

Moving Toward Organic Spintronics

Jung-Woo Yoo

*A. J. Epstein group, Department of Physics
The Ohio State University*



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Advisor : Prof. Arthur J. Epstein

Collaborators :

The Ohio State University

Dr. V. N. Prigodin

Dr. Ruth S. Edelstein

Dr. N. P. Raju

Chia-yi Chen

C. Kao

Bin Li

Deniz Duman

University of Utah

Prof. Joel S. Miller

Dr. Phokodnya

University of Wisconsin

Prof. C. B. Eom

Dr. H. W. Jang

Dr. C. W. Bark

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Outline

Organic Semiconductor as a Spin Channel

Organic-based Magnet as a Spin Injector

- Organic/molecule-based magnet
- $M(TCNE)_x$ magnet
- Spin injection/detection via an organic-based magnetic semiconductor

Conclusion

Why Organic for spintronic applications ?

Spin transporting channel

- Low spin-orbit coupling ($\sim z^4$)
 - light constitute atoms, C and H
- Low hyperfine interaction ($\sim \lambda \vec{I} \cdot \vec{S}$)
 - no nuclear spin in ^{12}C
 - π electron carriers
- Greater flexibility of processing and new materials
 - chemical methodology

Spin polarized carrier sources

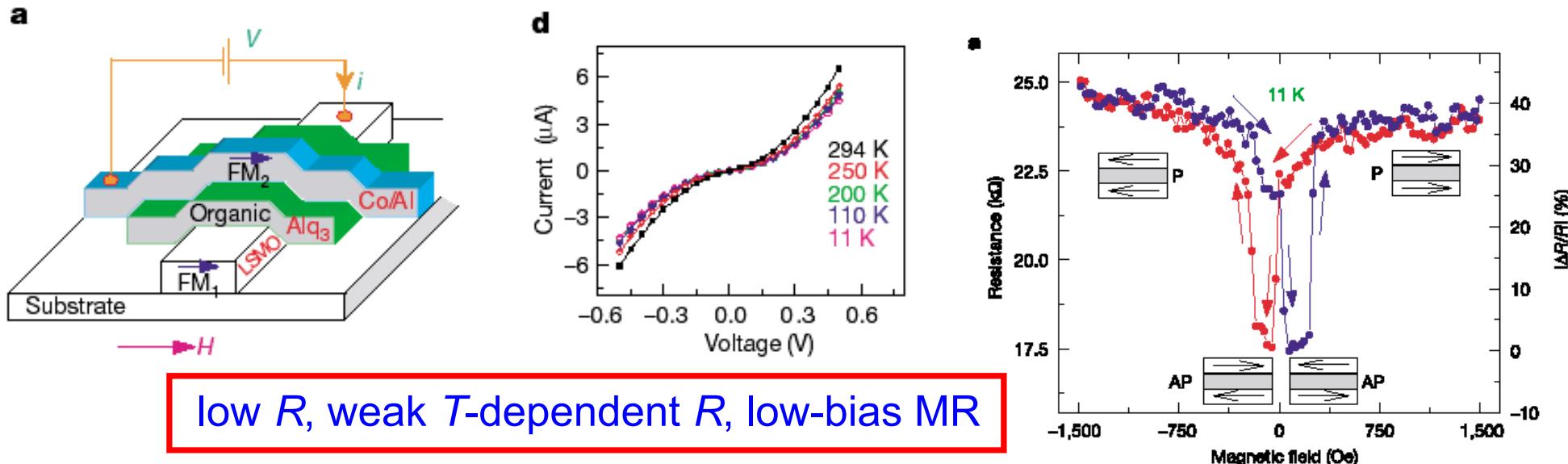
- High spin polarization
- Introduce greater functionality (magnetic bistability, photo- magnetism)
- Conductivity mismatch
- Greater flexibility of processing and new materials
 - chemical methodology

Organic-based Spin valve

- Spin valve based on OSE spacer

Xiong et. al. Nature **427** 821 (2004)

- Alq₃ for spacer : LSMO/Alq₃/Co, ~ 100 nm of Alq₃ spacer



Then.....

- thin Alq₃ layer ($t < 10\text{nm}$) for TMR device,
- TMR in the local defect due to rough surface
- TMR of Co island to island chain
- “Absence of spin transport in the organic semiconductor Alq₃”

- Muon spin rotation study
- Photoemission study
- Interface hybridization

Santos et. al. PRL **98** 016601 (2006)

Xu et. al. APL **90** 072506 (2007)

Vinzelberg et. al. JAP **103** 093720 (2008)

Jiang et. al. PRB **77** 035303 (2008)

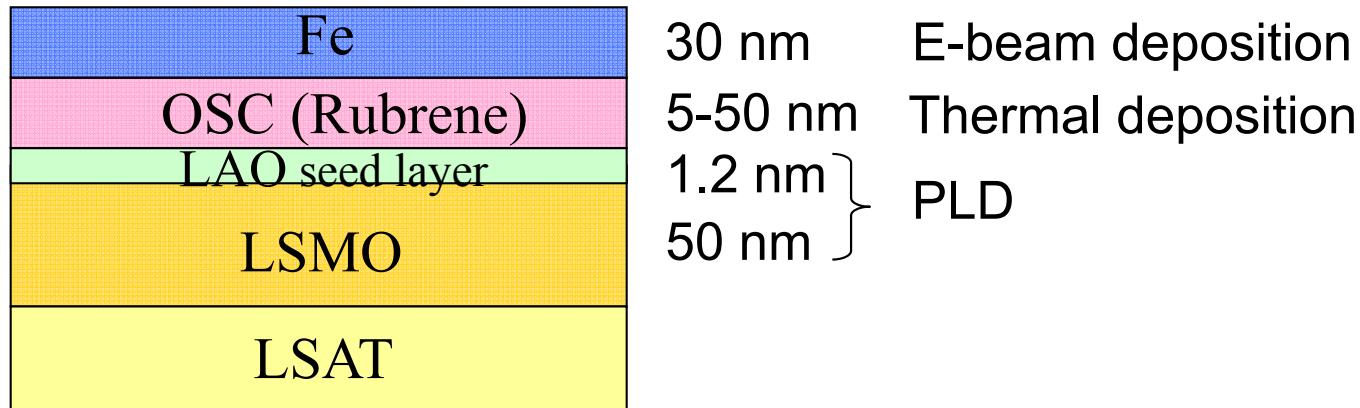
A. J. Drew et al. Nature mater. **8** 109 (2009)

M. Chinchetti et al. Nature mater. **8** 109 (2009)

C. Barraud et al., Nature Phys. **6** 615 (2010)

Device Structure

Device size ~ 200 by 200 um



Rubrene ($C_{42}H_{28}$) :

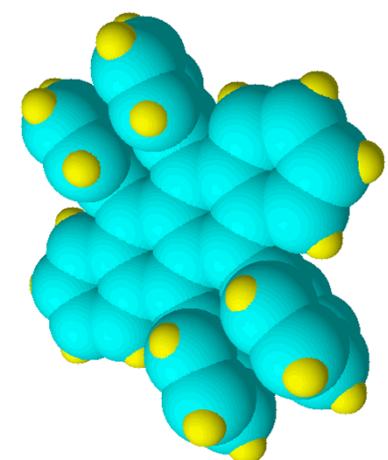
only C & H

LAO ($LaAlO_3$) :

Improve metal/OSC interfacial quality
(PRL **98** 016601 (2007))

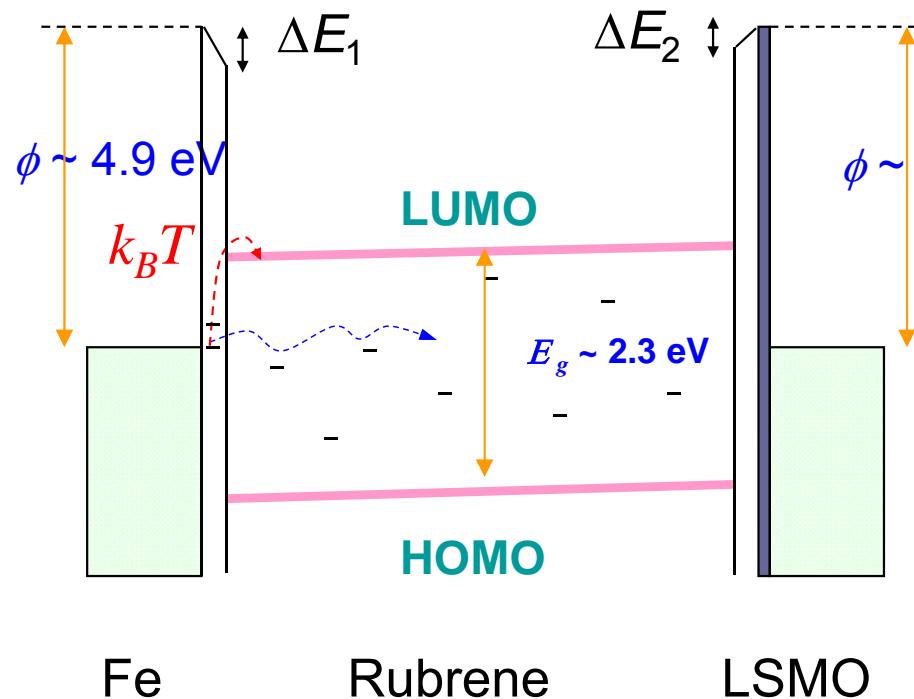
LSMO ($La_{2/3}Sr_{1/3}MnO_3$) :

well known half-metallic magnet

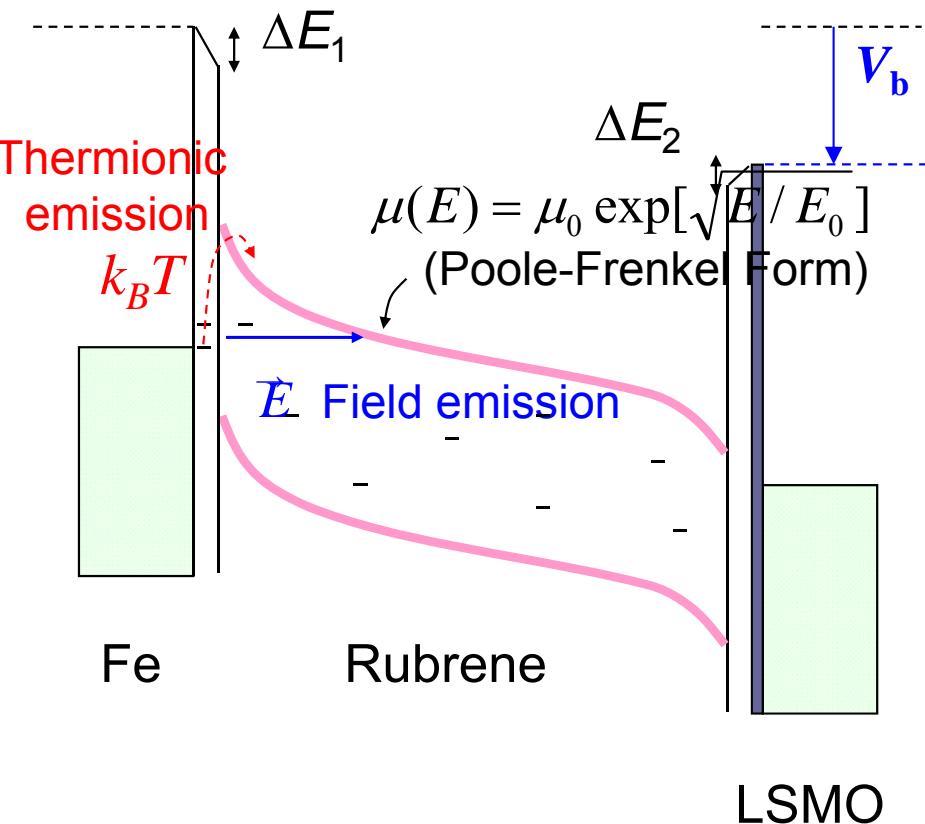


www.acdlabs.com

Tunneling vs Carrier Injection



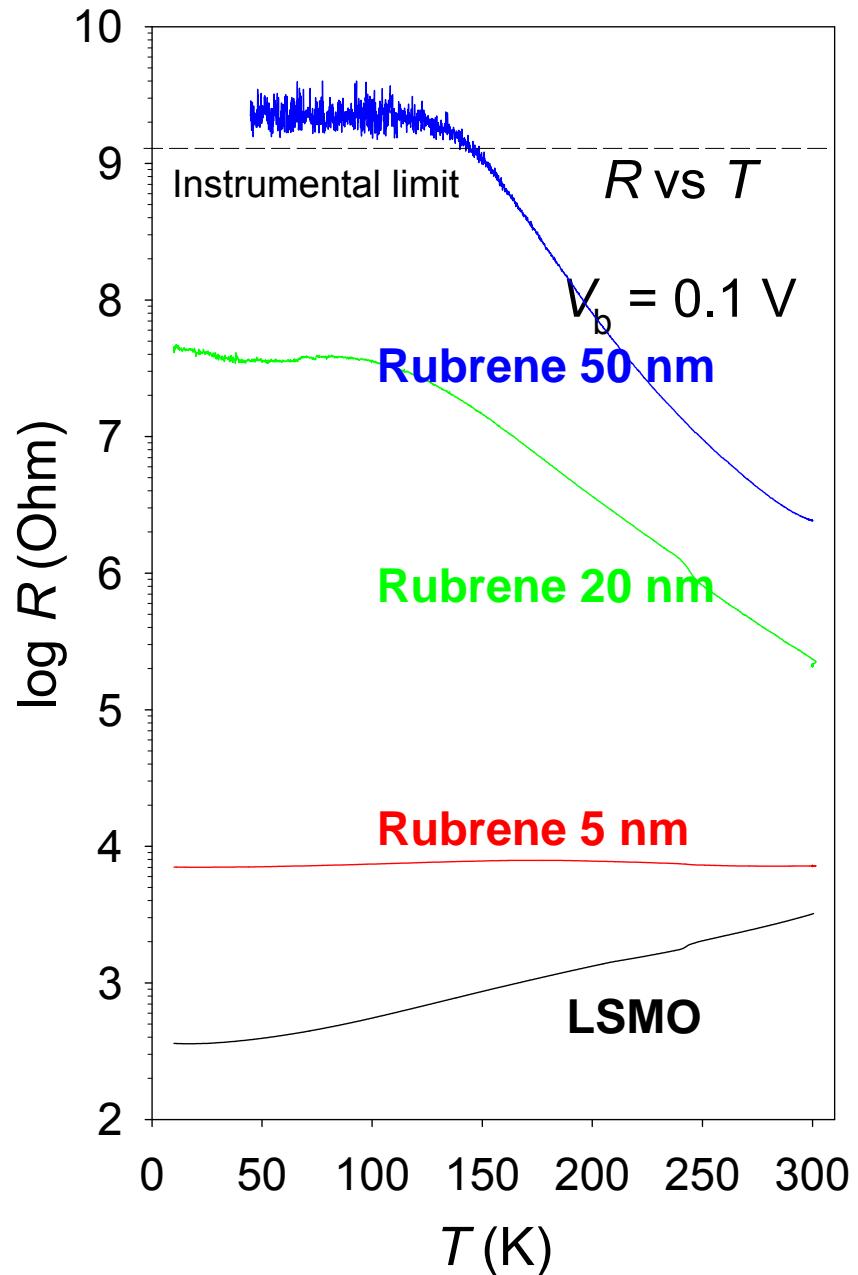
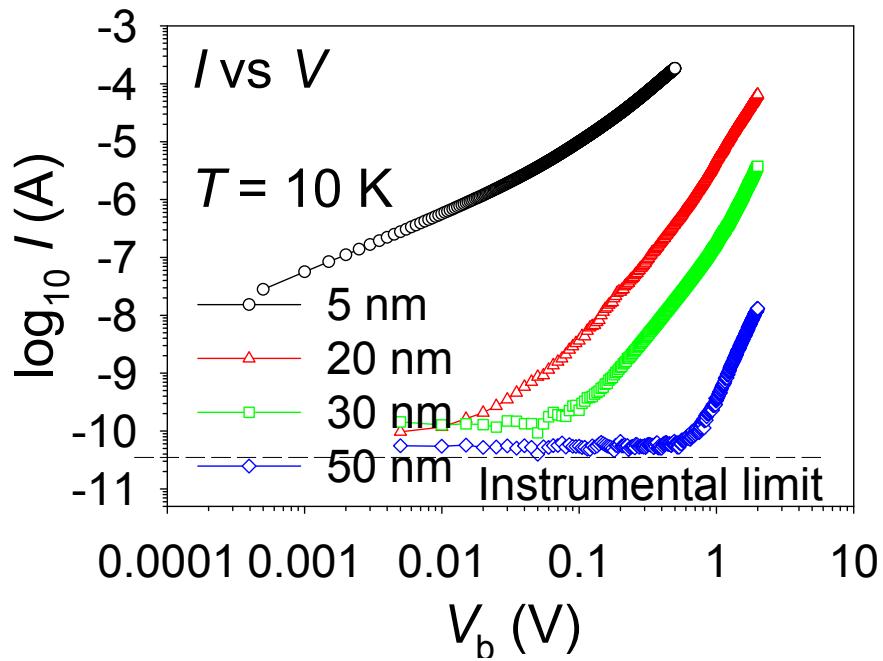
Low bias



High bias

Thermionic field emission

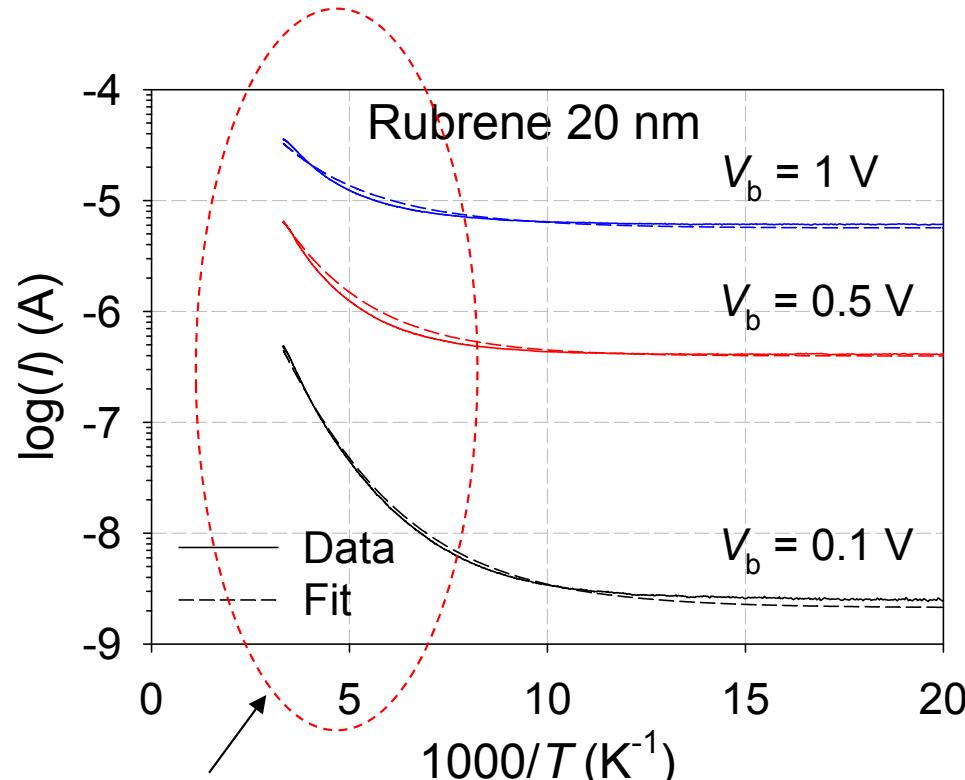
Tunneling vs Carrier Injection



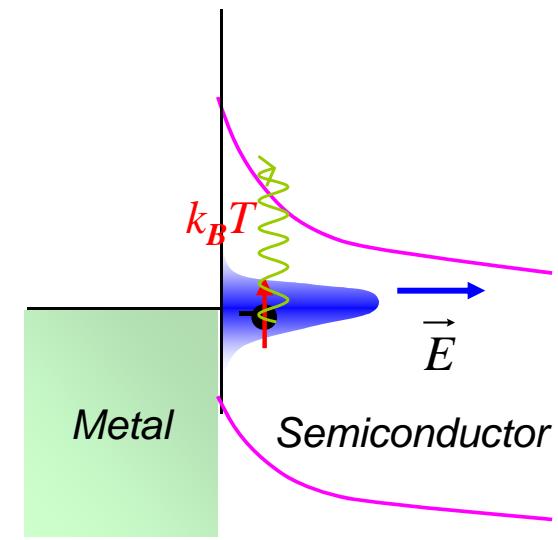
Spin injection into OSC

Yoo et al., PRB **80** 205207 (2009)

Rubrene : 20 nm



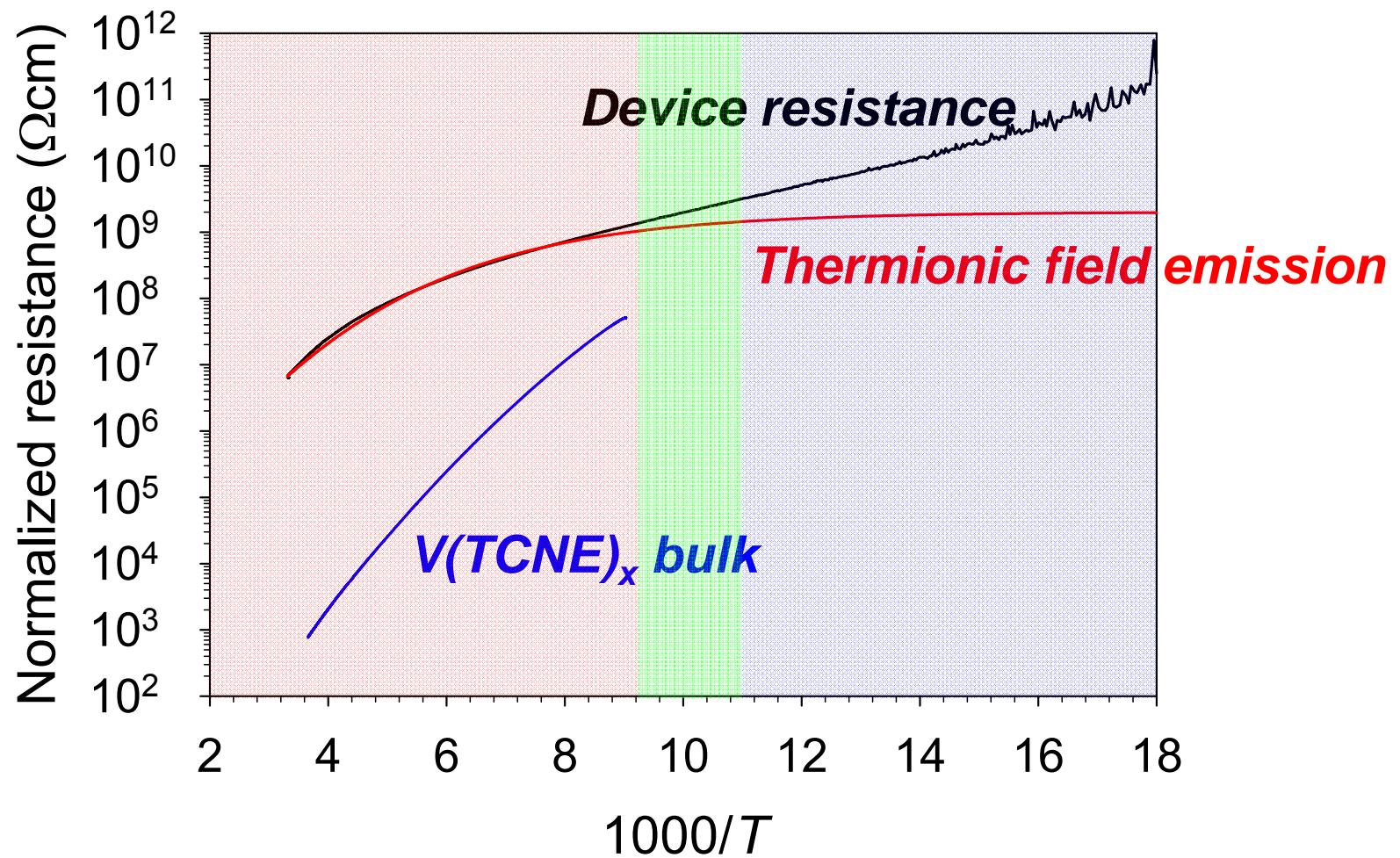
Thermionic emission



Thermionic field emission

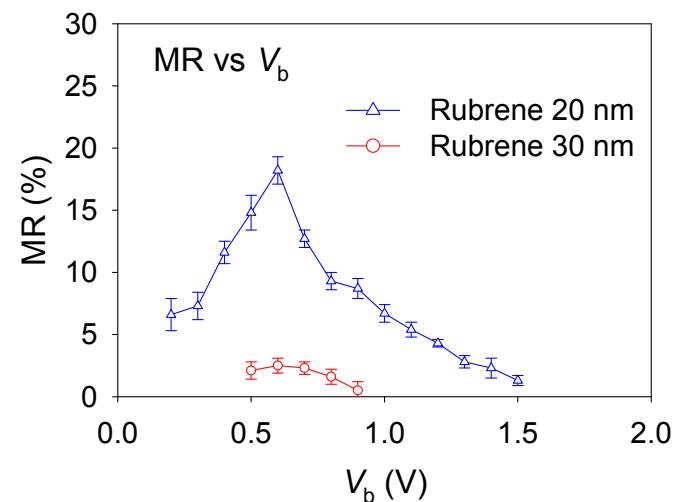
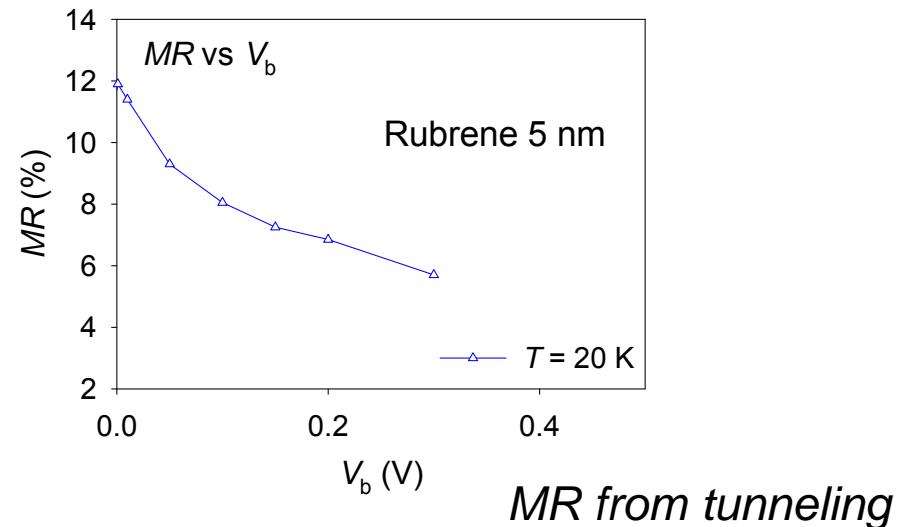
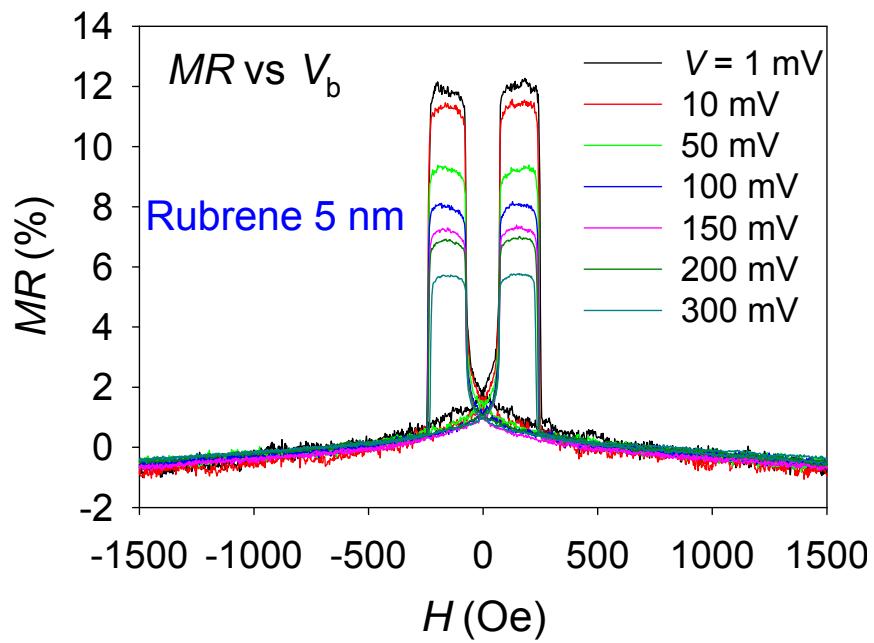
- Established charge injection/transport limit device characteristic
- Magnetoresistance induced from spin injection/transport into/in OSC

Intrinsic limitation



Magnetoresistance

Yoo *et al.*, PRB **80** 205207 (2009)



MR from tunneling

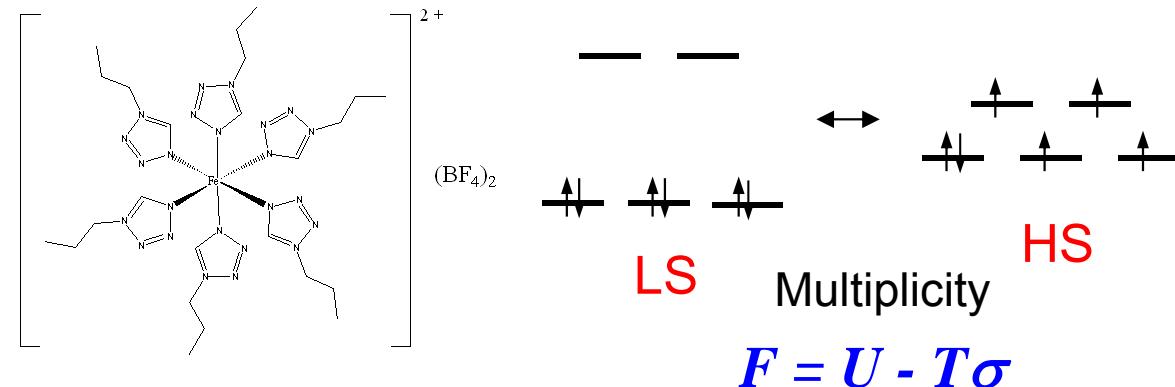
MR from injection/transport

Organic/Molecule-based Magnets

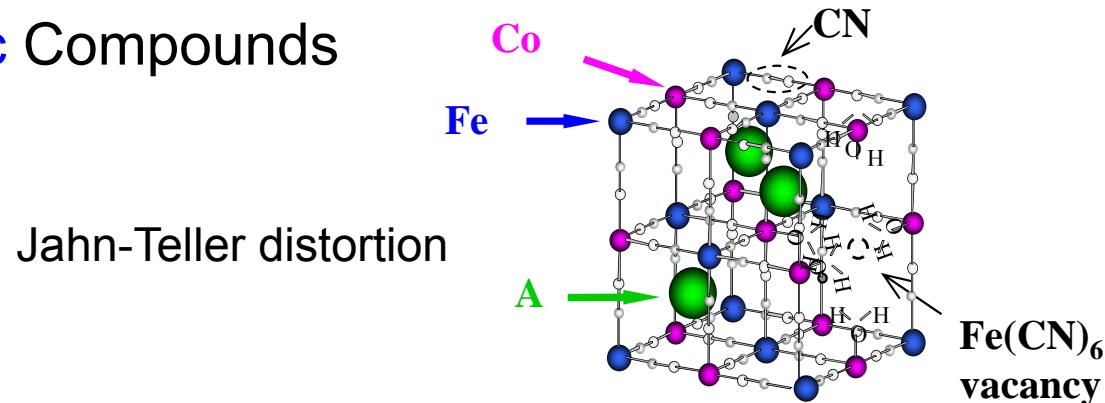
- Building block : Molecular units
- Spins in *p*, *s* orbitals as well as *d* orbitals
- Magnetic interaction : superexchange, direct exchange, dipolar
- Low-*T* synthesis
- Modulation/tuning of properties by means of organic chemistry
 - T_c , H_c
 - Magnetic ordering (ferro-, ferri-, antiferro-, spin glass)
 - Dimensions (1-D, 2-D, 3-D)
 - Types of spin (Ising, XY, Heisenberg)

Magnetic Bistability

- Spin Crossover complexes

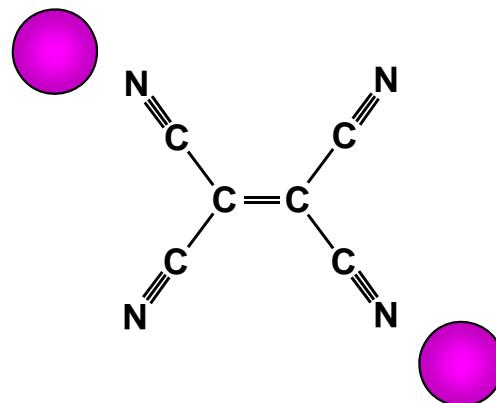


- Cyano-bimetallic Compounds

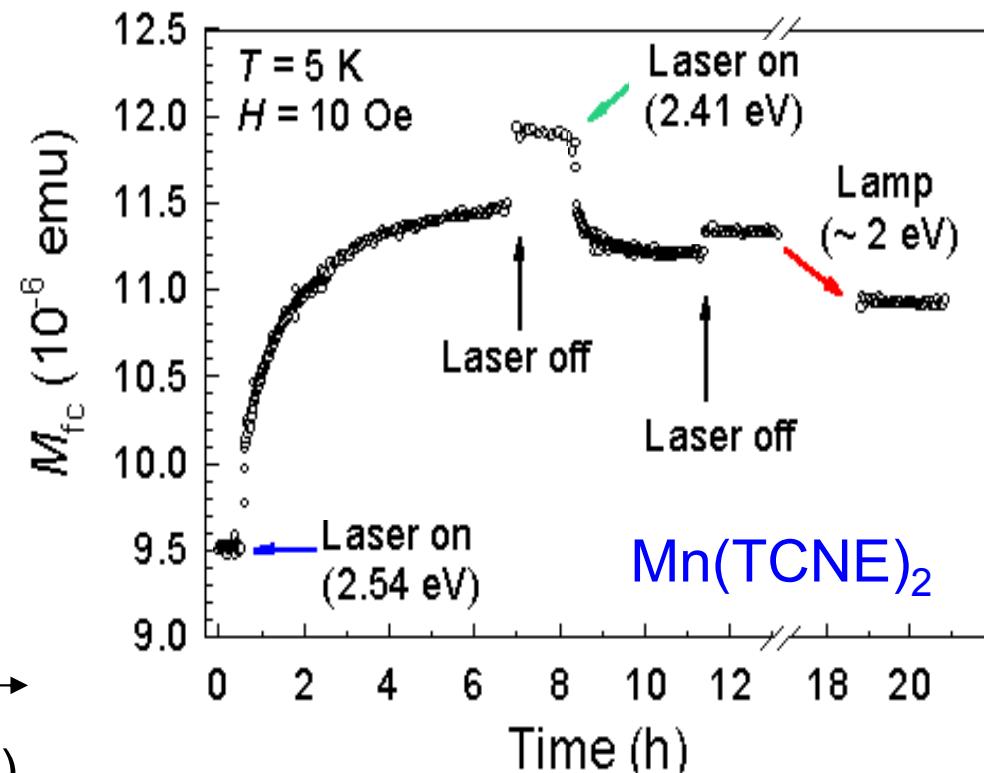
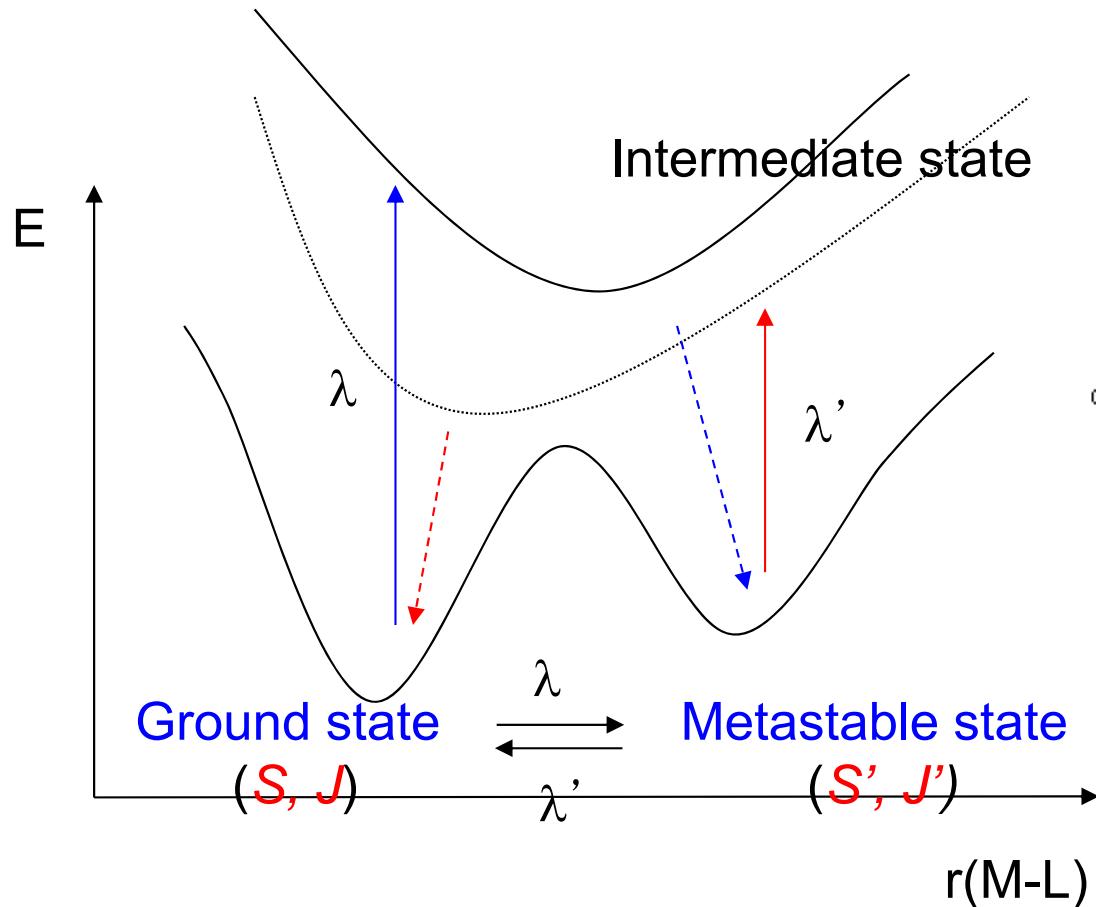


- M(TCNE)_x magnet (M = Mn, V, ...)

Metastable state



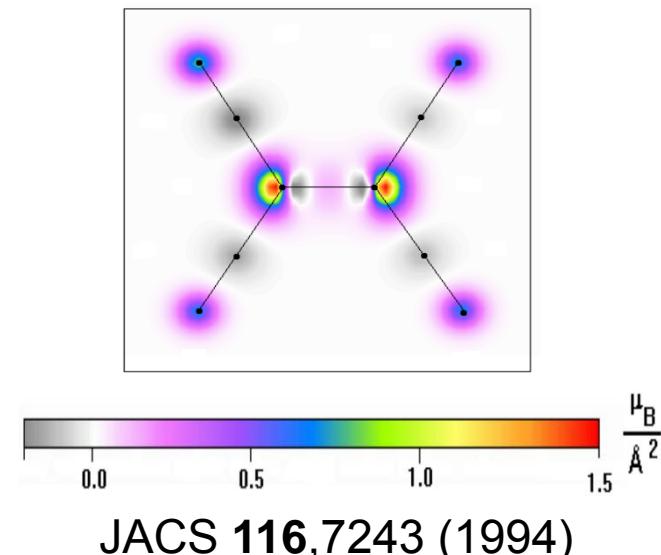
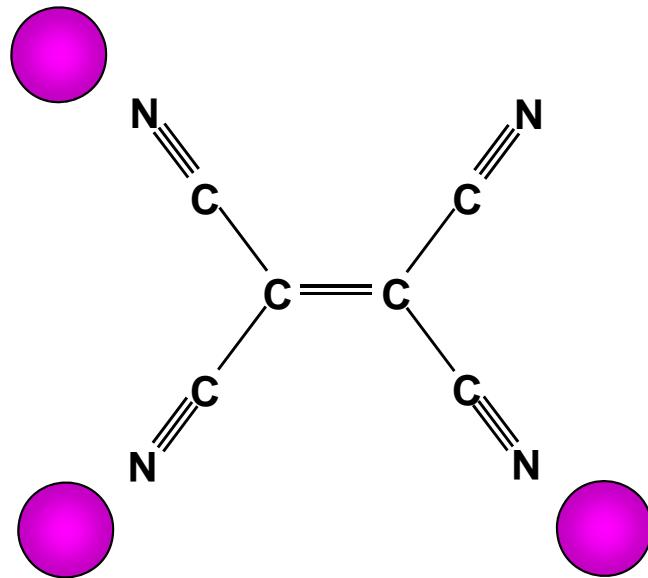
Photoinduced magnetism



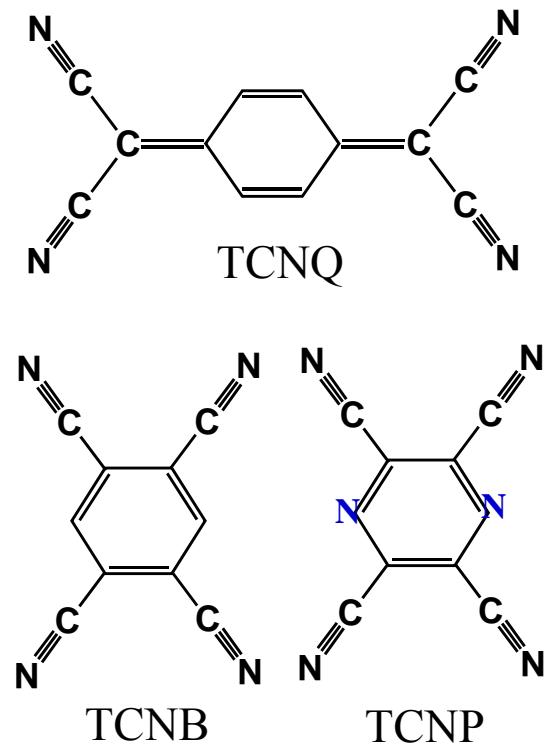
Schematic view on switching process by the light irradiation

D. A. Pejakovic *et al.*, PRL (2002)

$M(TCNE)_x$ magnets ($x \sim 2$)

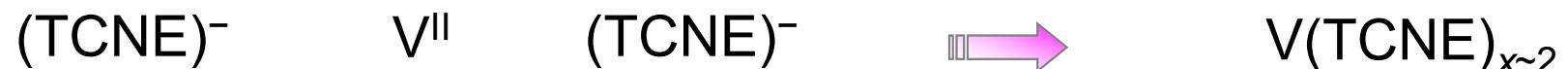
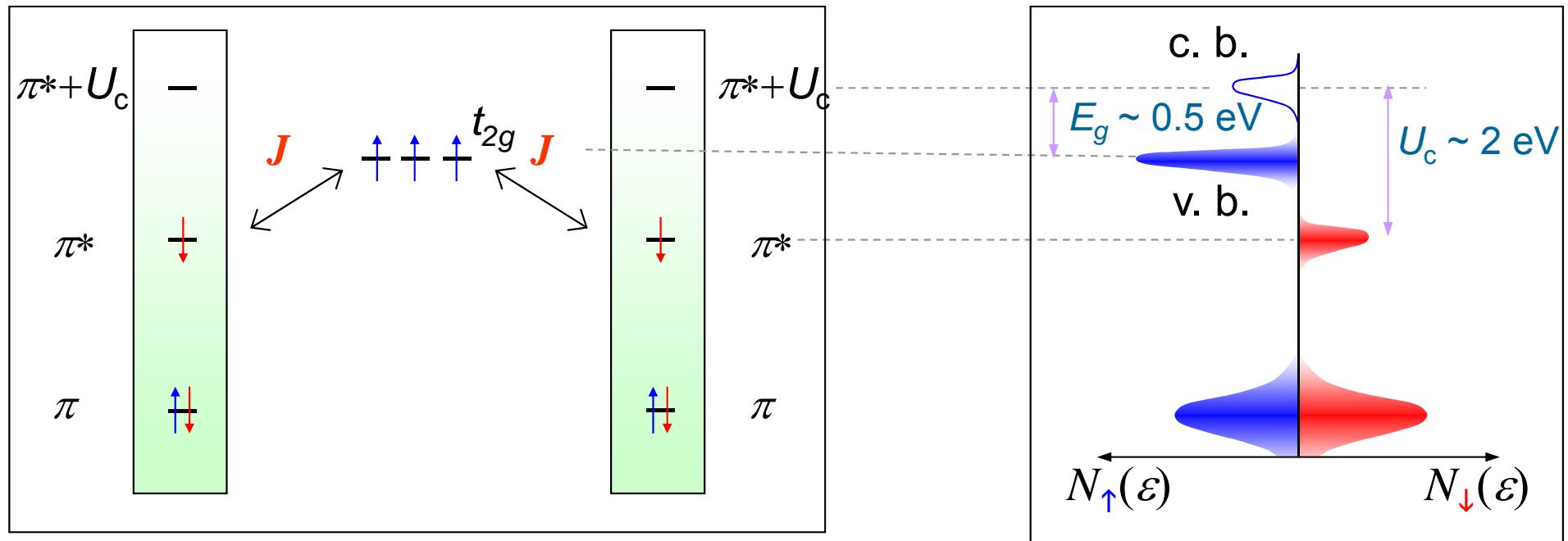


- Building block: Tetracyanoethylene (TCNE)
M = V, Cr, Mn, Fe, Co, Ni
- Modulation of magnetic properties:
 $M_x M_{1-x}(TCNE)_y S_{2-y}$, S = CH_3CN , THF
- Photo-induced magnetism: $\text{Mn}(\text{TCNE})_2$, $\text{V}(\text{TCNE})_2$
Pejakovic et al., PRL (2002)
Yoo et al., PRL 97, 247205 (2006)
- Magnetic bubble in 2D layer: $[\text{Fe}(\text{TCNE})(\text{NCMe})]$
Yoo et al., PRL 101, 197206 (2008)
- $\text{V}(\text{TCNE})_{x \sim 2}$, room temperature magnetic semi-con.
- $T_c \sim 400$ K, $\sigma_{RT} \sim 10^{-2}$ S/cm, CVD



Half Semiconductor

Yoo et al., Nature Mater. 9, 638 (2010)



Both spatially and energetically separated spin subbands

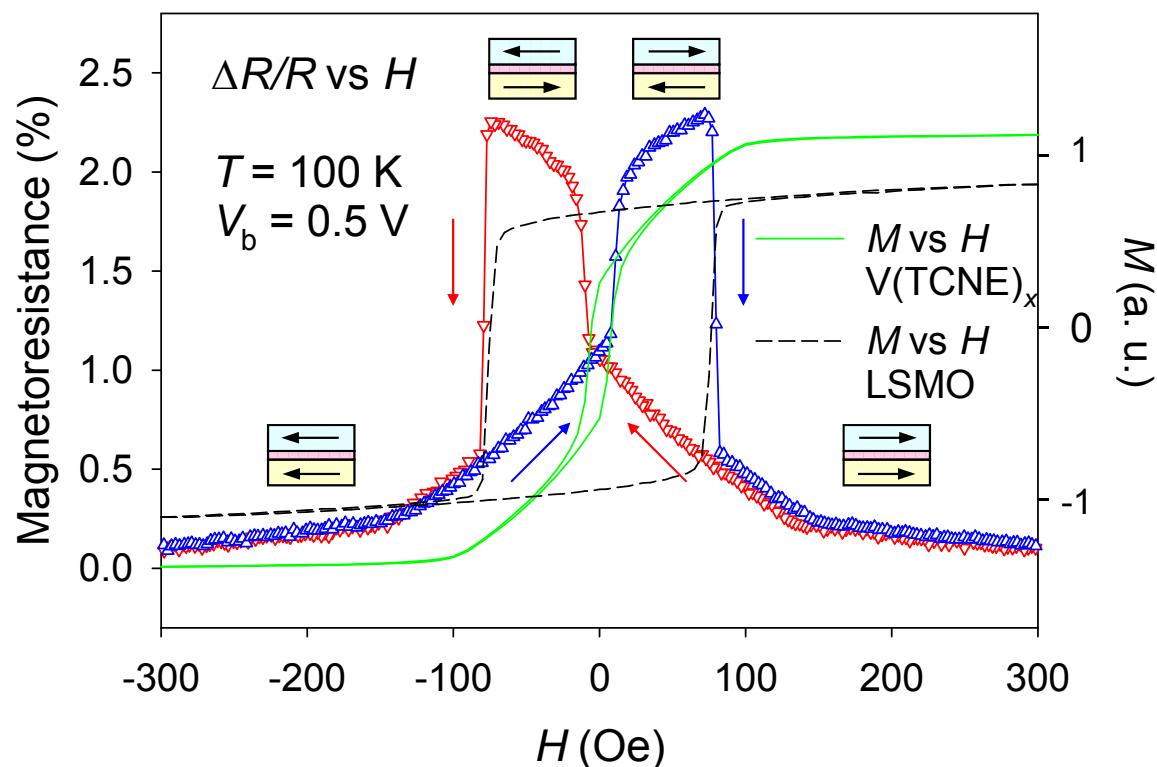
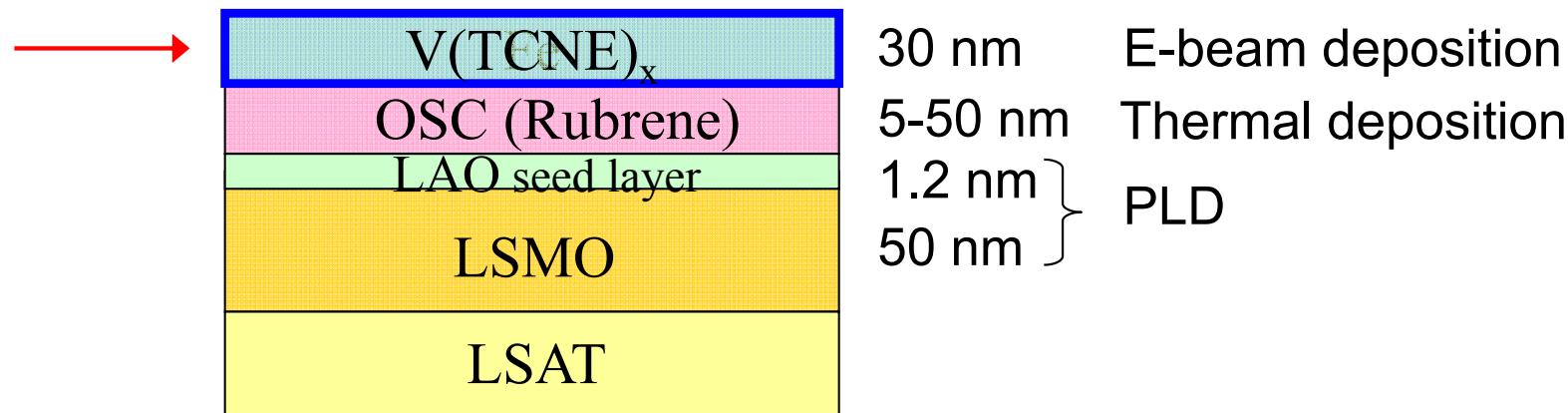
Prigodin et al. Adv. Mater. (2002)

$U_c \sim 2$ eV RPE PRL (2006)

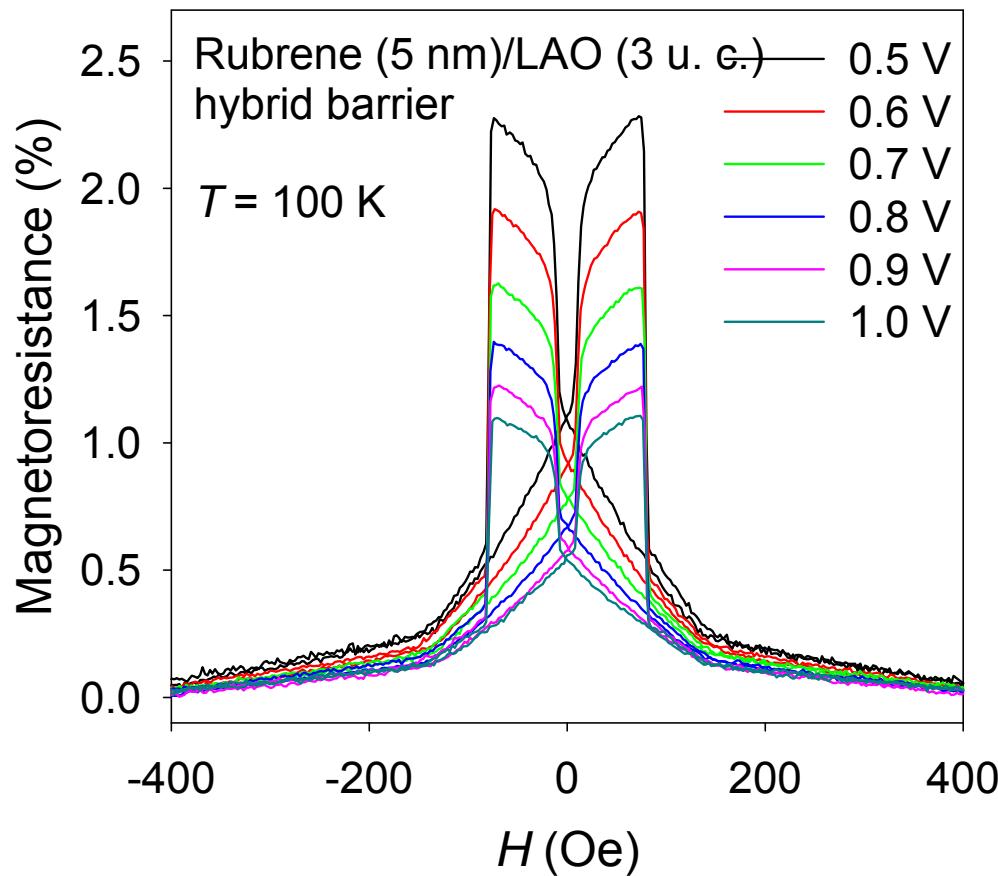
Organic-based Magnet as a Spin Injector

Device size ~ 200 by $200 \mu\text{m}$

CVD deposited
 $\text{V}(\text{TCNE})_x$ film
 $\sim 500 \text{ nm}$

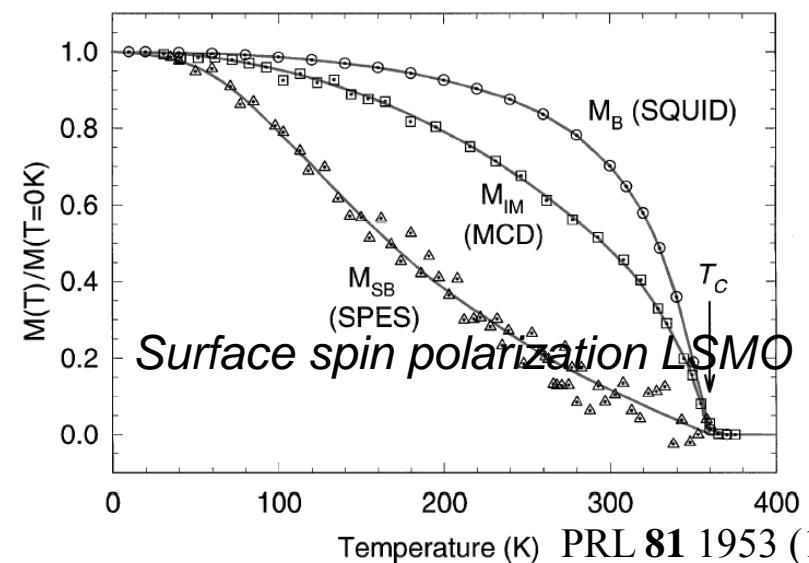
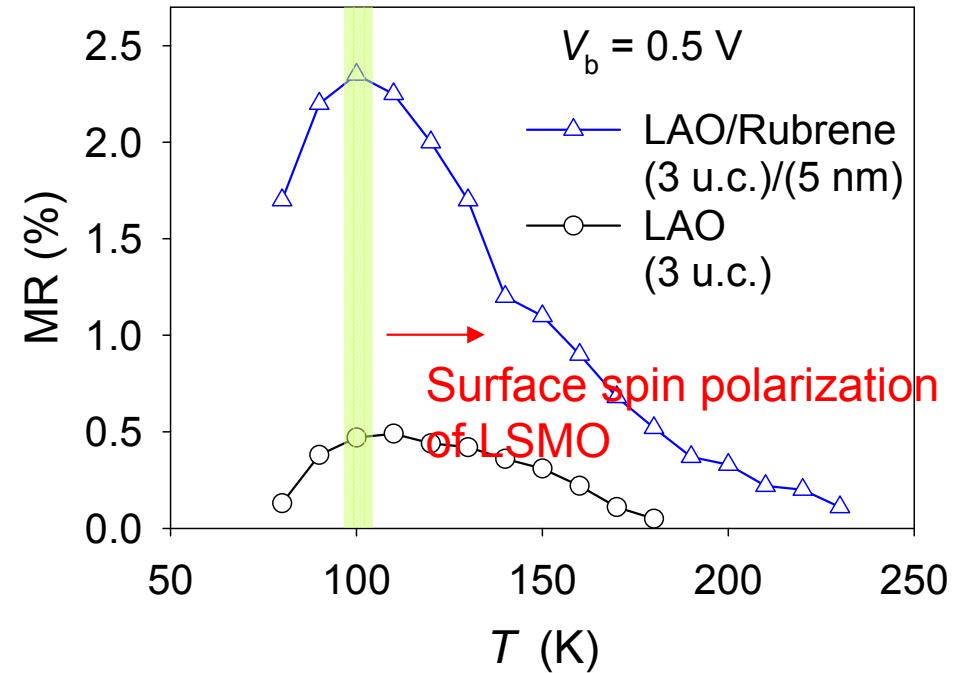
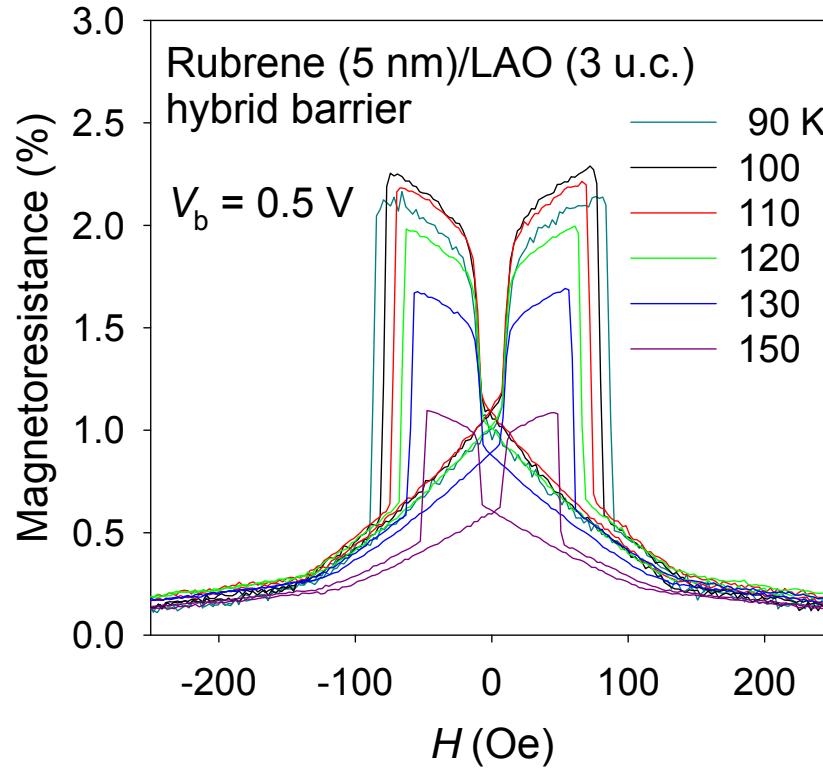


Hybrid Magnetic Tunnel Junction

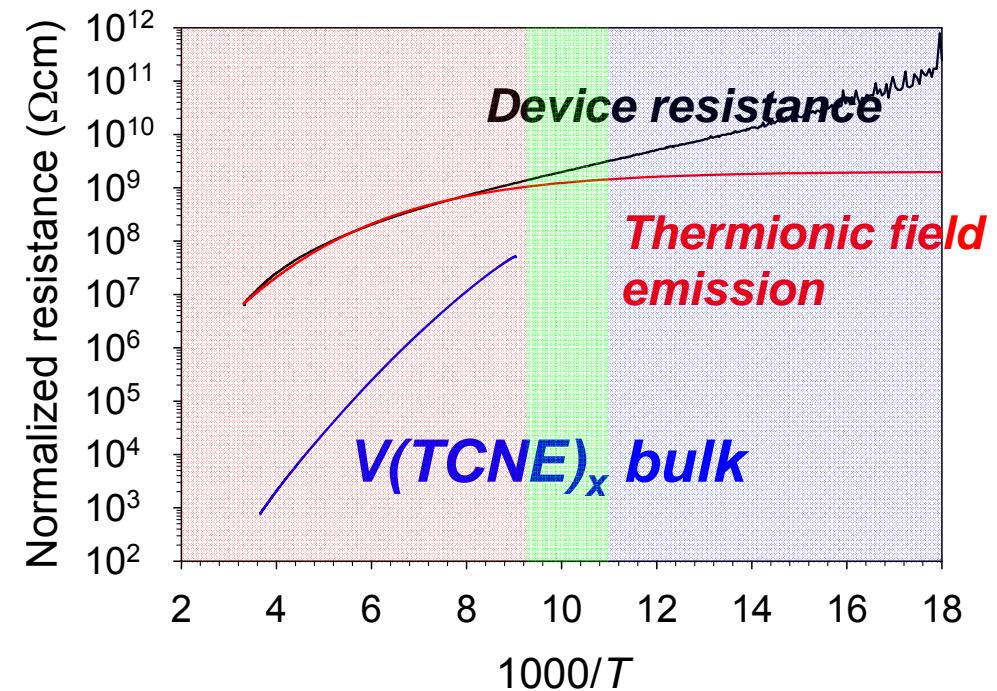
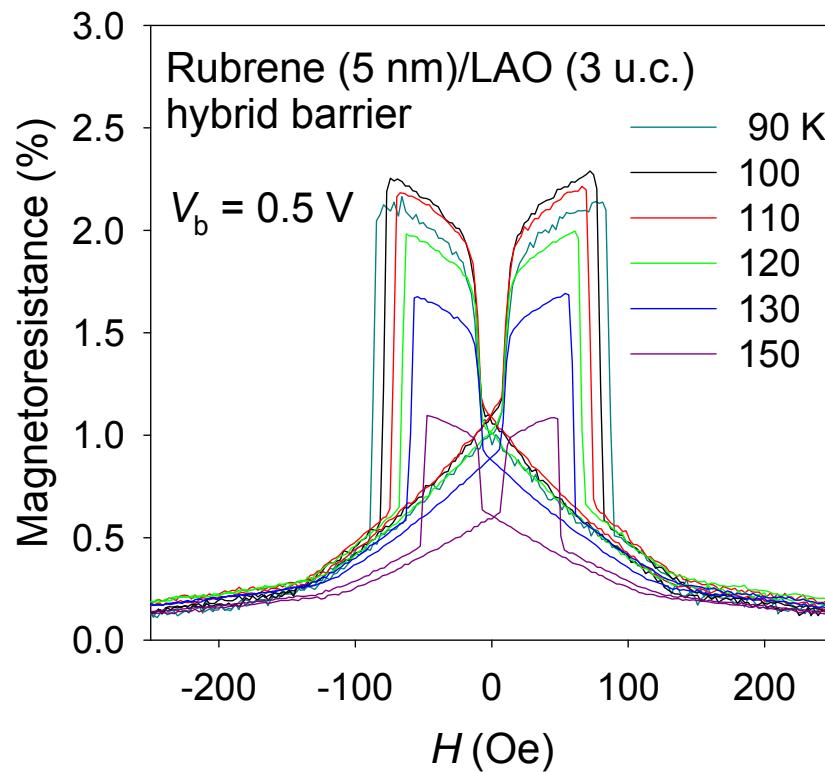


- Net spin-polarized transport in organic compounds
- Demonstration of its function as a spin injection/detection

Hybrid Magnetic Tunnel Junction



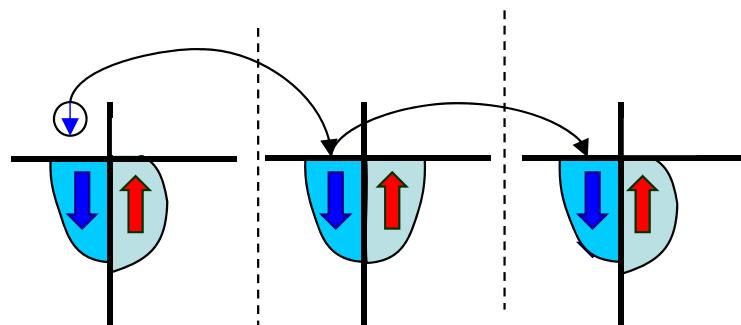
Hybrid Magnetic Tunnel Junction



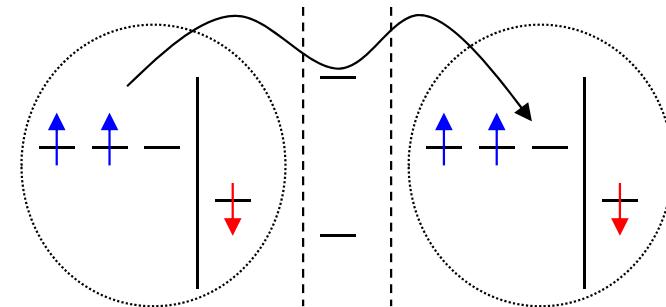
Need control on molecular layer deposition!

Conclusion

- Introduce new class of magnet as a spin injector/detector
- Application to wide range of spintronics
 - Organic semiconductor, Carbon nanotubes, graphene, semiconductor spintronics
- Introduce new chemical route for developing magnetic semiconductor and low- T device fabrication
- **Need control on molecular layer deposition**



Conventional magnetic device



Molecular magnet Molecule Molecular magnet