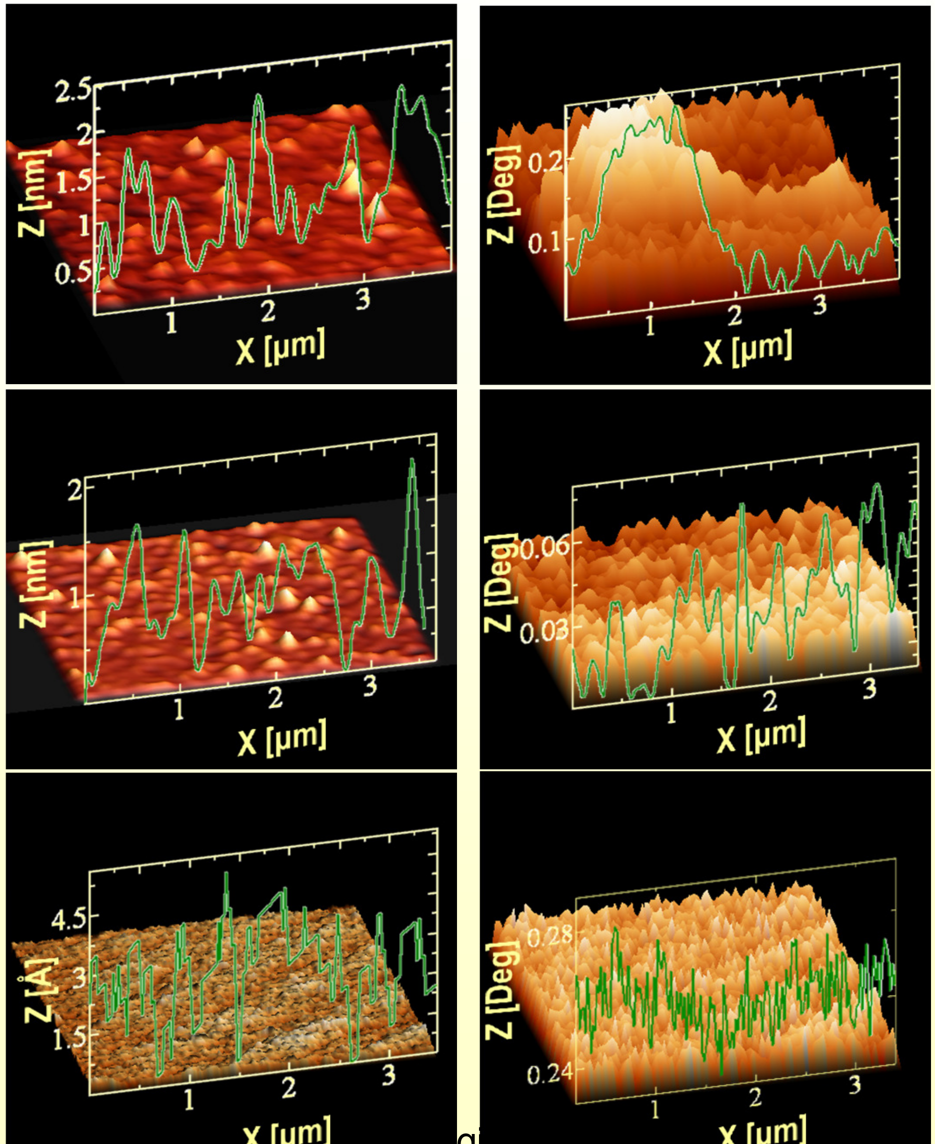


Topography | **Magnetism**

Illuminated area
in illuminated sample

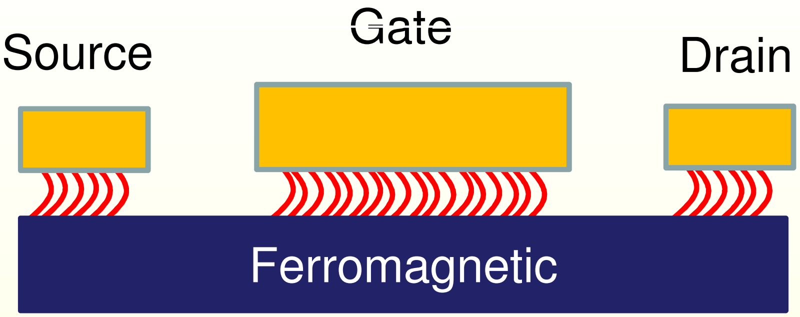
Unilluminated area
in illuminated sample

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



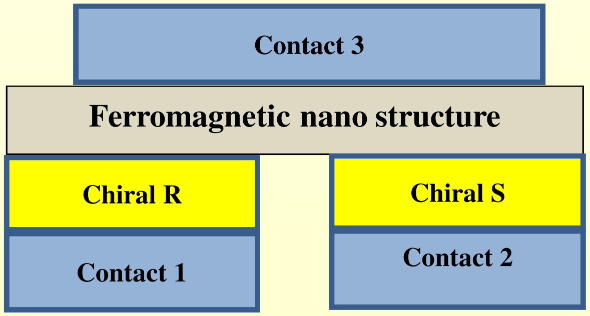
CISS Future Applications

- Magnetic memory
- Spin transistors
- 3D spin logic
- Local EMR



Electrical gating

A scheme of the XOR MSM device



Changing the world of memory device as we know