Devices logic and spinterface using CISS

8.3.2017

Special thanks to
Antonio Correia

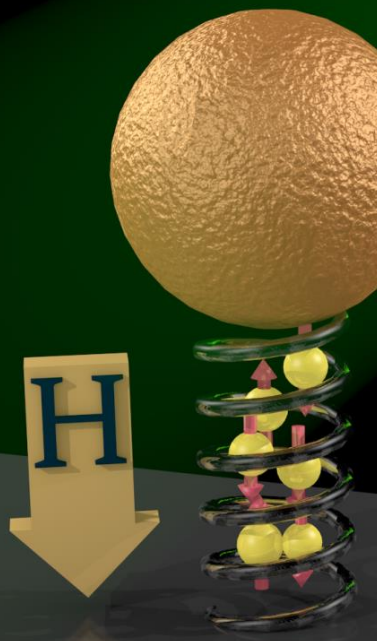
Yossi Paltiel

Applied Physics Department

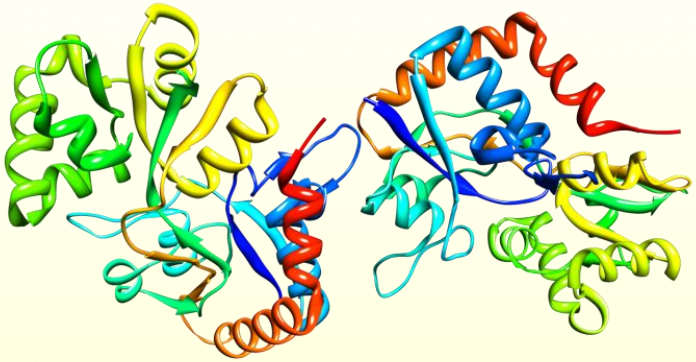
Center for nano science

and nano technology,

HUJI, Israel



QuEBS 2017 in Jerusalem!!! Quantum Effects In Biological Systems March 26-30

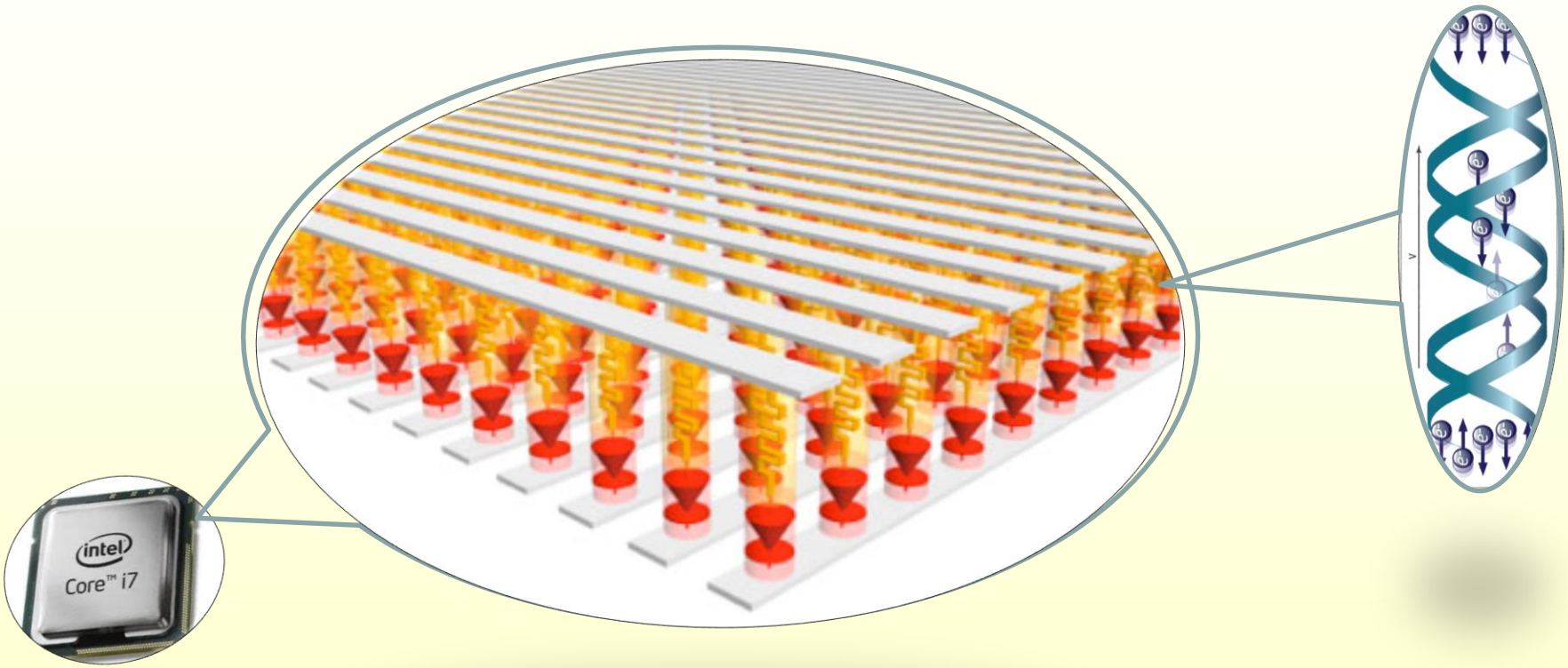


QuEBS 2017

Why nature is chiral?

Q N E Lab

nm simple MRAM memory

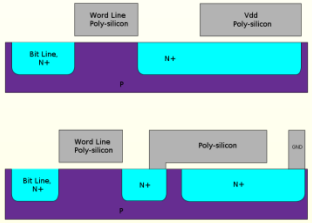


Memory devices

Fast but need constant power

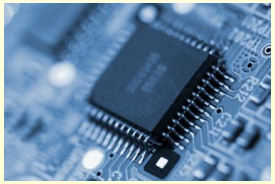
DRAM - Dynamic random-access memory

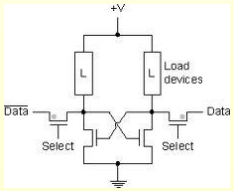
refreshed periodically



SRAM- Static random-access memory

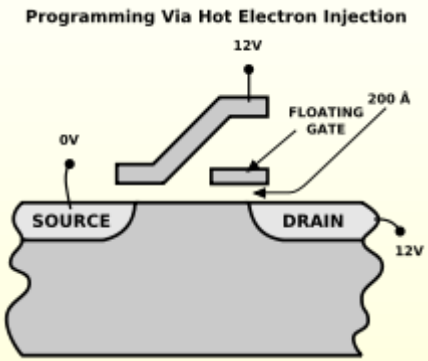
Does not need to be periodically refreshed





Slow last for 10 years

Flesh memory



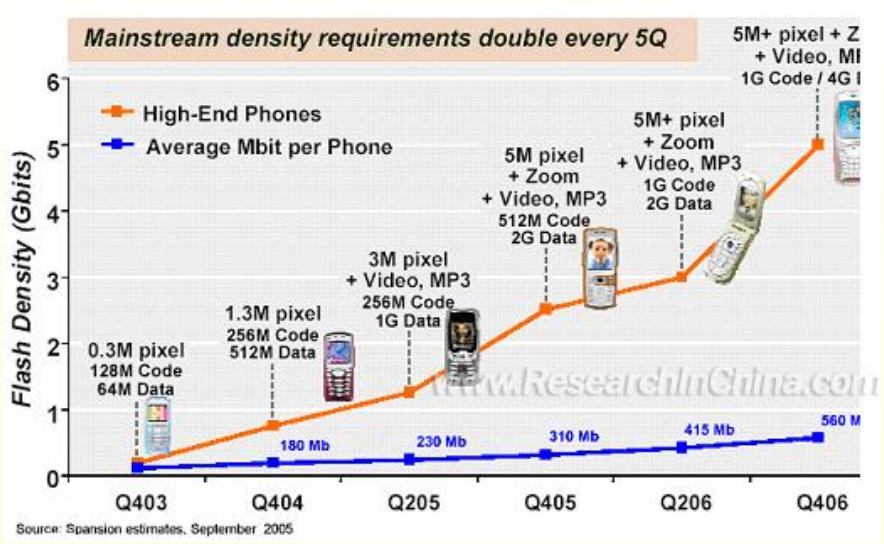
All existing memory technologies challenged when critical size is smaller than 45 nm

We want:

No constant power, long lived, fast, standard technology

Embedded Memory

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

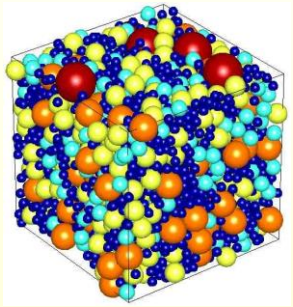


Why is it good??? high-speed and wide bus-width capability, which eliminates inter-chip communication.

Simple Universal Magnetic Memory

Fast

Dense



Non-Volatile

Power efficient

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

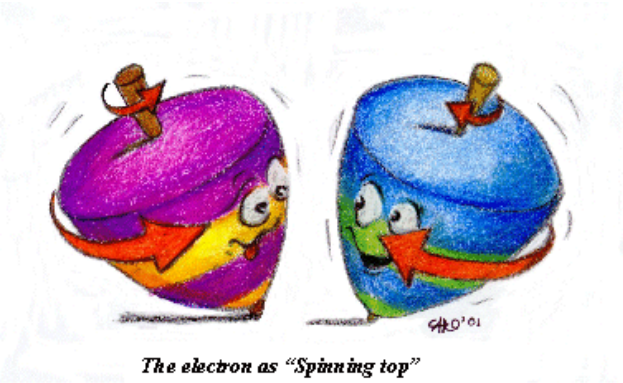
Spin Electronics

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

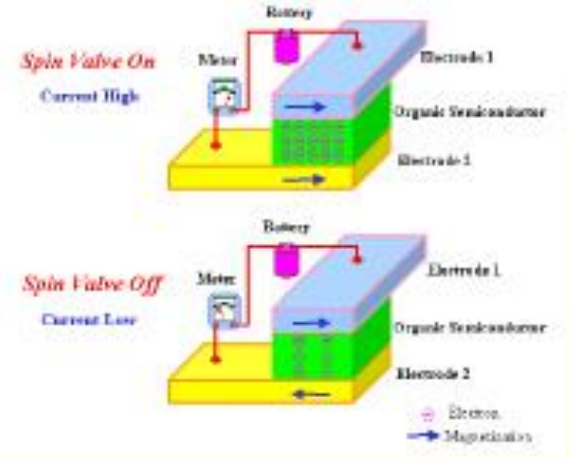
Why Spintronics?

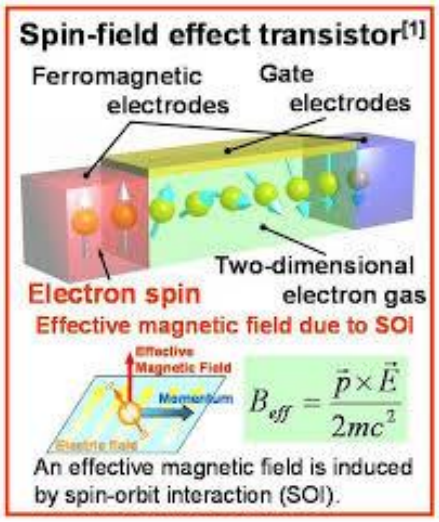


- **Energy and heat**- For Spintronics, less energy

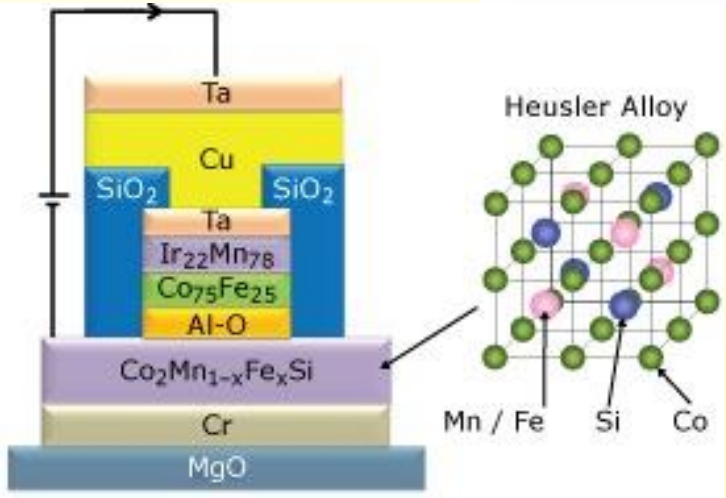
- **Quantum effects** -It may be a way for introducing the spin properties to our tool arsenal.

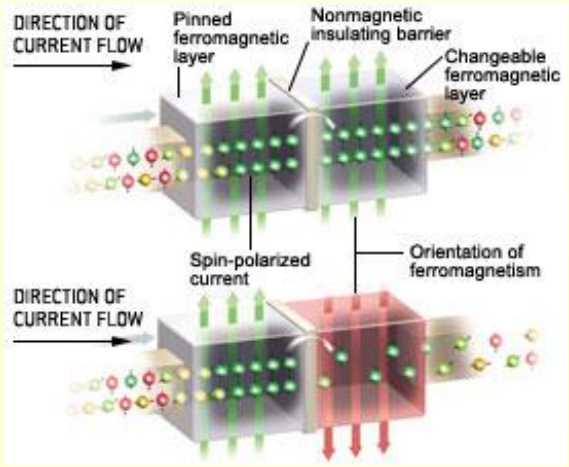
Spintronics Devices





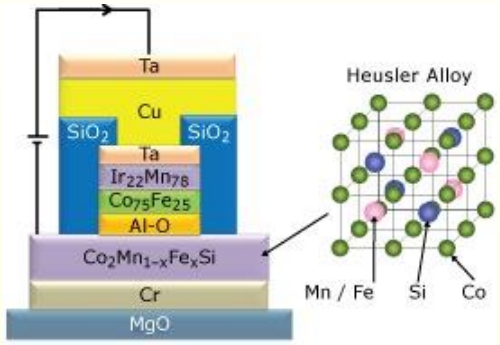
The 2007 Nobel Prize in Physics was awarded to :
Albert Fert and Peter Grünberg
for the discovery of GMR





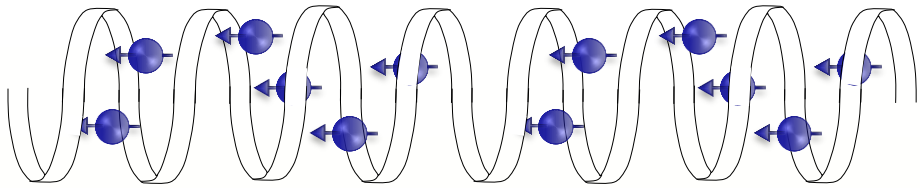
Two Major Problems

- **Material problem**



- **Spin separation requires high current**

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

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 Particle Physics, Weizmann Institute of Science, Rehovot 76100, Israel

[∥]Institute for Materials Science, Dresden University of Technology, D-01062 Dresden, Germany

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

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

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 [b]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. 1*A*). Electron conduction through these purple membranes was measured recently (9) in

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*

Interdisciplinar de Sistemas Complejos (GISC), Departamento de Física de Materiales, Universidad Co E-28040 Madrid, Spain

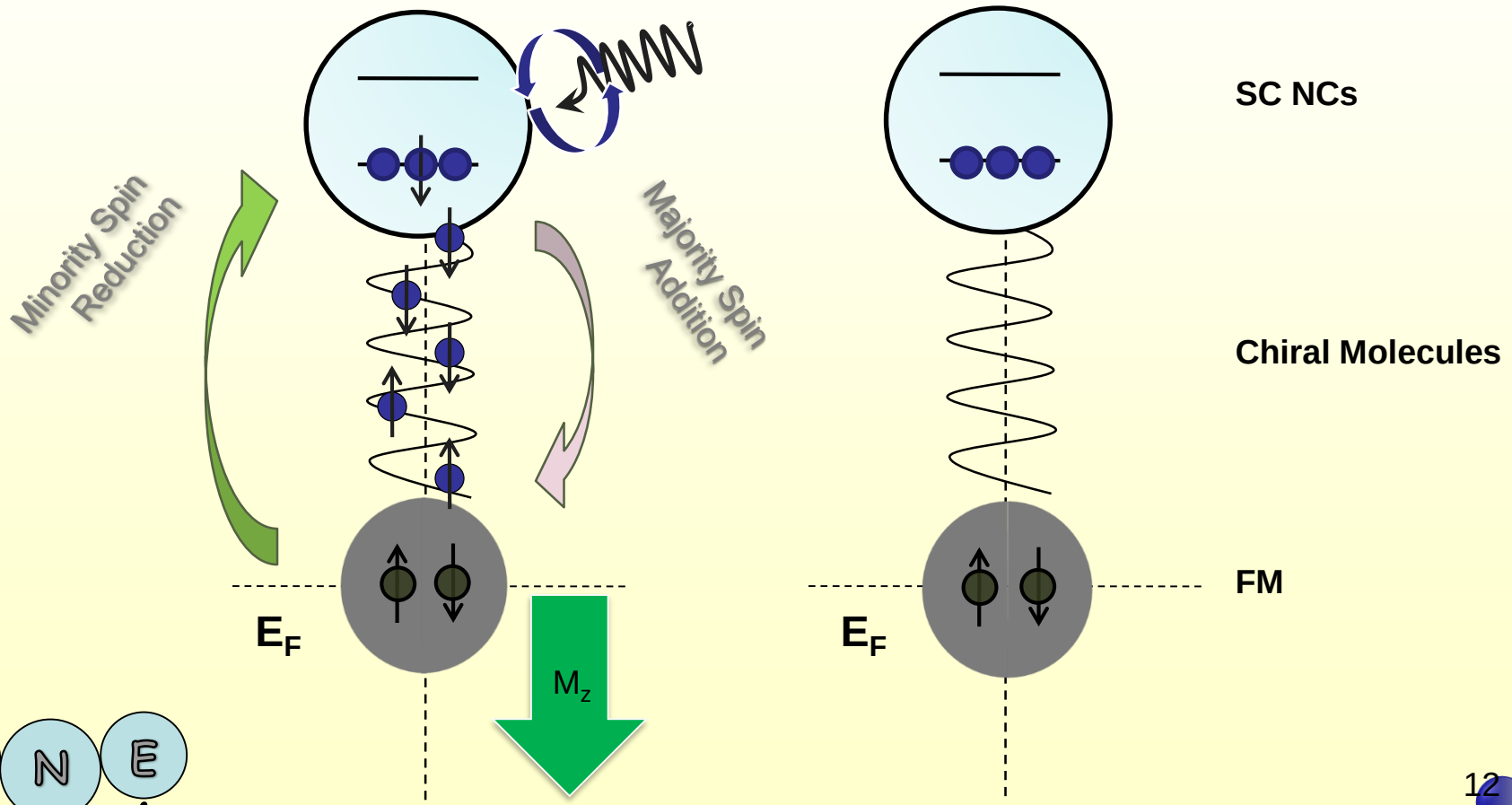
[3]*Department of Chemical Physics, Weizmann Institute, 76100 Rehovot, Israel*

Convergence Engineering National Center for Nanomaterials Technology, Pohang University of Scienc

SOC is the main cause for CISS

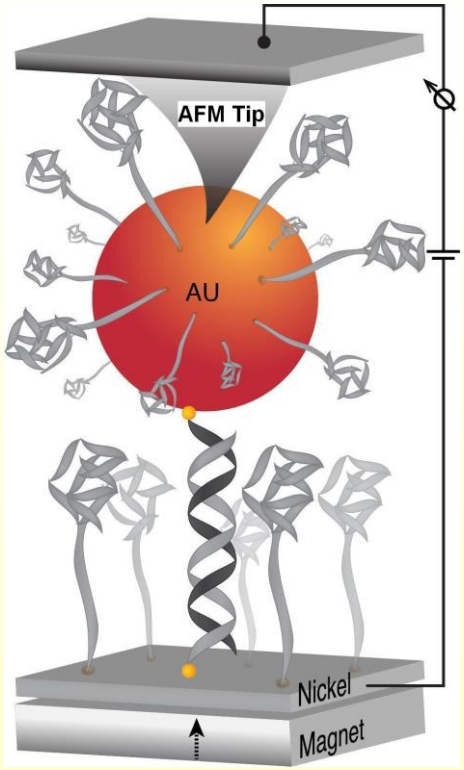
Transport Vs Optics

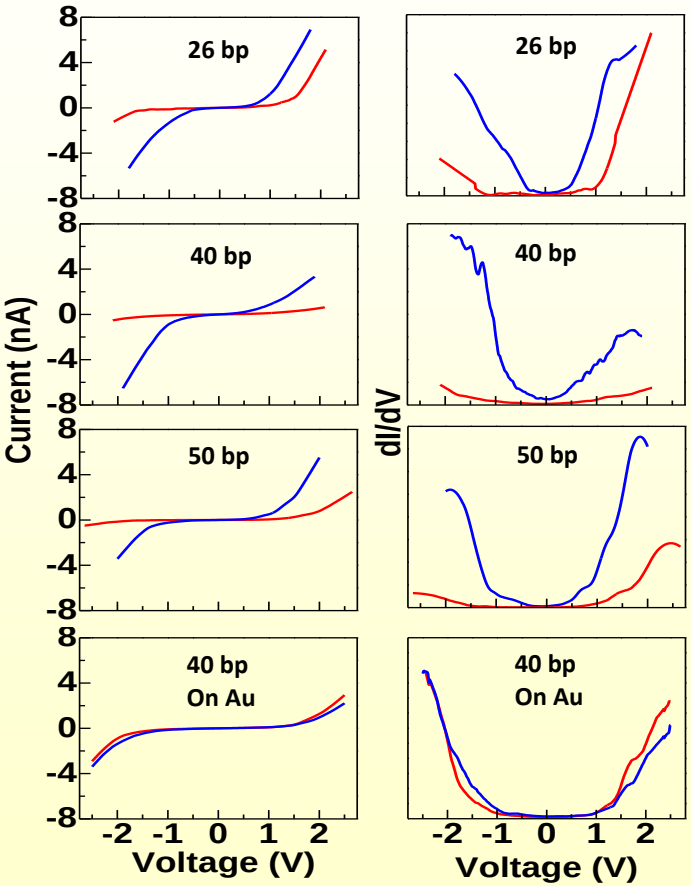
Chirality Induced Spin-selectivity (CISS) effect •



The CISS Effect

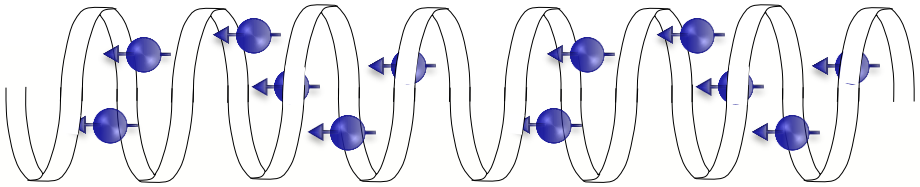
- Chiral Induced Spin Selectivity - CISS





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

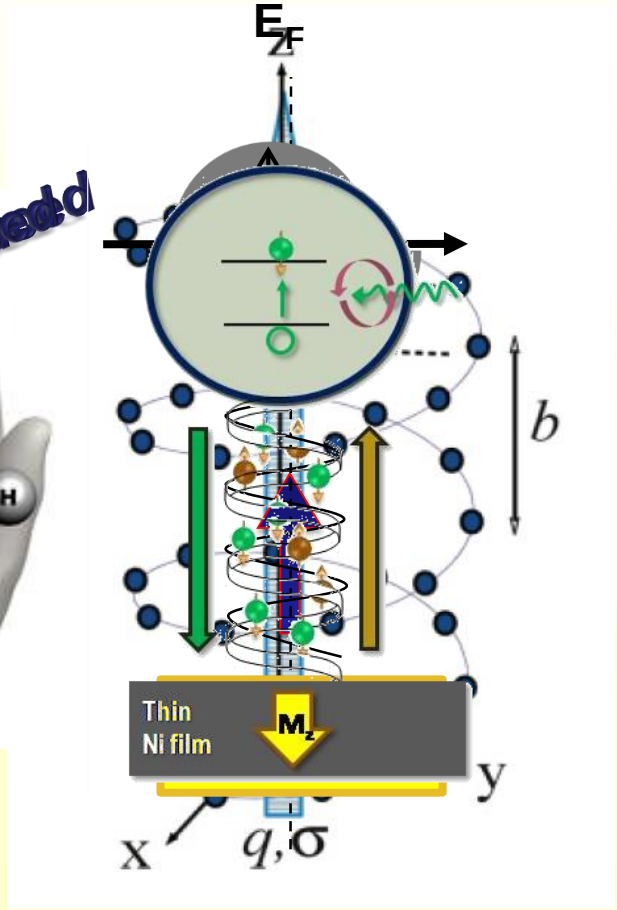
Theory



- Chirality Induced Spin-selectivity (CISS) effect

Major Transport mechanism is Spin-Orbit Coupling (SOC)

$$\vec{B} = \frac{\vec{v}}{c^2} \times \vec{E}$$

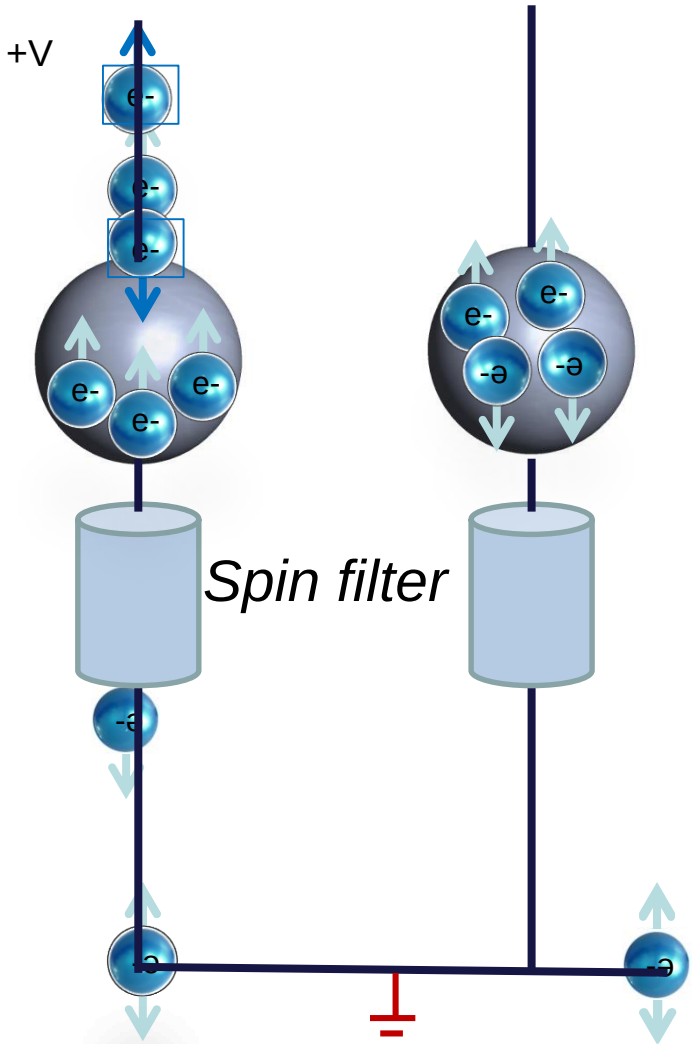


Rashba like term due to chiral orbit

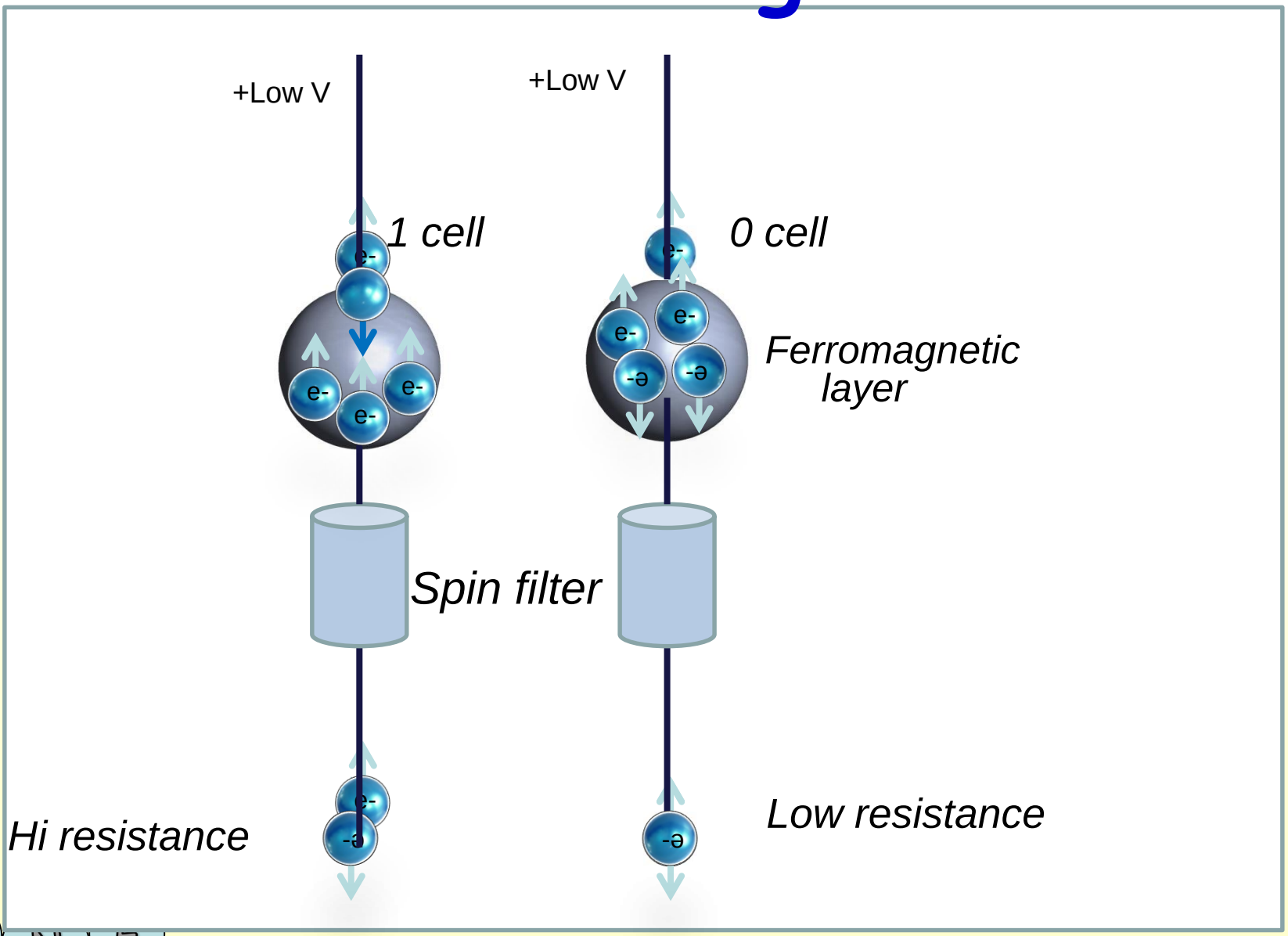
R. Gutierrez, E. Díaz, R. Naaman, and G. Cuniberti, PHYSICAL REVIEW B 85, 081404 (2012)

14

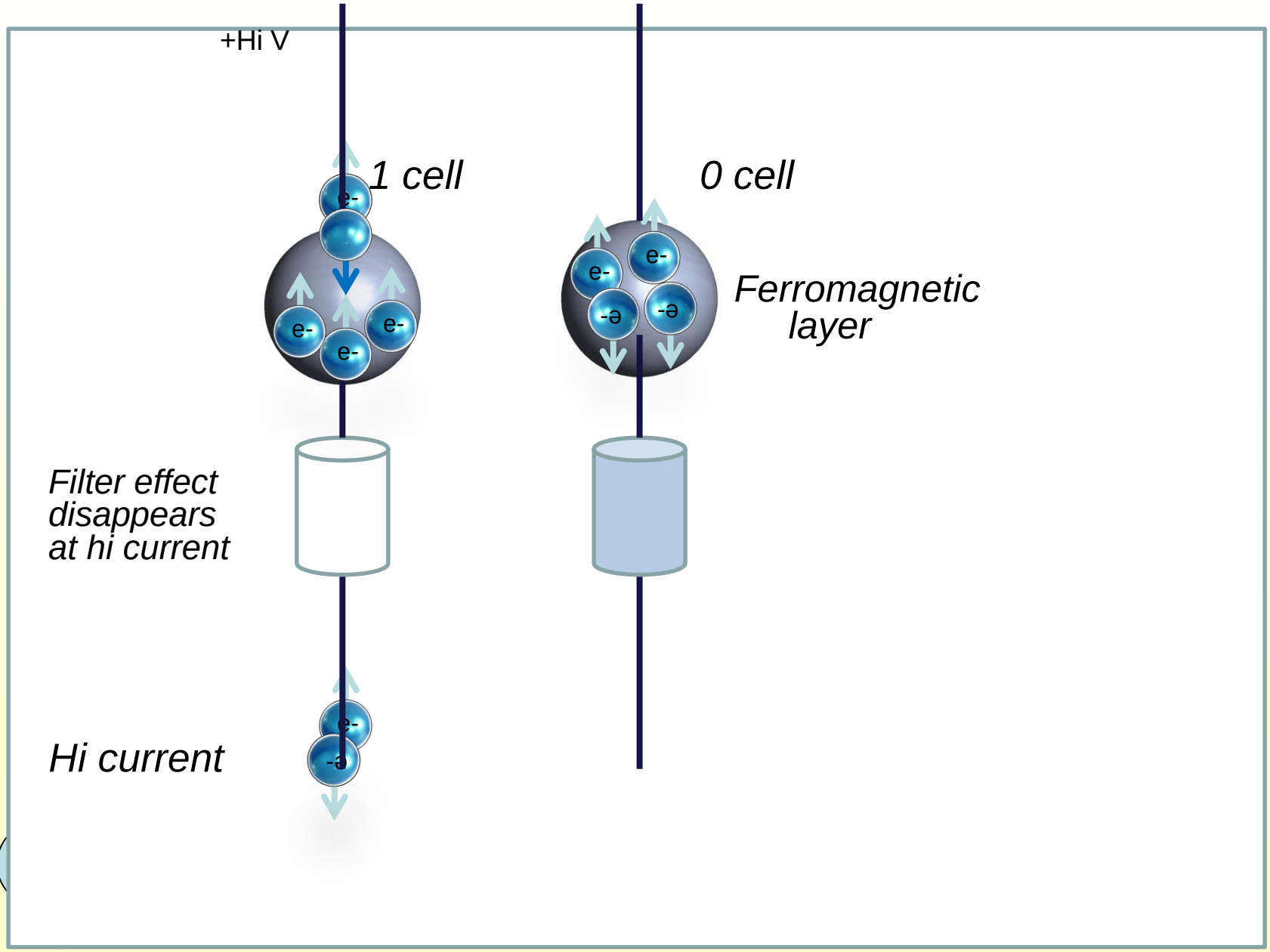
Writing cell



Reading

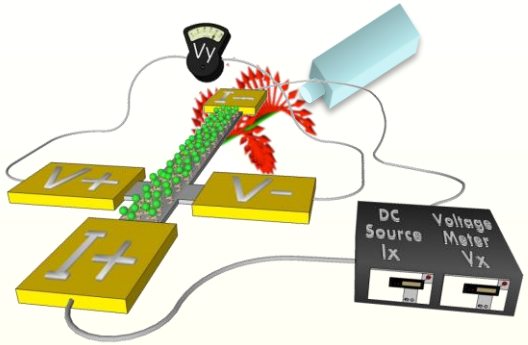

+Low V
+Low V
1 cell
0 cell
Ferromagnetic layer
Spin filter
Hi resistance
Low resistance

Erase


+Hi V
1 cell
0 cell
e-
e-
e-
e-
e-
e-
-ə
-ə
Ferromagnetic layer
Filter effect disappears at hi current
Hi current

CISS Devices solves material problem RT simple devices

Nano letters **14** 6042 (2014).
ACS Photonics, , ***2*** (10), pp 1476–1481 (2015).

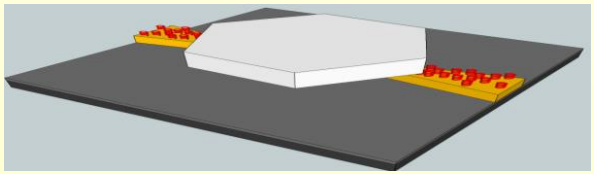


Optical – photon driven:

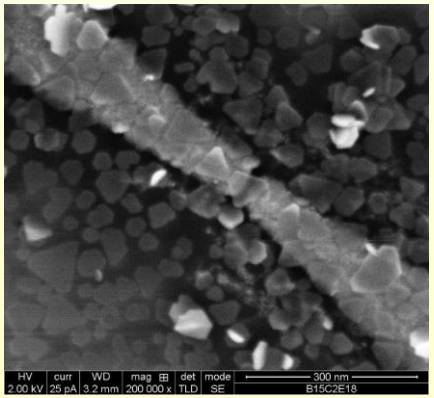
- **Local magnetization/local optical memory.**
- **Nano metric charge separation.**

Electrical – electrons driven:

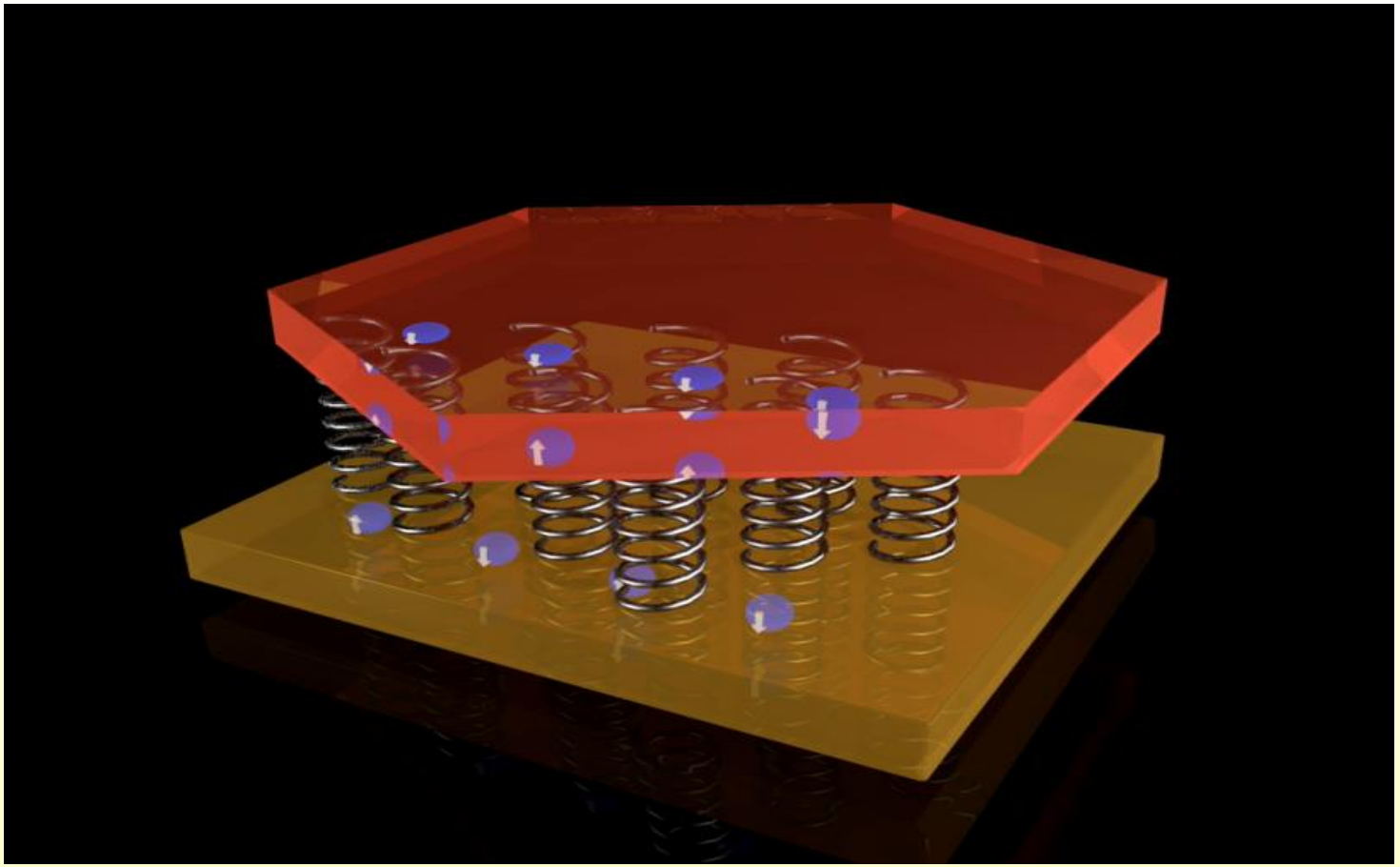
- **Spin injector**
- **Nano memristor.**



Nature Communications **4**, 2256 (2013).
Applied Physics Letters, **105** 242408 (2015).

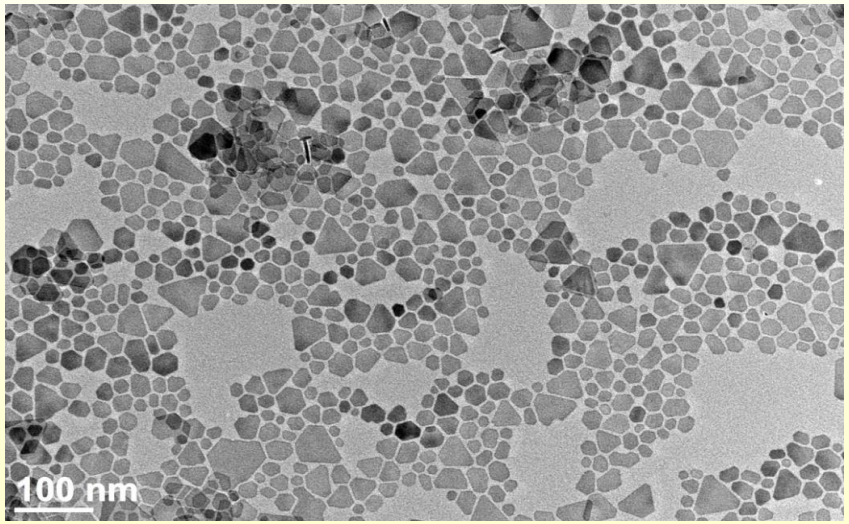


Electrical CISS Memory



Room Temperatures CISS Memristors

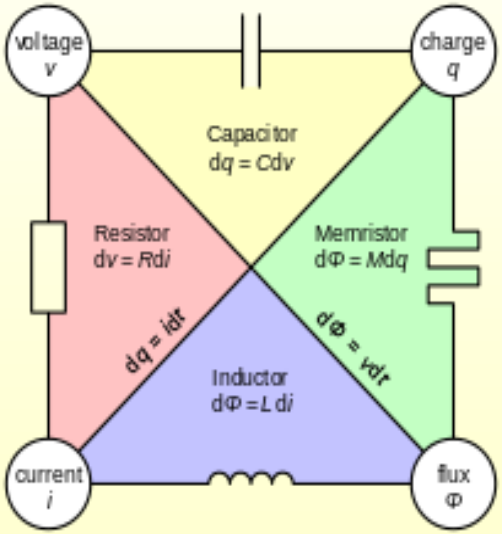
Embedded memory using the CISS effect and magnetic nano particles

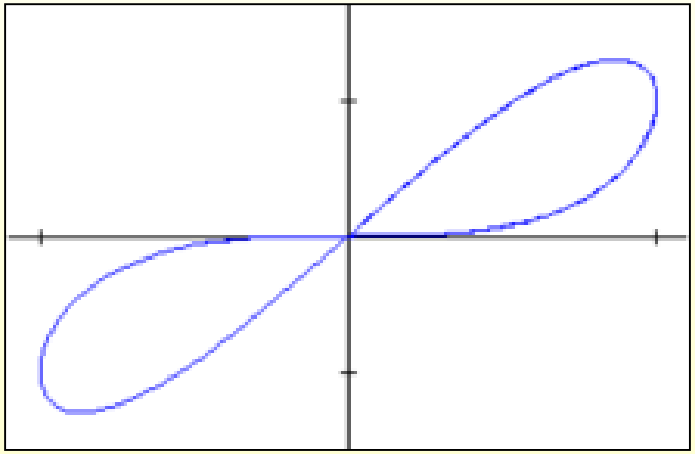


FerroMagnetic Nano Platelets (FMNPs)

Two designs for embedded memory devices based on the CISS effect and magnetic nano palettes.

- Four layers vertical printable device (easy to fabricate).
- Lateral 40nm device based on two layers.



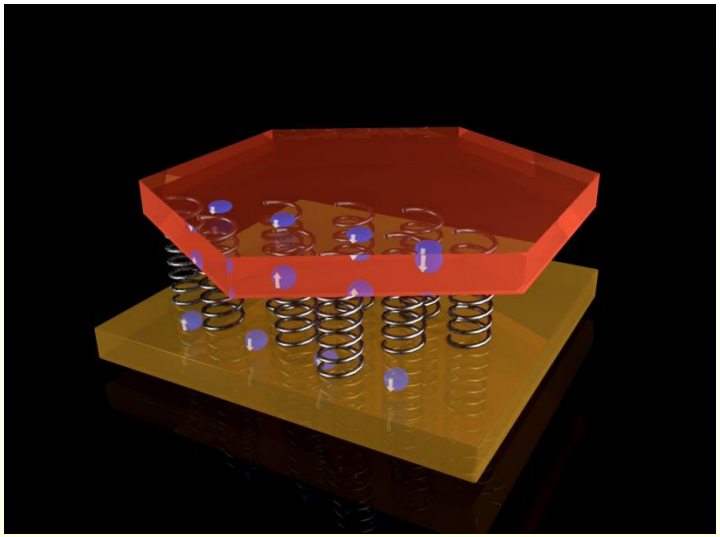


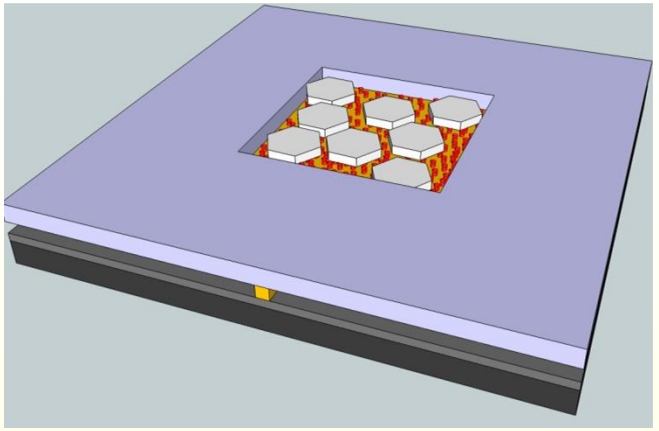
Different resistance states

Chua, L. O. (1971), "Memristor—The Missing Circuit Element", IEEE Transactions on Circuit Theory, CT-18 (5): 507-519

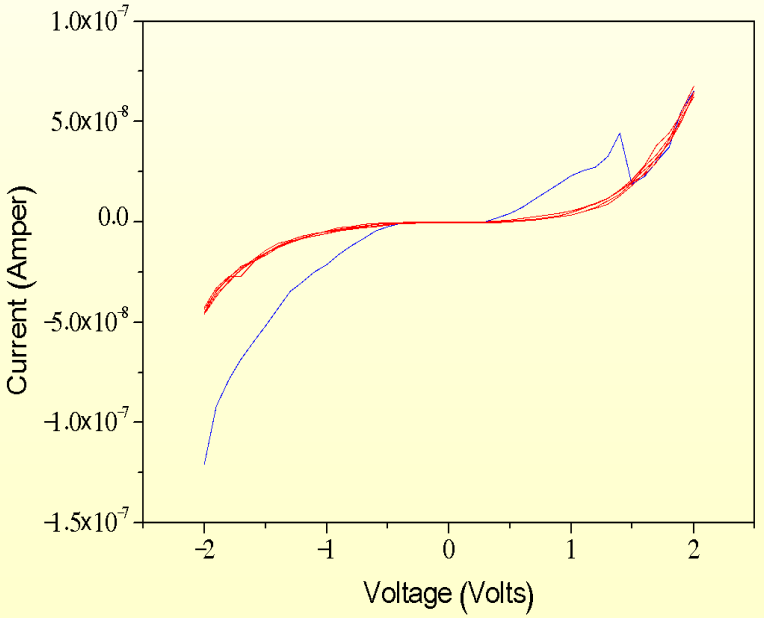
Vertical Memristor Device

Advanced Materials March 2017



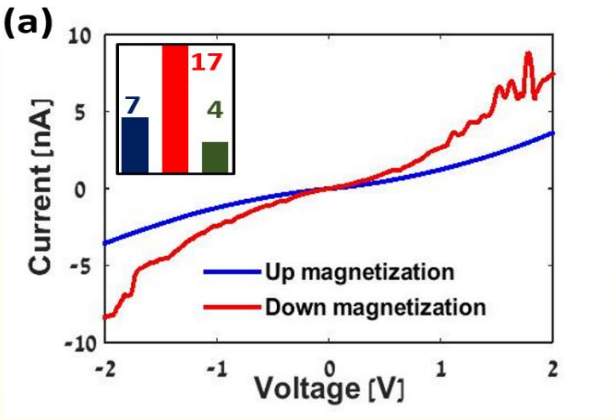


- **Bottom electrode**
- **Adsorb AHPA-L or AHPA-D and multiple FMNPs**
- **Al_2O_3 tunnel barrier**
- **Top electrode**

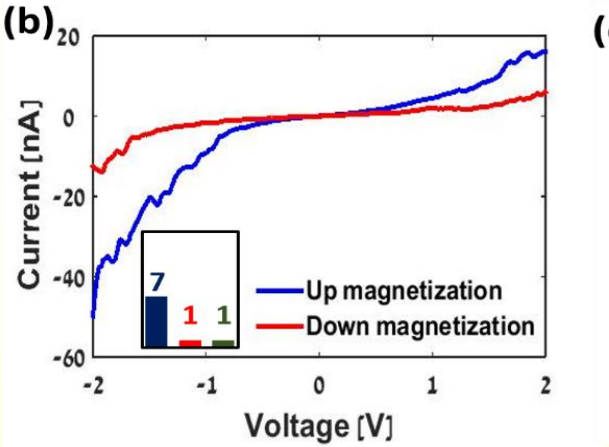


Vertical Memristor Device

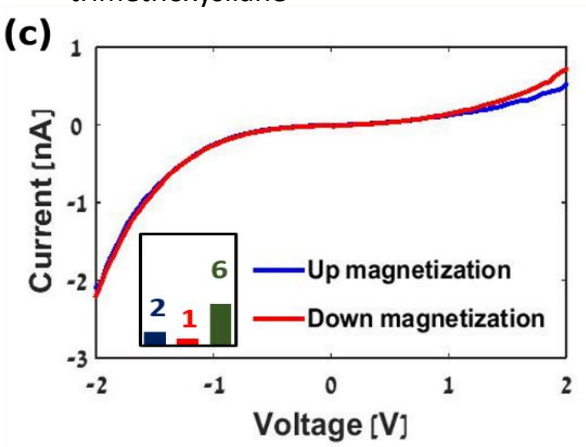
AHPA-L (α-Helix Poly-Alanine –L)

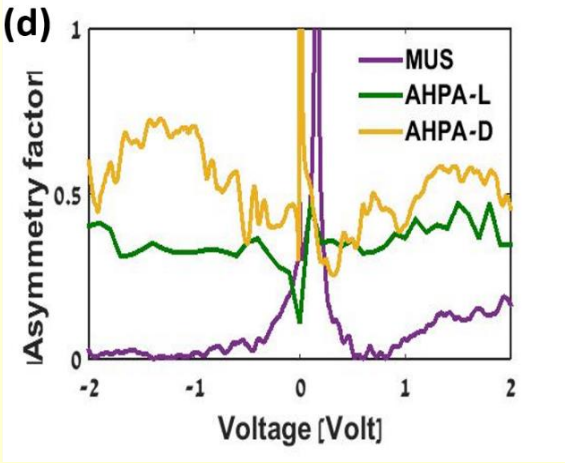


AHPA-D (α-Helix Poly-Alanine – D)



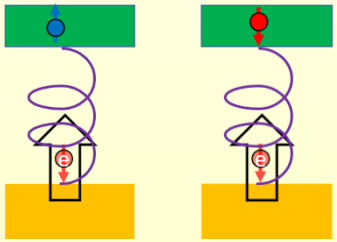
MUS- non-chiral 11-mercaptoundecyl-trimethoxysilane



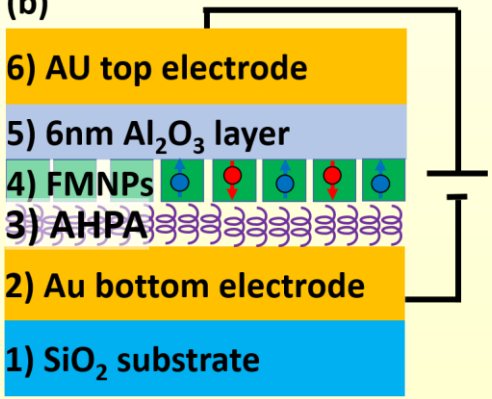


(c) Low resistance

(d) High resistance

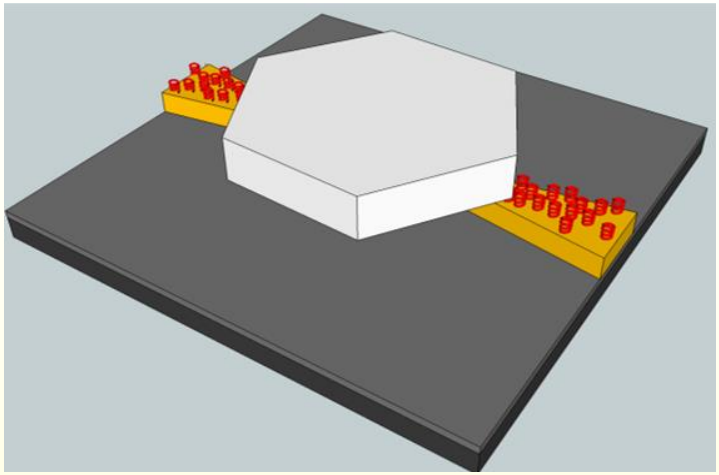


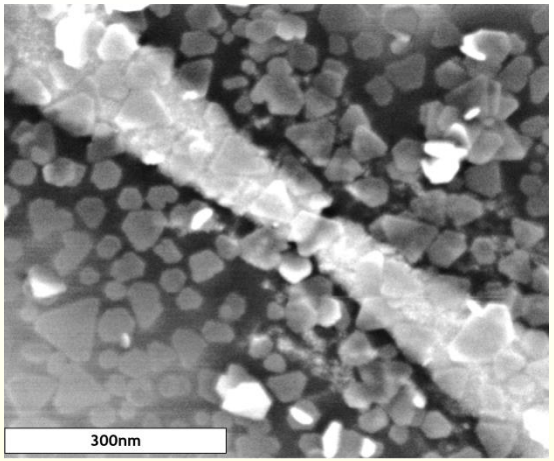
(b)



Advance materials March 2017

40nm Lateral Device

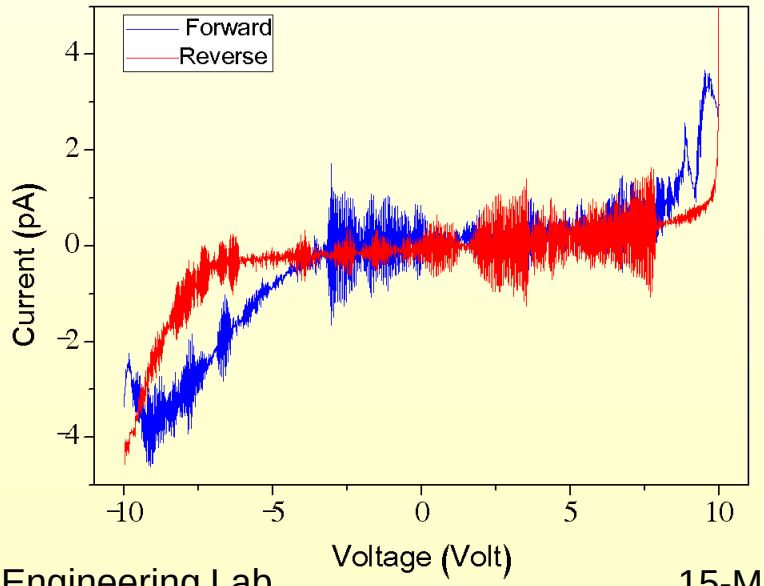




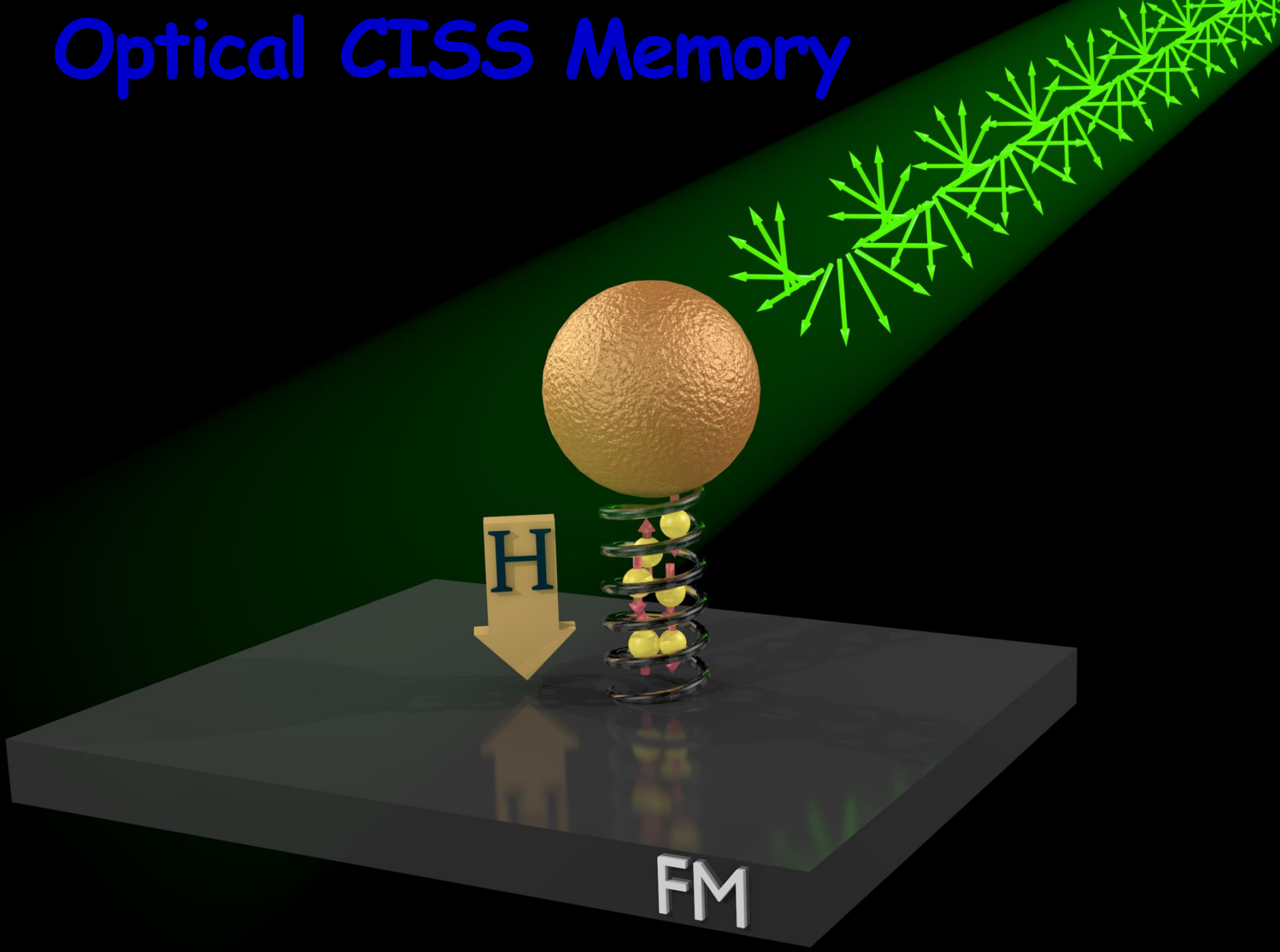
Bottom electrode

Adsorb AHPA-L and multiple FMNPs

The blue curve is before "writing" it jumps to high resistance when exposed to current.

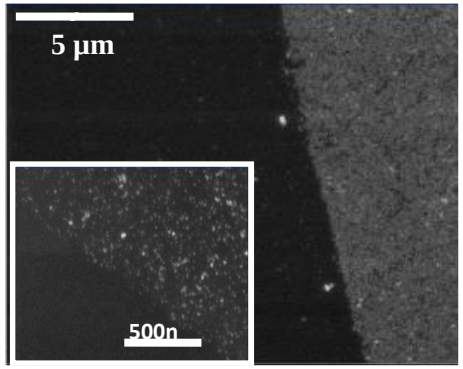


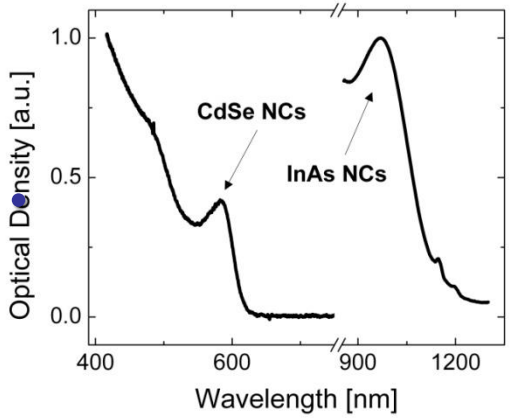
Optical CISS Memory



Methods

Optically induced charge transfer device





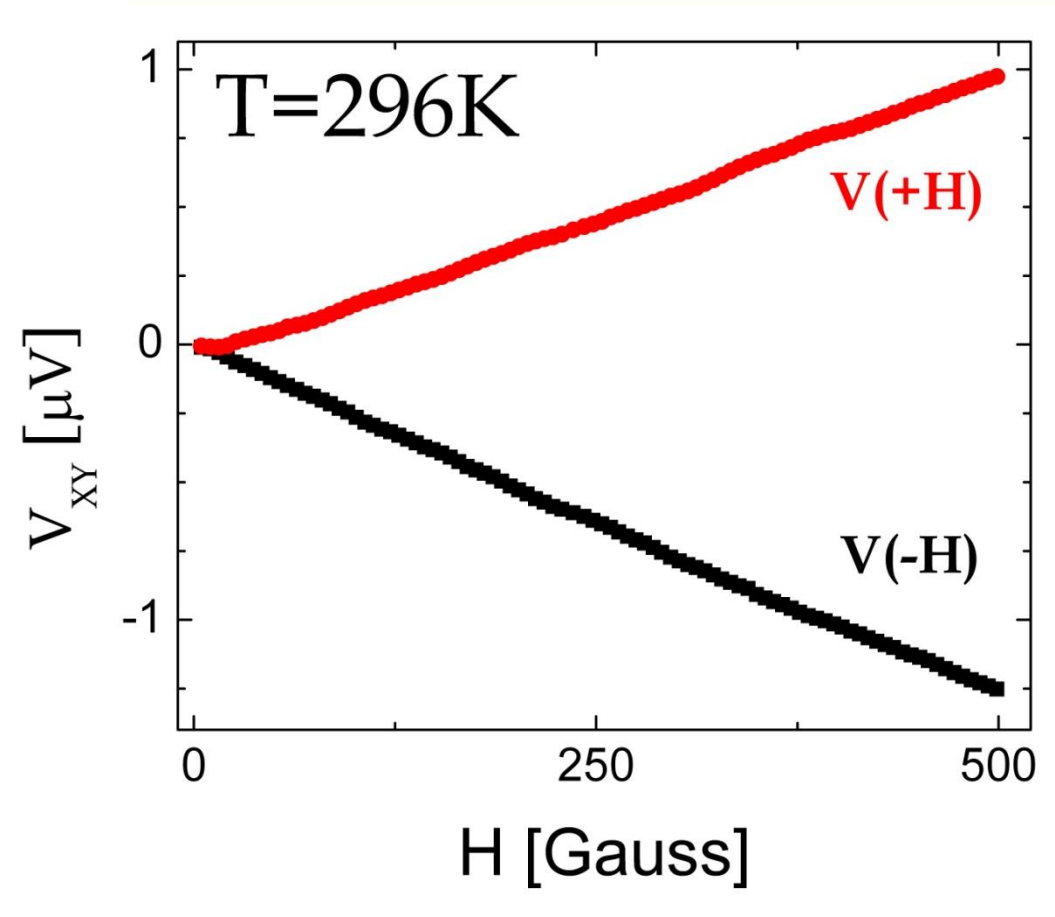
Ni-based Hall effect device (anomalous HE)

532nm Circular Polarized Beam

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

Q N E Lab

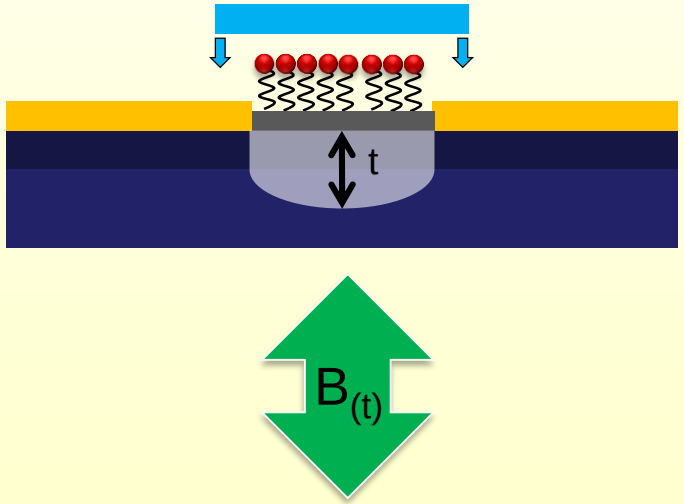
Calibration



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

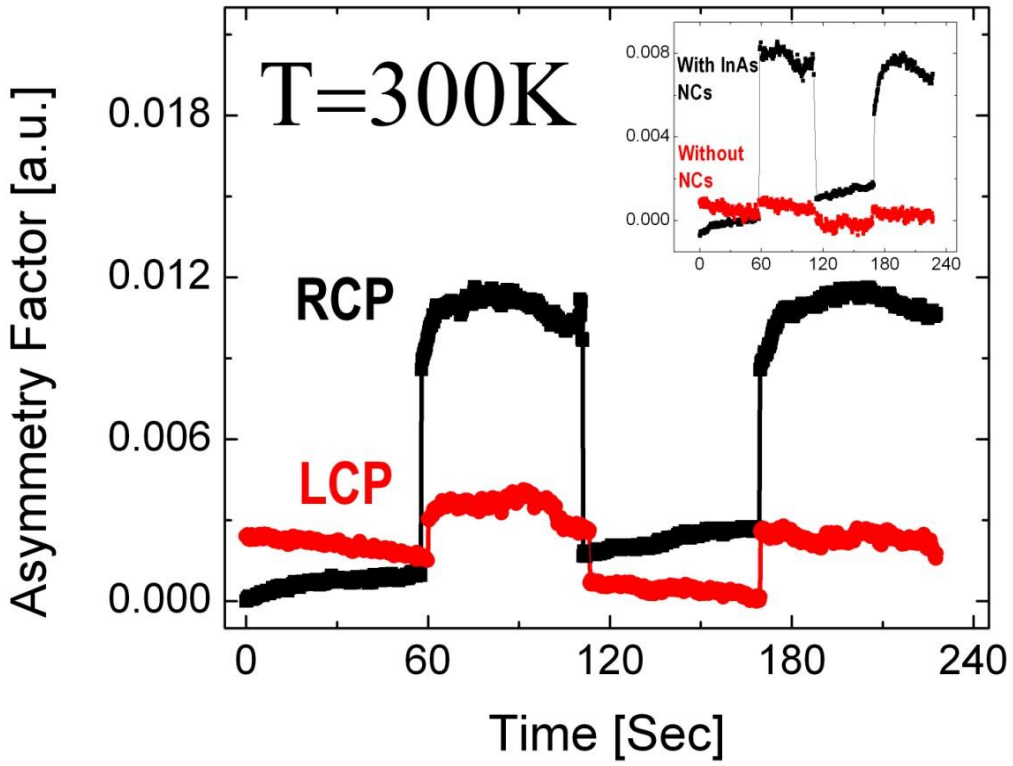
$$\Rightarrow \; n_{experiment} \sim 10^{27} \; electrons / Meter^3$$

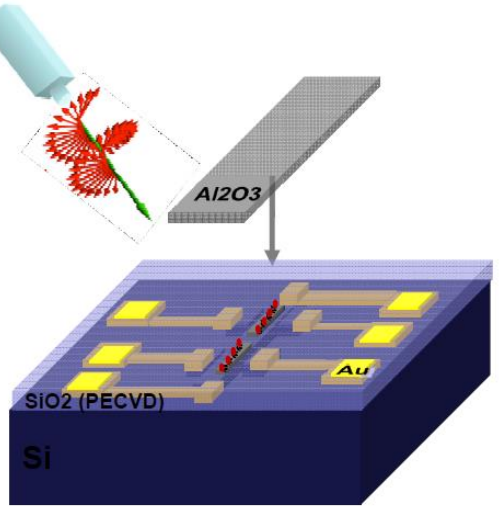
$$n_{theory} \sim 5 \cdot 10^{26} \; electrons / Meter^3$$



Optical CISS memory

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



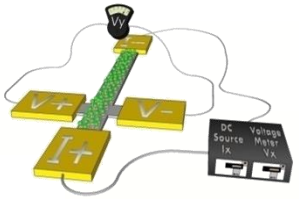


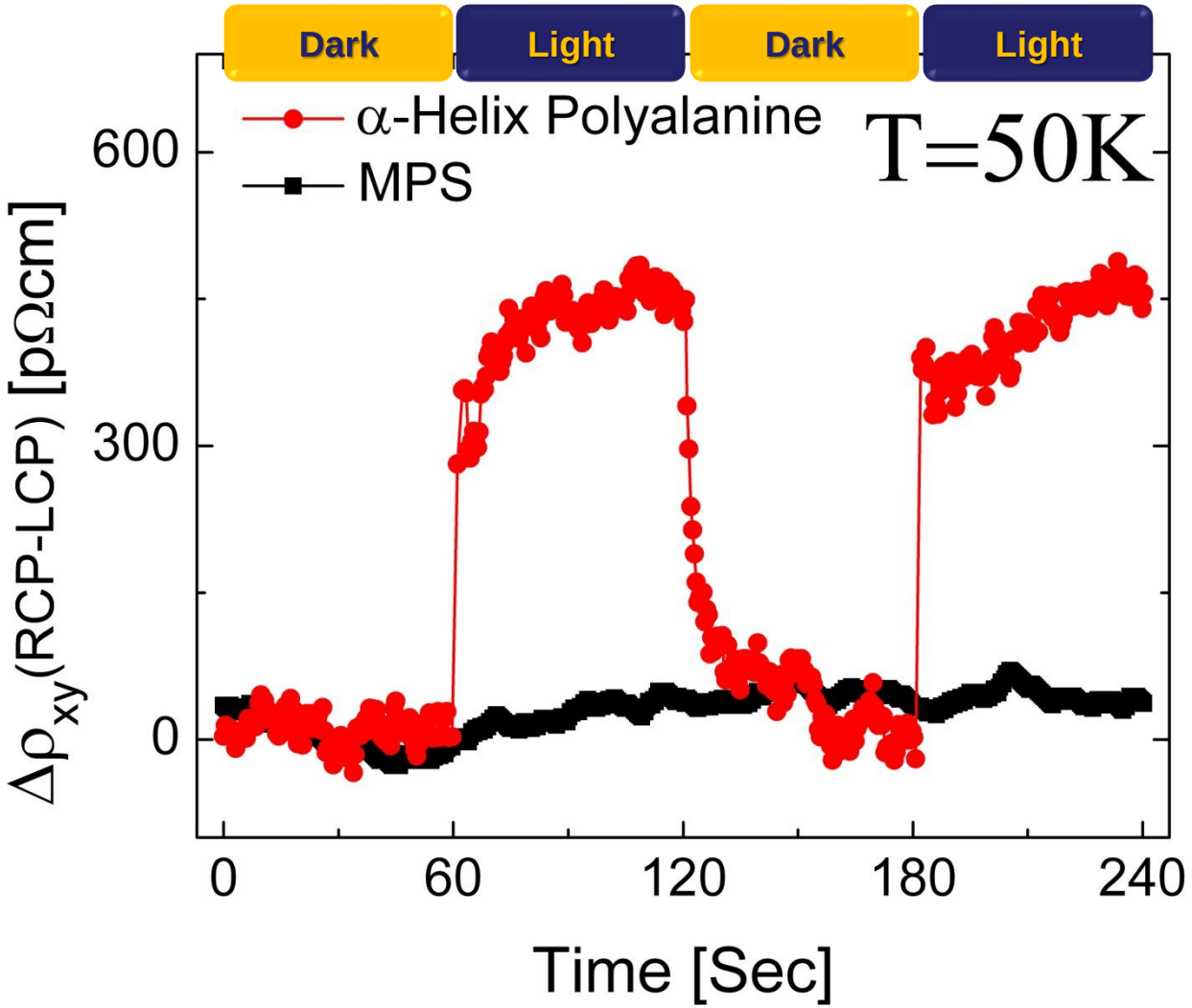
Nano letters **14** 6042 (2014).

One order of magnitude difference – Spin detector

Results

Nano letters 2014

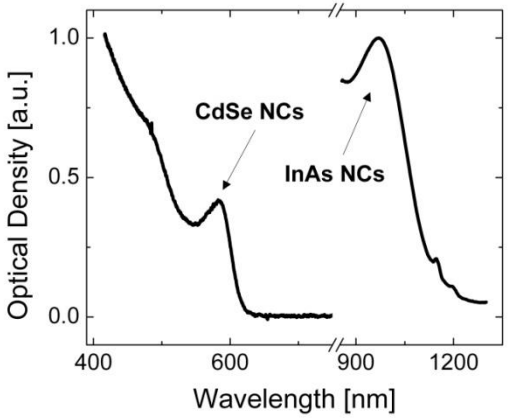


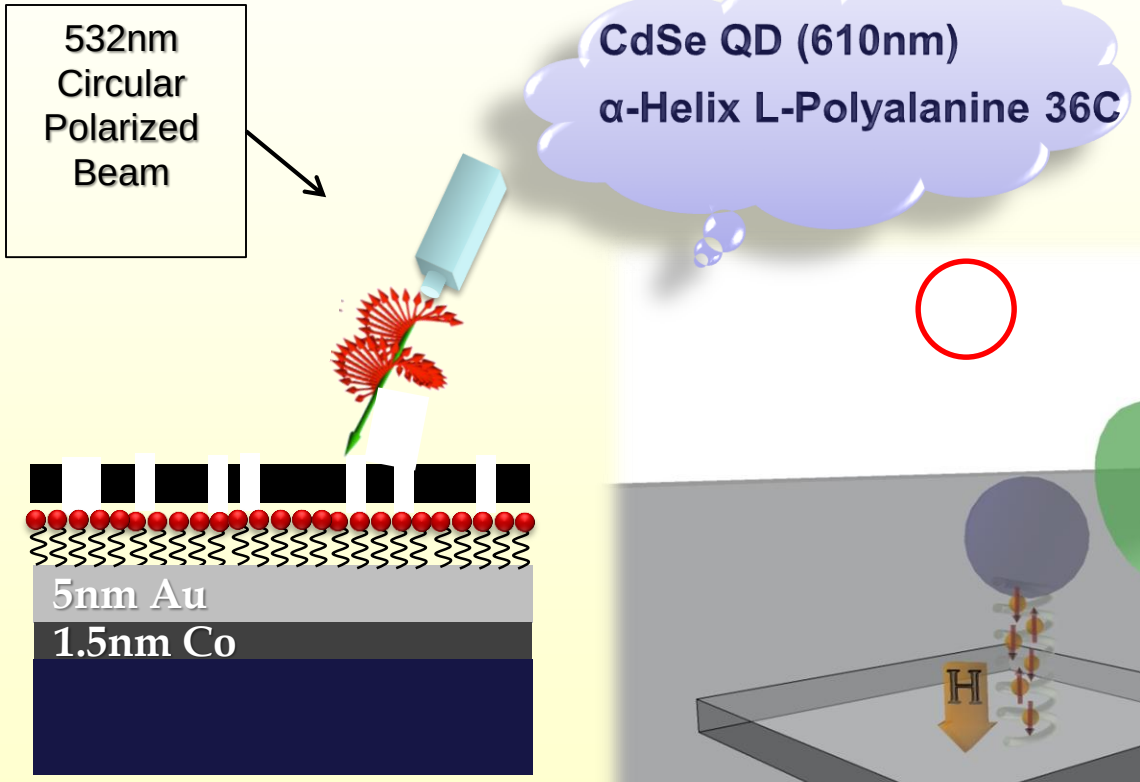


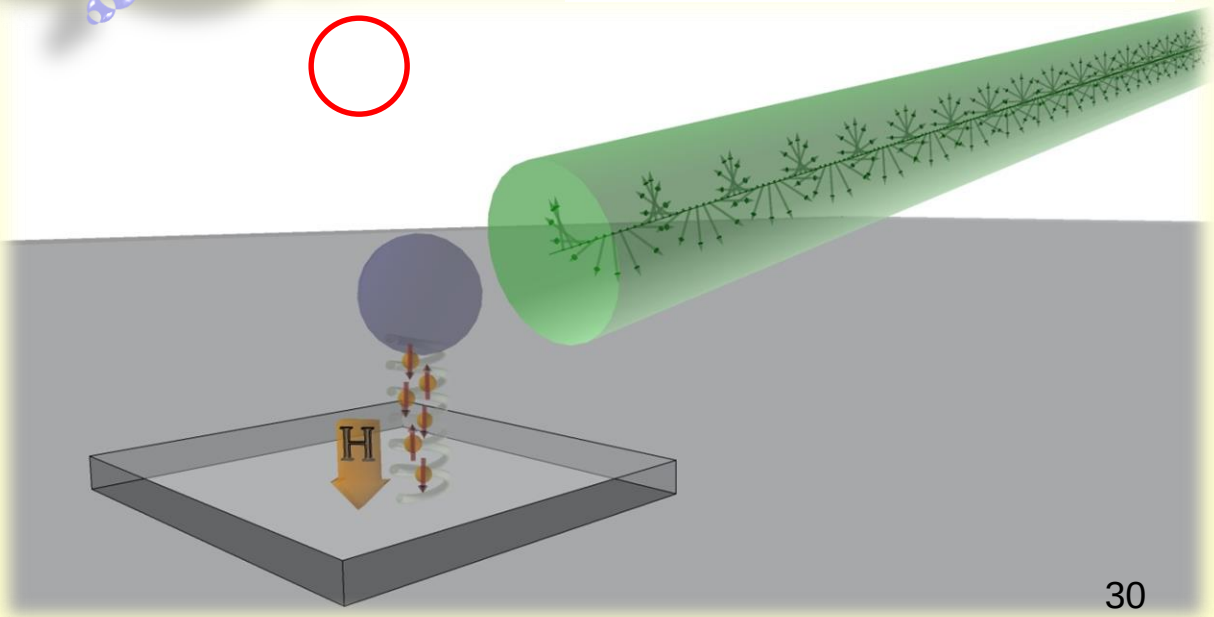
Methods

Optically induced charge transfer device

Highly localized magnetization device (measured with MFM)

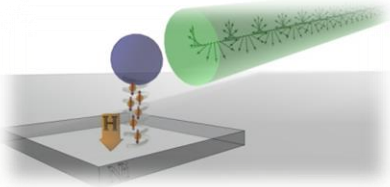






Results

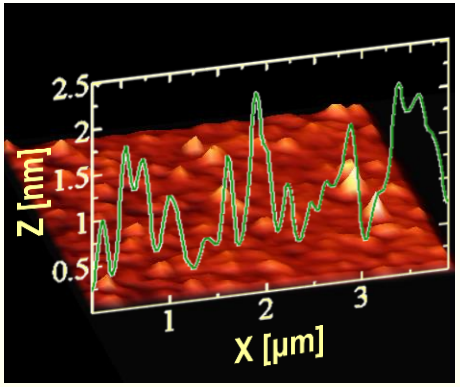
Nano letters 2014

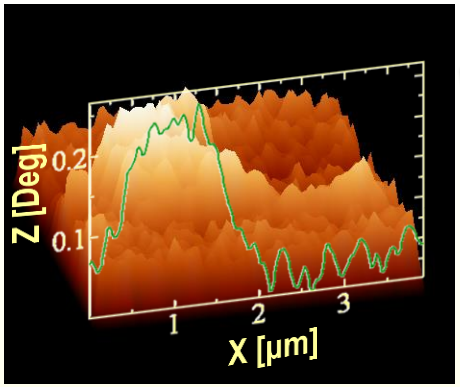


Topography

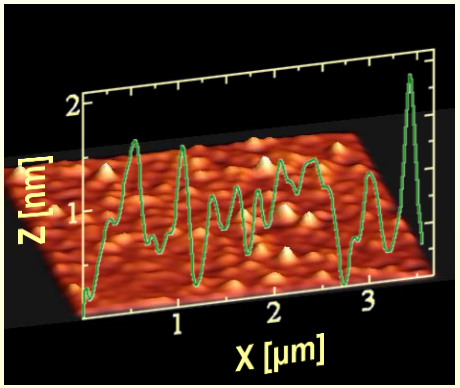
Magnetism

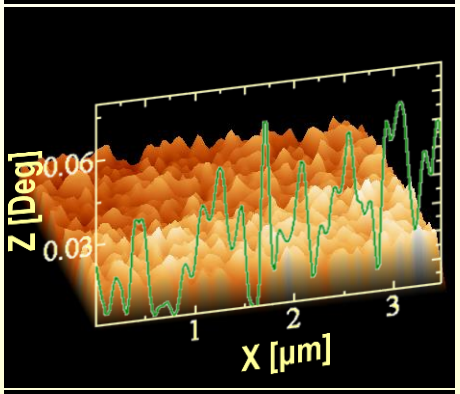
Illuminated area
in illuminated sample



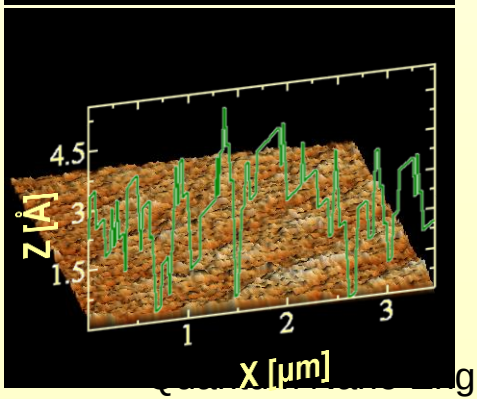


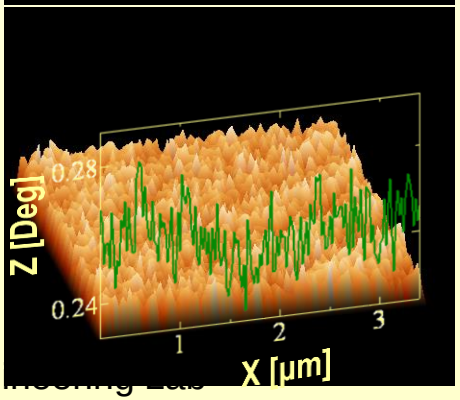
Unilluminated area
in illuminated sample



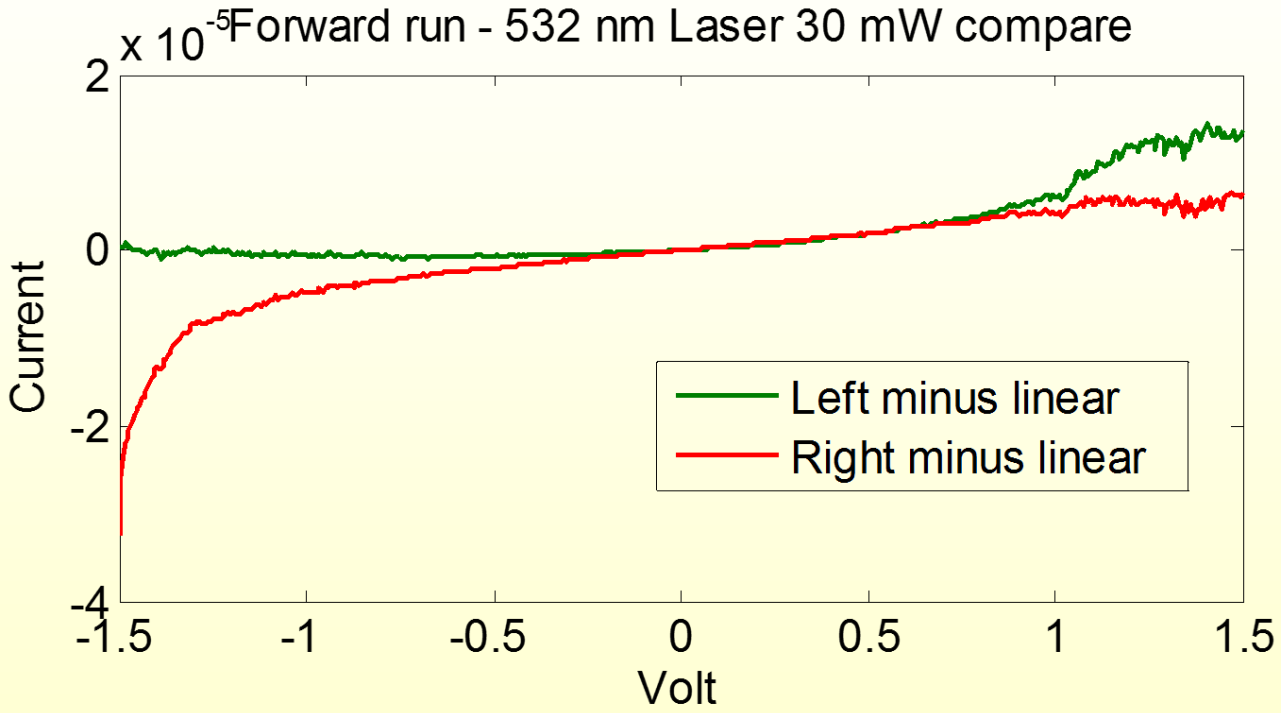


Illuminated area
in reference sample
(no Molecules & no NC)





Nano Metric charge separation



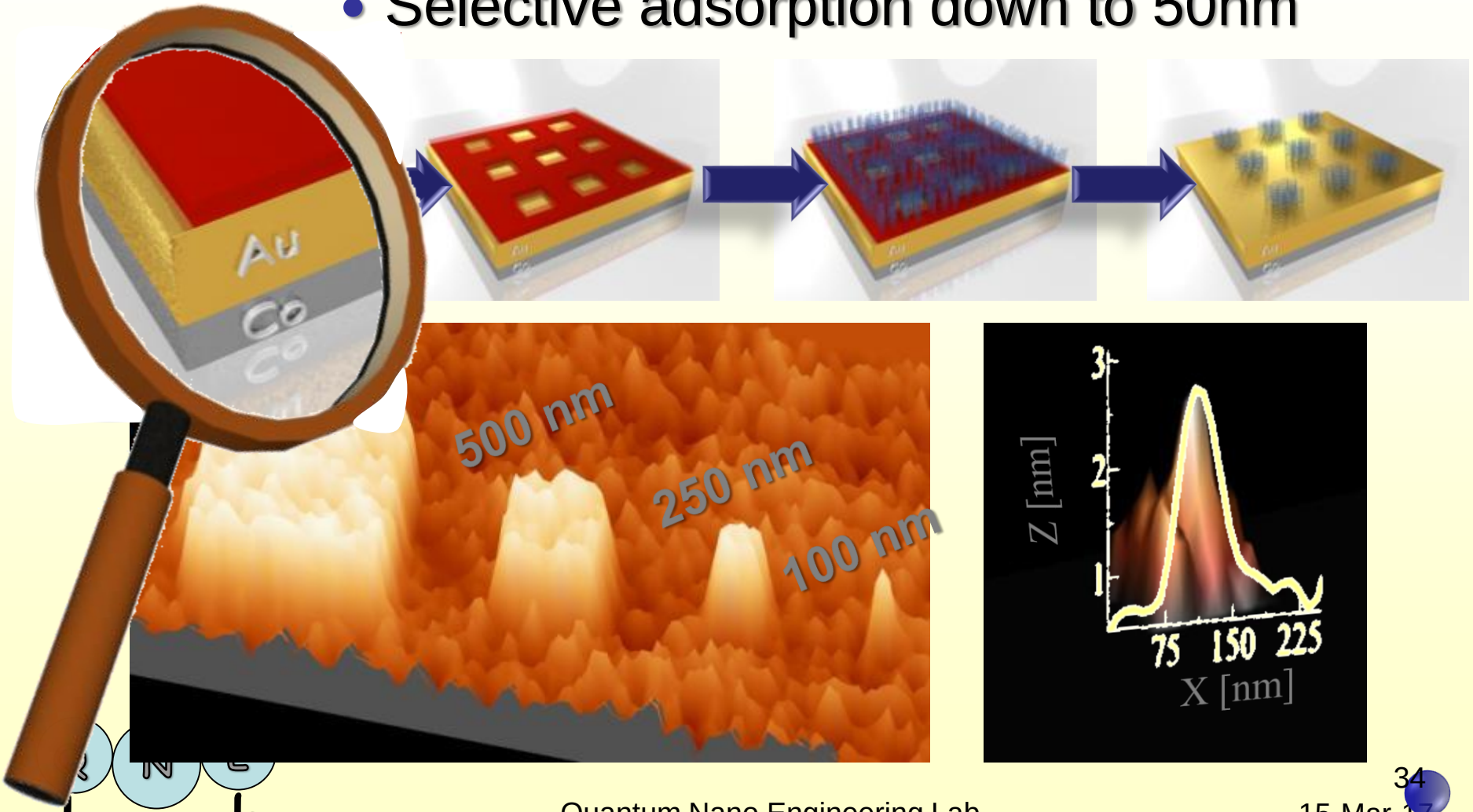
Peer *et al*. ACS photonics (2015).

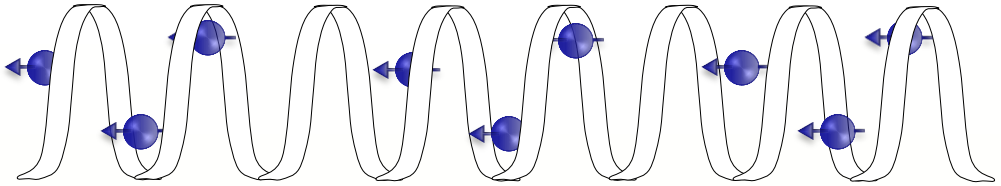
Can we do it without light, current, or external magnetic field ???

Magnetization with no current

Ben-Dor et al. Nature Communications February 2017

- Selective adsorption down to 50nm



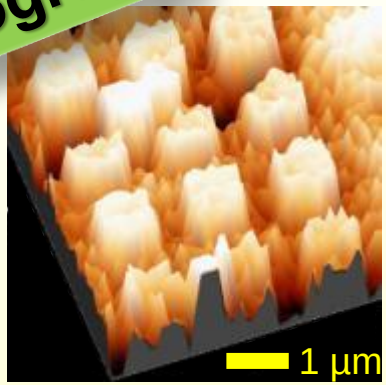


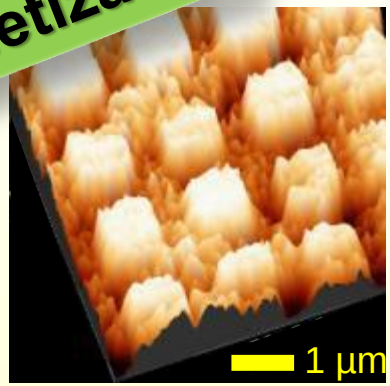
Selective adsorption -> Selective magnetization

Topography

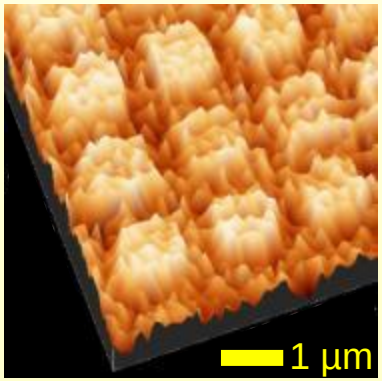
Magnetization

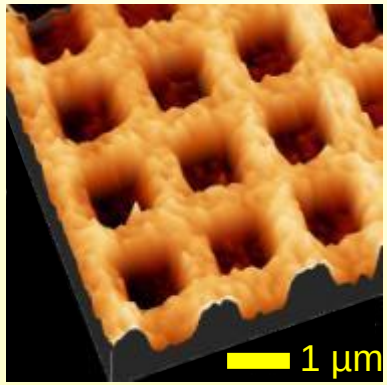
AHPA-L





AHPA-D



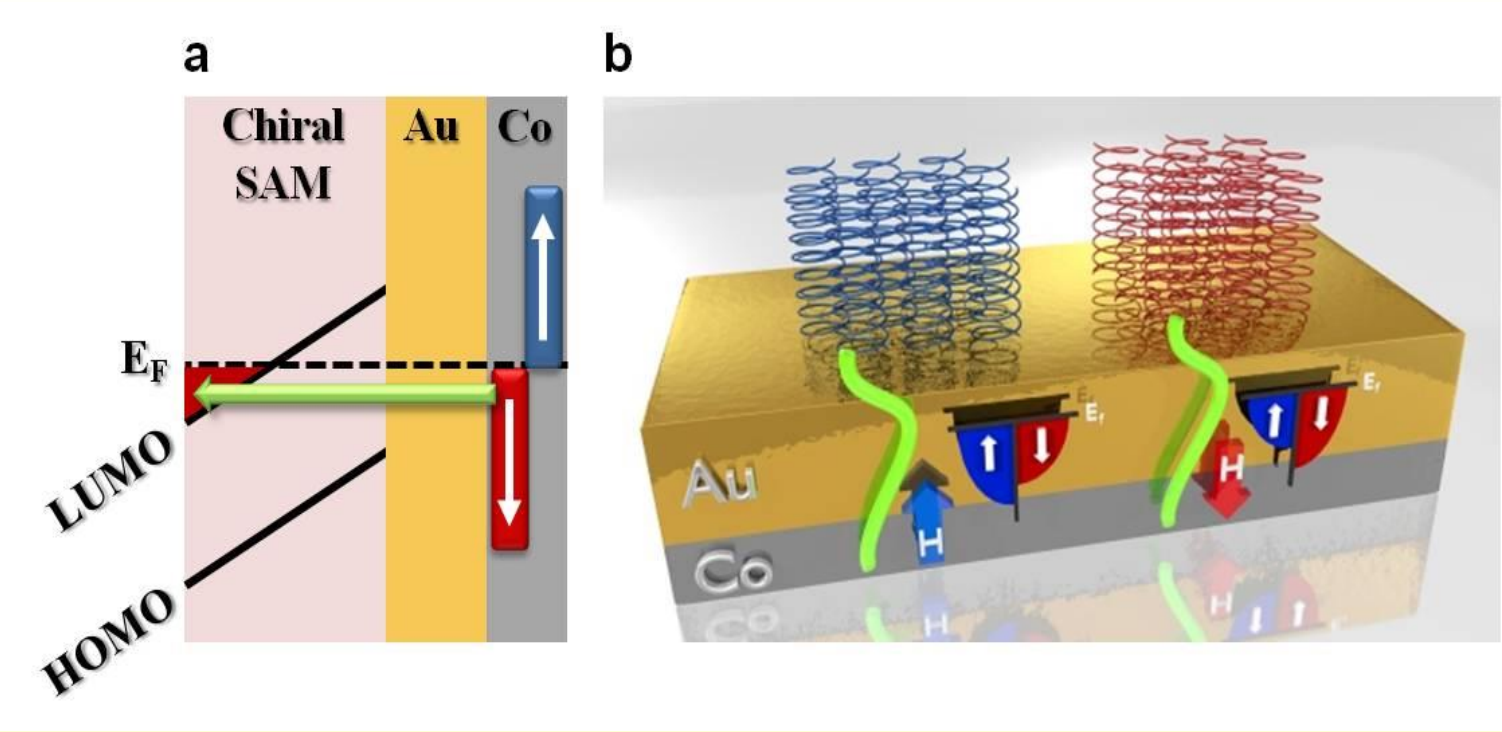


Ben-Dor et al.

Nature Communications

February 2017

Semi- Classical Vs Quantum

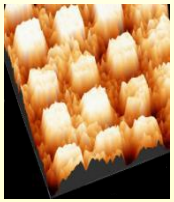


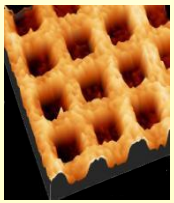
Fraction of a charge??

Coherent???

Summery We show a simple way to solve material and current problems

- CISS based devices work as optical/electrical memory at ambient in a device of 40x40 nm.
- It works as a reading head at ambient with dimensions of 10x10 nm.
- The hystheresis is “meristor like” which can be used as embedded memory in integrated circuits.
- Induced local magnetization switching by local adsorption of chiral molecules on ferromagnets
- No need for current or external magnetic field – down to single domain size only 0.5nm deep.





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