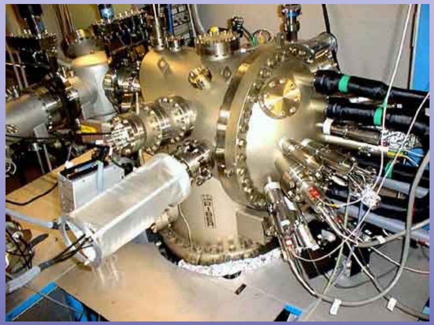
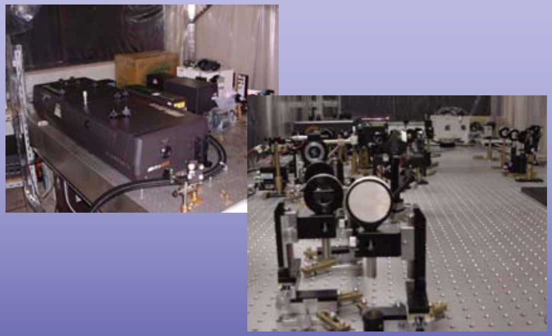
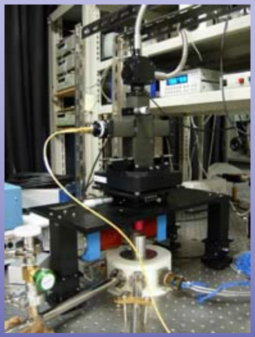
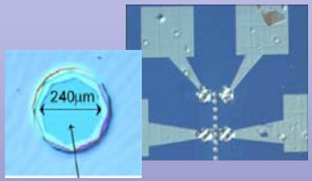
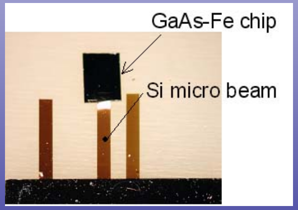










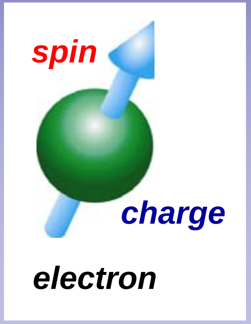
Think and grow *Act and test* *Show and discuss*

Study of optical manipulation of ferromagnetism and spin-based photonics

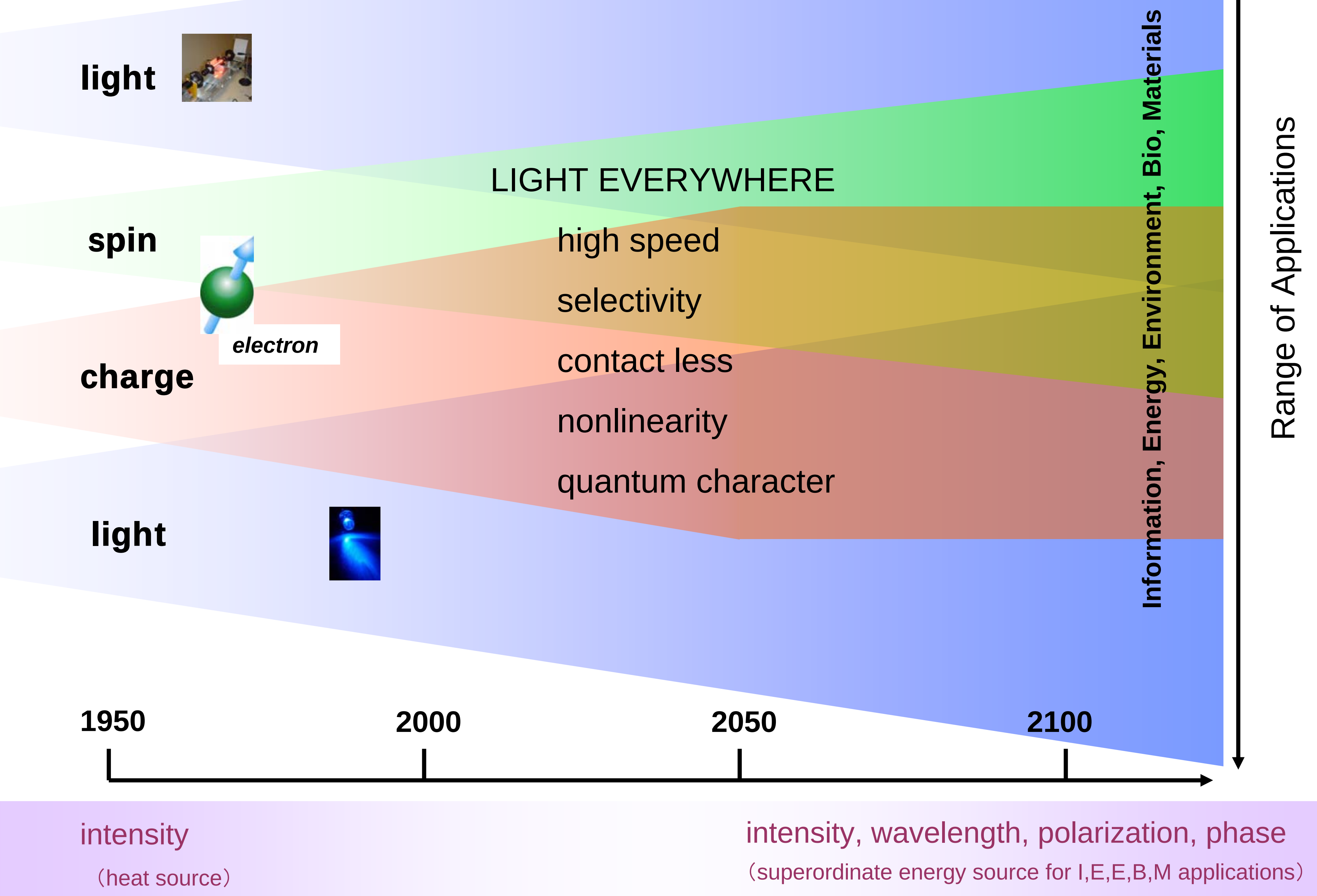
Hiro Munekata, *Tokyo Tech.*

Outline :

1. **Why light and spins?**
2. **Manipulation of *M* without *H***
3. **Detection and emission of circular polarization**



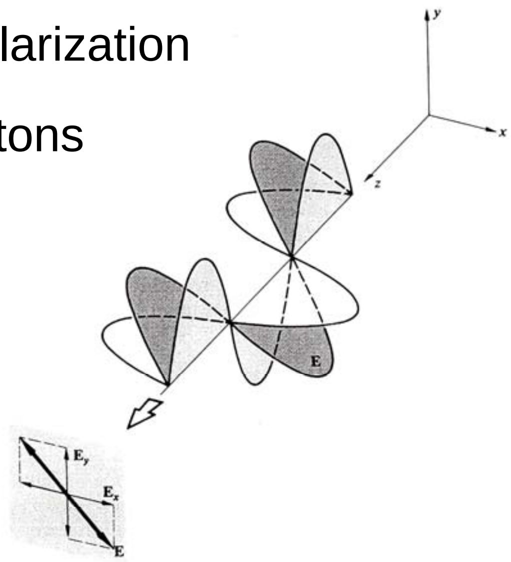
Vision

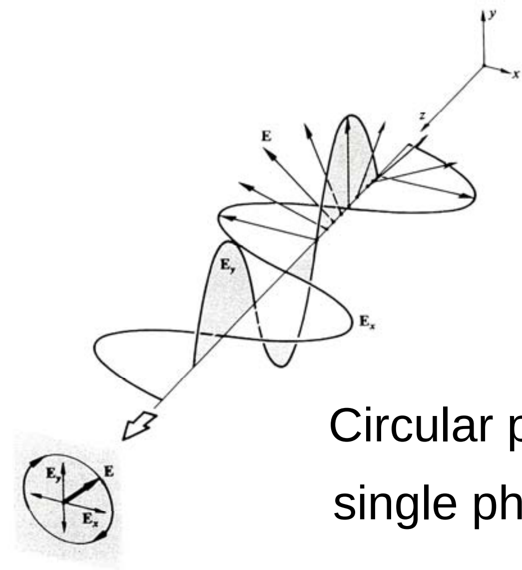

light
spin
electron
charge
light
LIGHT EVERYWHERE
high speed
selectivity
contact less
nonlinearity
quantum character
Information, Energy, Environment, Bio, Materials
Range of Applications
1950
2000
2050
2100
intensity
（heat source）
intensity, wavelength, polarization, phase
（superordinate energy source for I,E,E,B,M applications）

Angular momentum *h* would be the smallest quantity that would handle physical information.

Linear polarization

multi photons



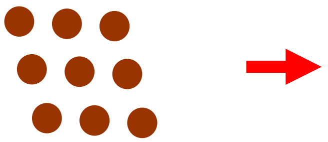


Circular polarization

single photon

E. Hecht "Optics", 2nd ed. (1990, Addison-Wesley Publishing Comp., Reading, MA)

Competition with chemical bonds (lattices)

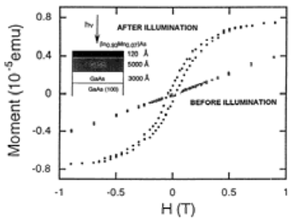


heat, chemical reaction, etc.

Signals are small and fast-disappearing

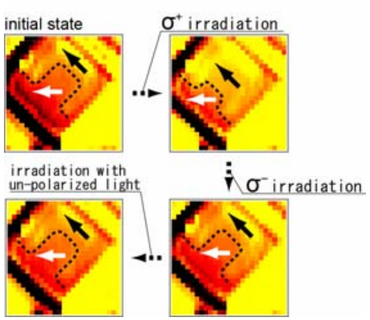
(In,Mn)As
(Ga,Mn)As
etc.

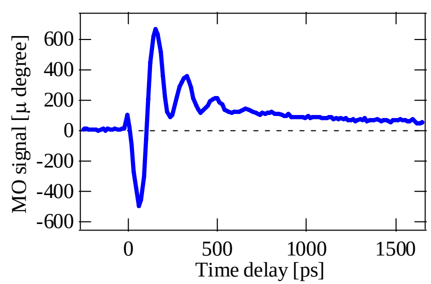
III-V based diluted magnetic semiconductors (1988 -)



Light-induced magnetization
In (In,Mn)As (1997 -)

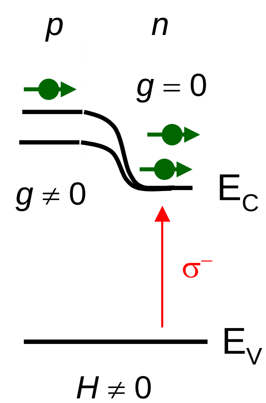
Influence of circular polarization, pulsed excitation;
(Ga,Mn)As, (In,Mn)As (2002 -)

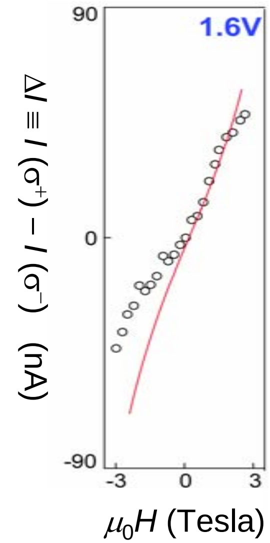




light-induced precession of *M*

Circular polarization detection;
diff.-*g* *p*-*n* junction (2003 -)

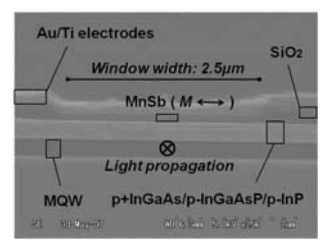


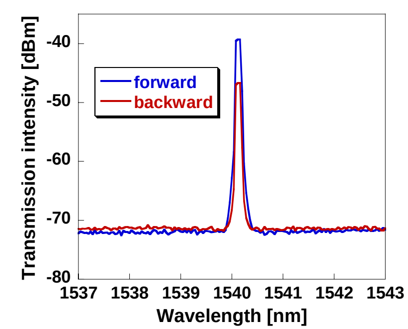


Spin voltaic effect, InGaAs-AlGaAs

Spin-LED, MnSb-GaAs

Hybrid optical isolator,
(MnSb with InP-based structures)

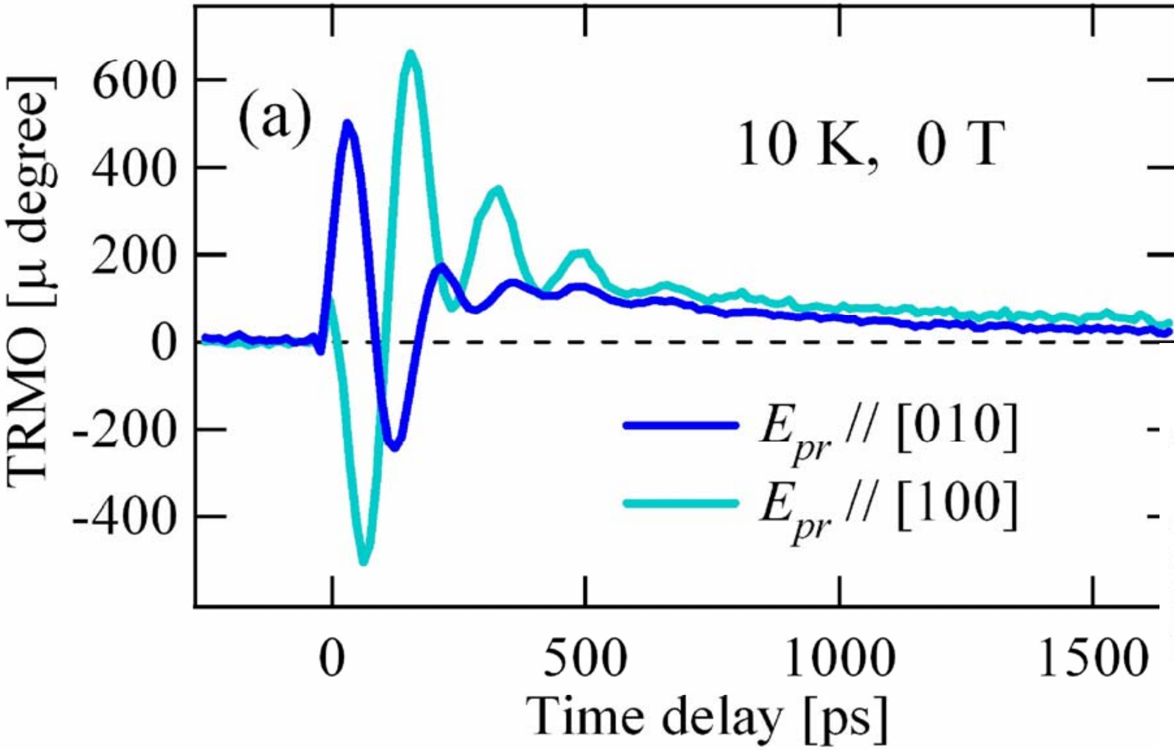


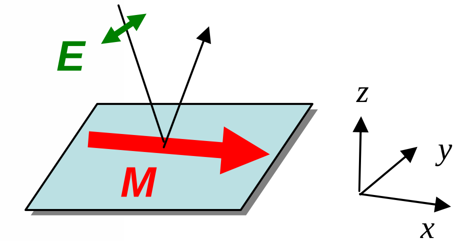


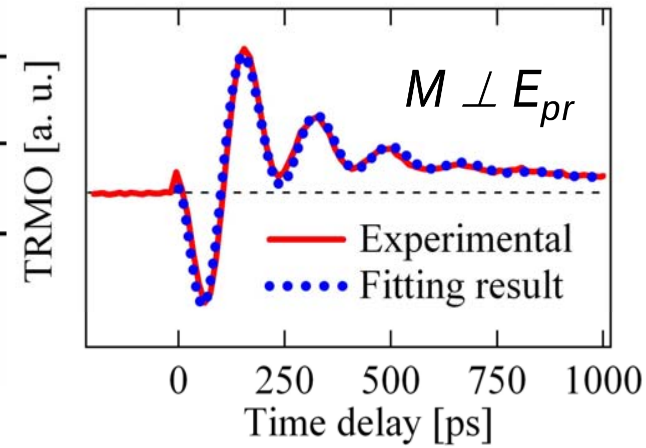
T. Amemiya, *et al*., Appl. Phys. Exp. **1**, 022002 (2008).

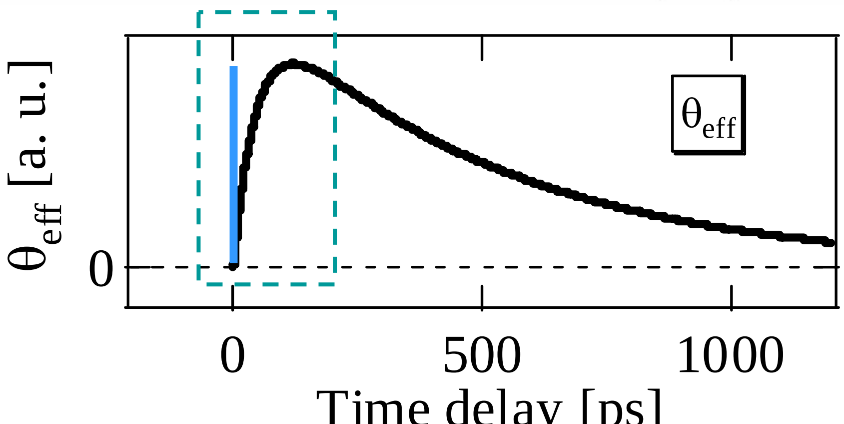
Photo-induced precession in GaMnAs

(P&P, λ = 790nm, P ≈ 3μJ cm^{-2})





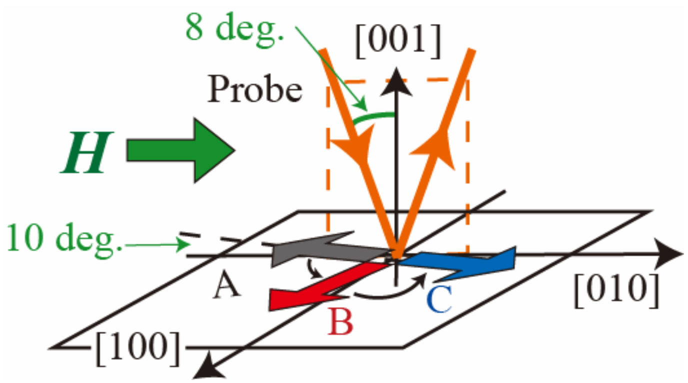


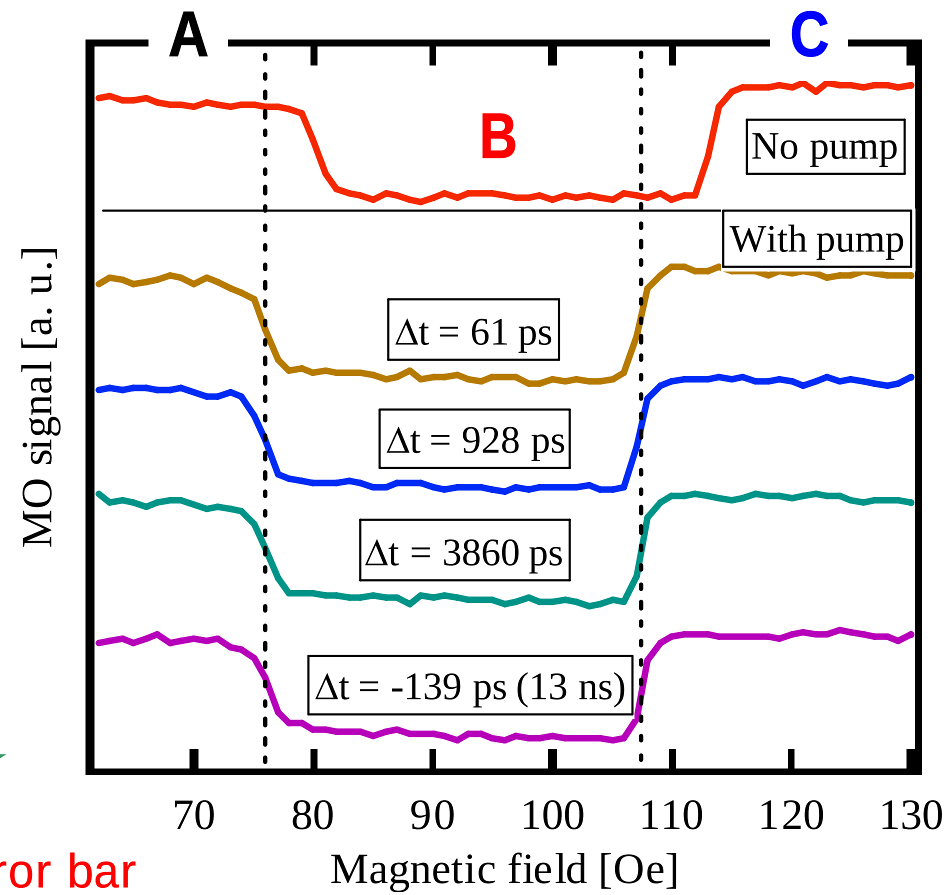


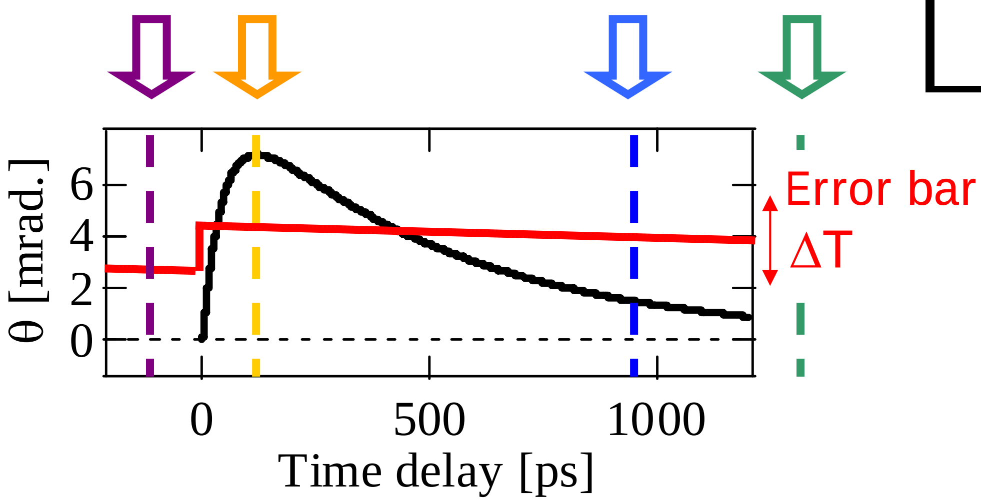
It takes time to change magnetic anisotropy ! Why?

Why it tilts toward z direction ?

Thermal Heating of Lattice Temperature







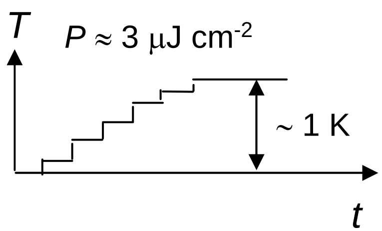
Thermal heating ~ 1 K

$\tau_{lattice}$ *>> 13 ns*

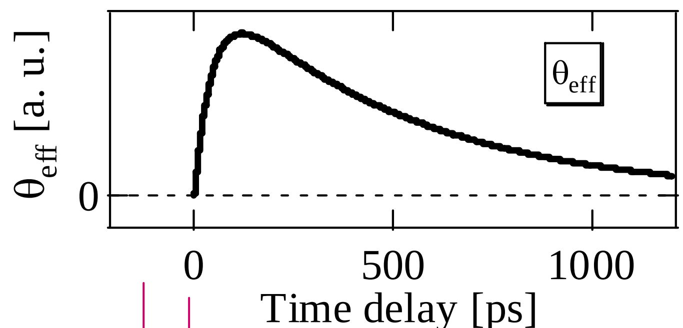
A change in hole number at around E_F is the key.

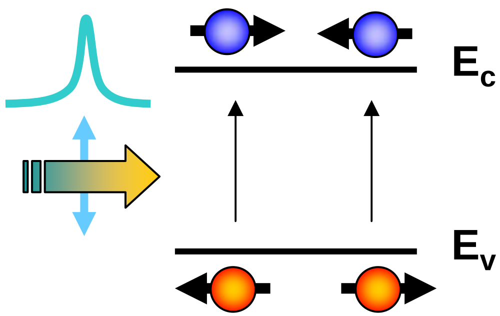
YH SK

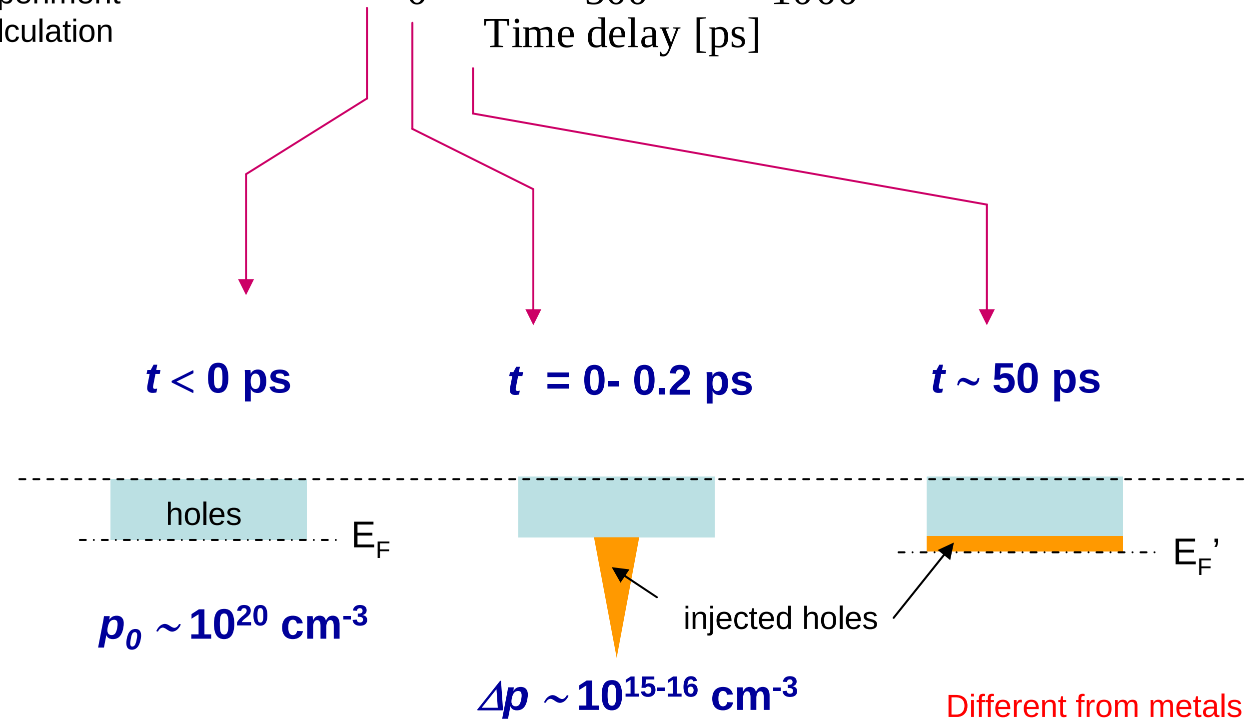
Y. Hashimoto, S. Kobayashi, and H. Munekata, PRL **100**, 067202 (08)



experiment
calculation



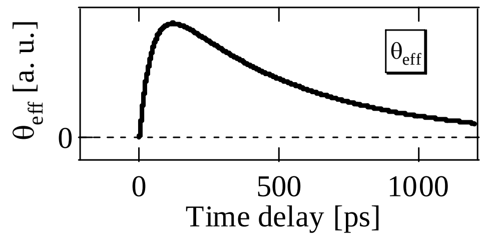


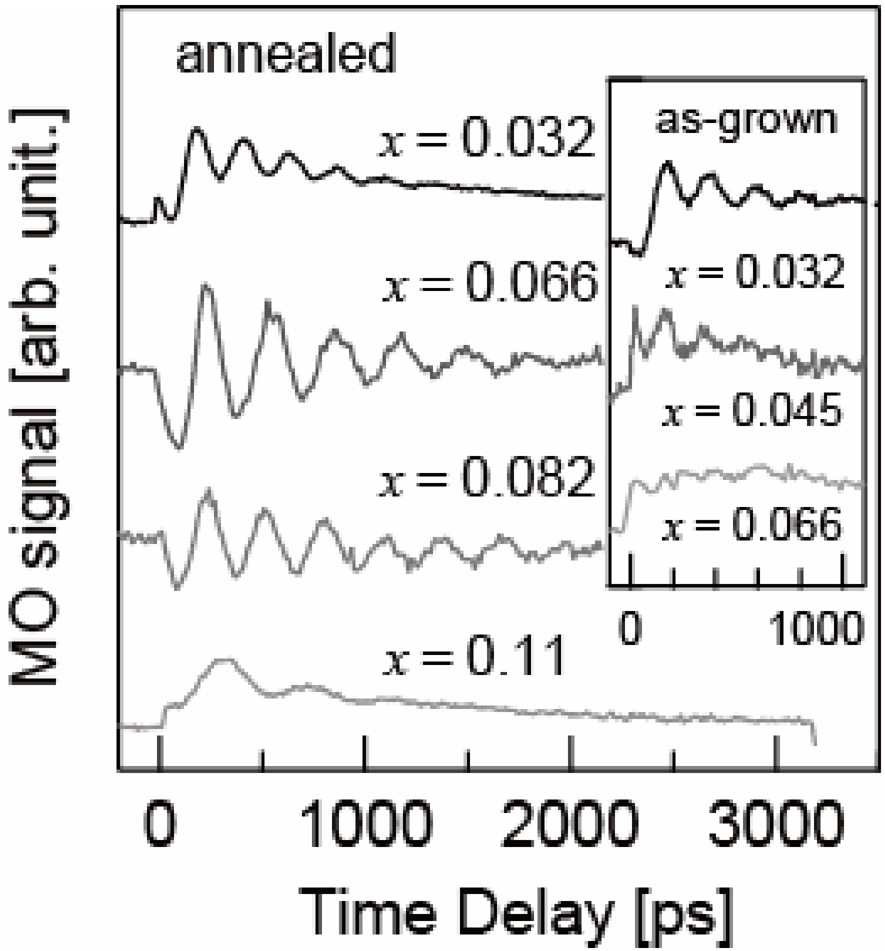


Different from metals !

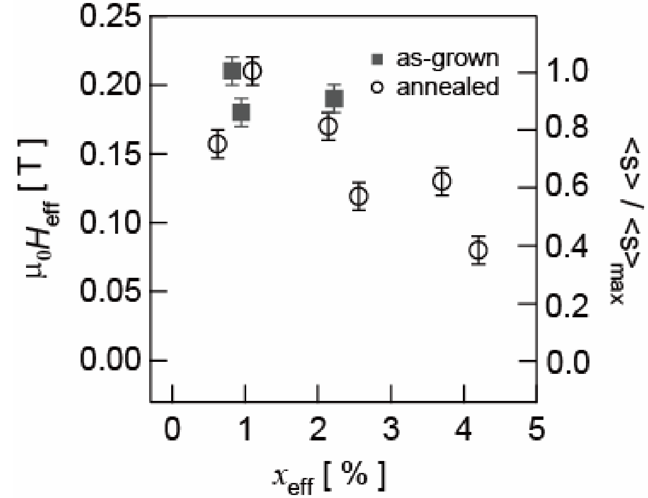
Dependence of Mn contents on precession of magnetization

SK

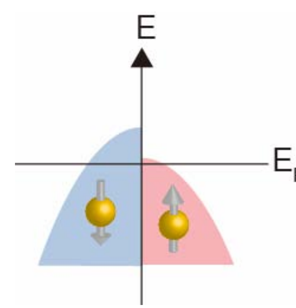




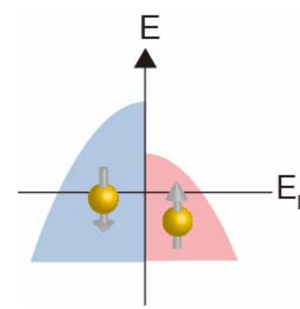
$$h\omega = g\ \mu\ H_{eff}$$



$$H_{eff} = H_{Mn} = J_{pd} \langle s \rangle$$



small x, low p



large x, high p

T. Dietl *et. al.*, Phys. Rev. B **63**, 195205 (2001)

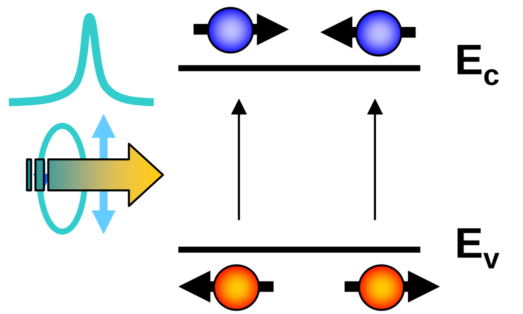
Non-thermal influence of pulsed optical excitation on magnetization has been clearly shown.

- low power excitation]
- a system with free carriers
- dynamical change in magnetic anisotropy
- spin-orbit interaction

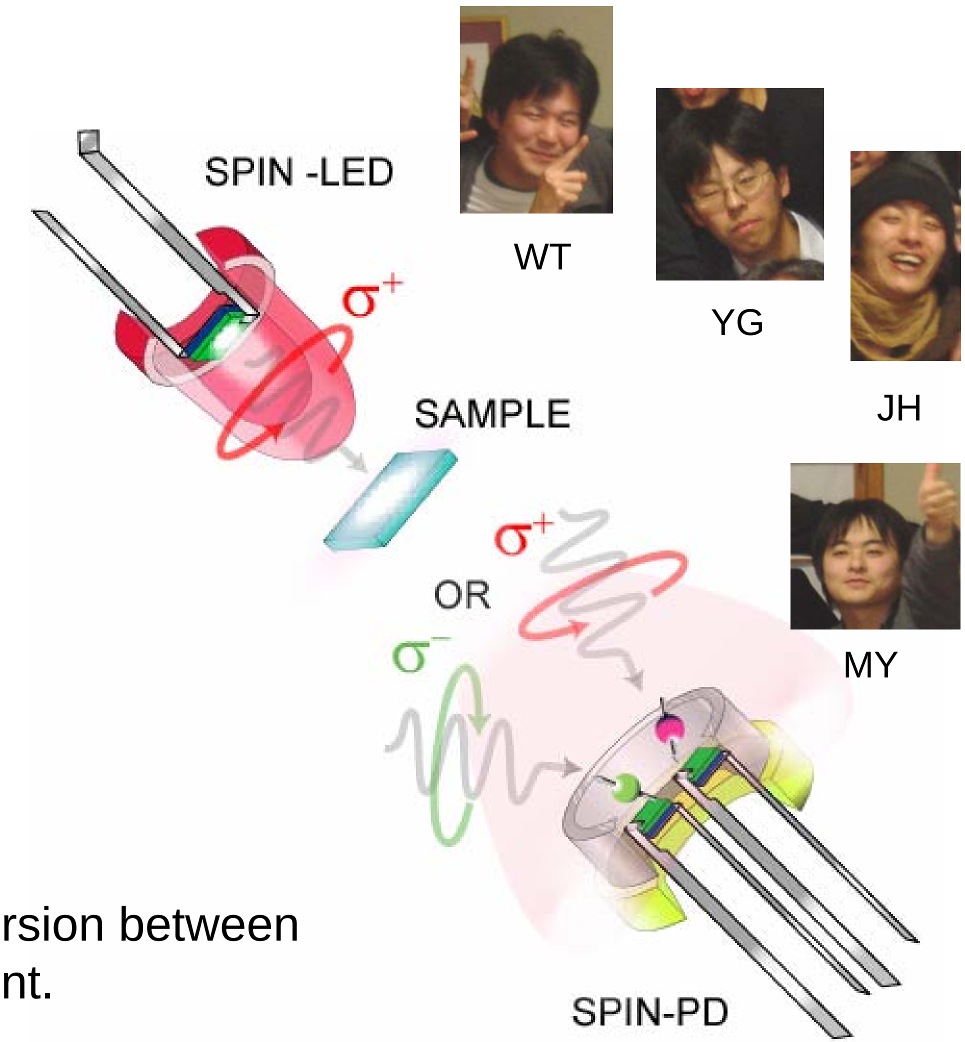
Systematic study of an effective magnetic field for Mn spins without an external magnetic field.

Coherent control

Spin - Photonics

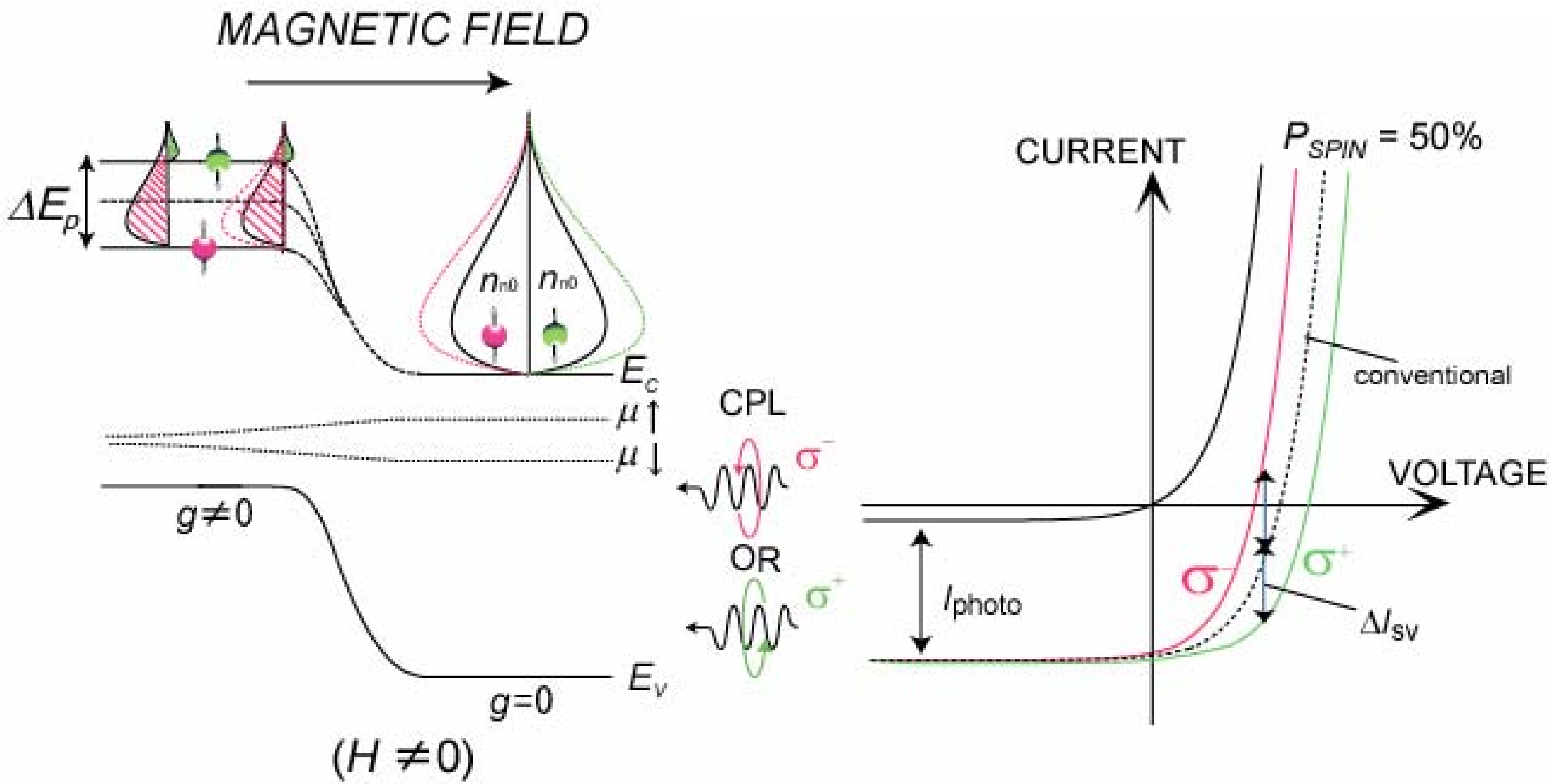


σ⁺ and σ⁻ ⟺ spins



We began with studying the conversion between circular polarization and spin current.

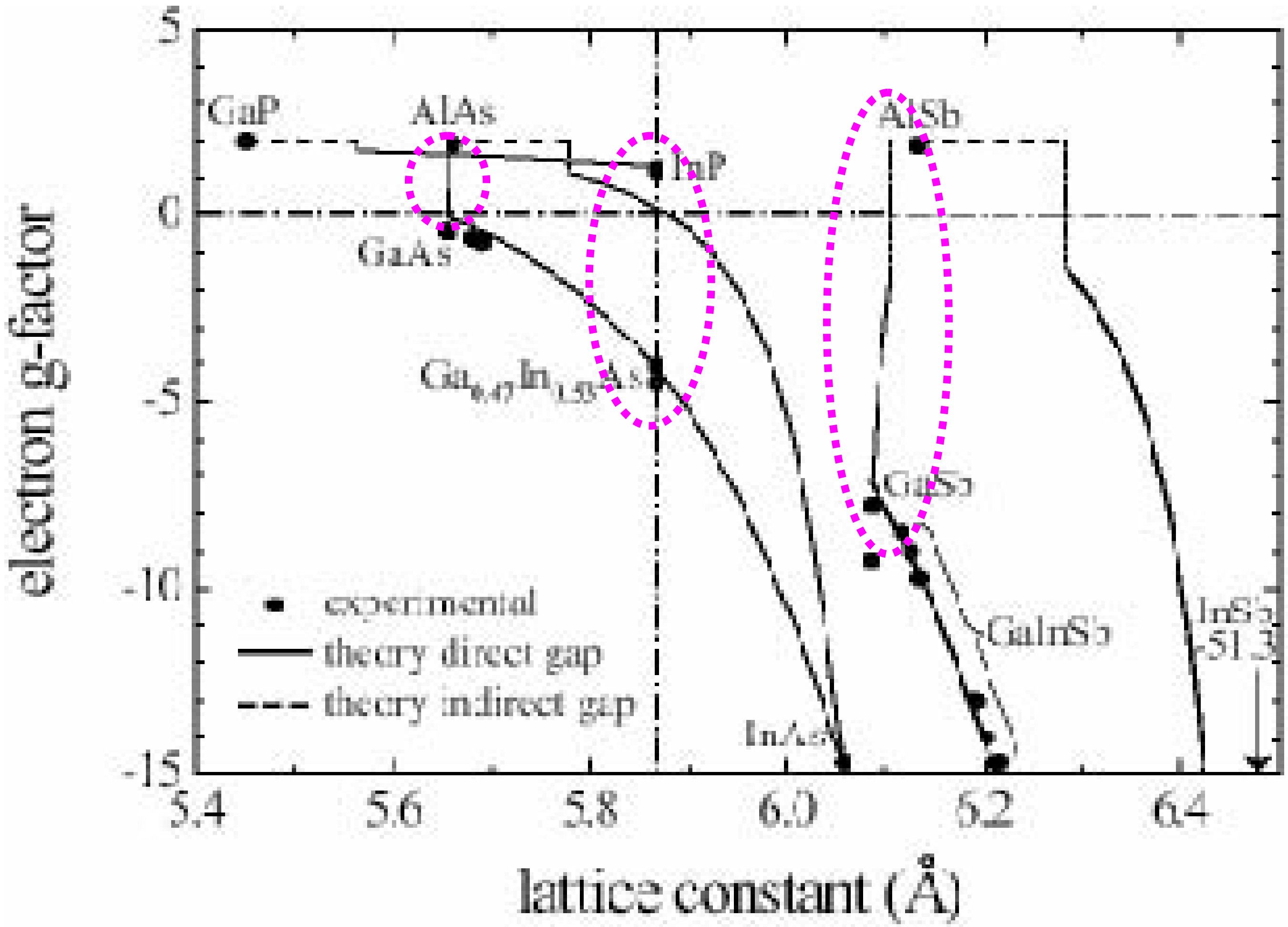
Spin voltaic effect



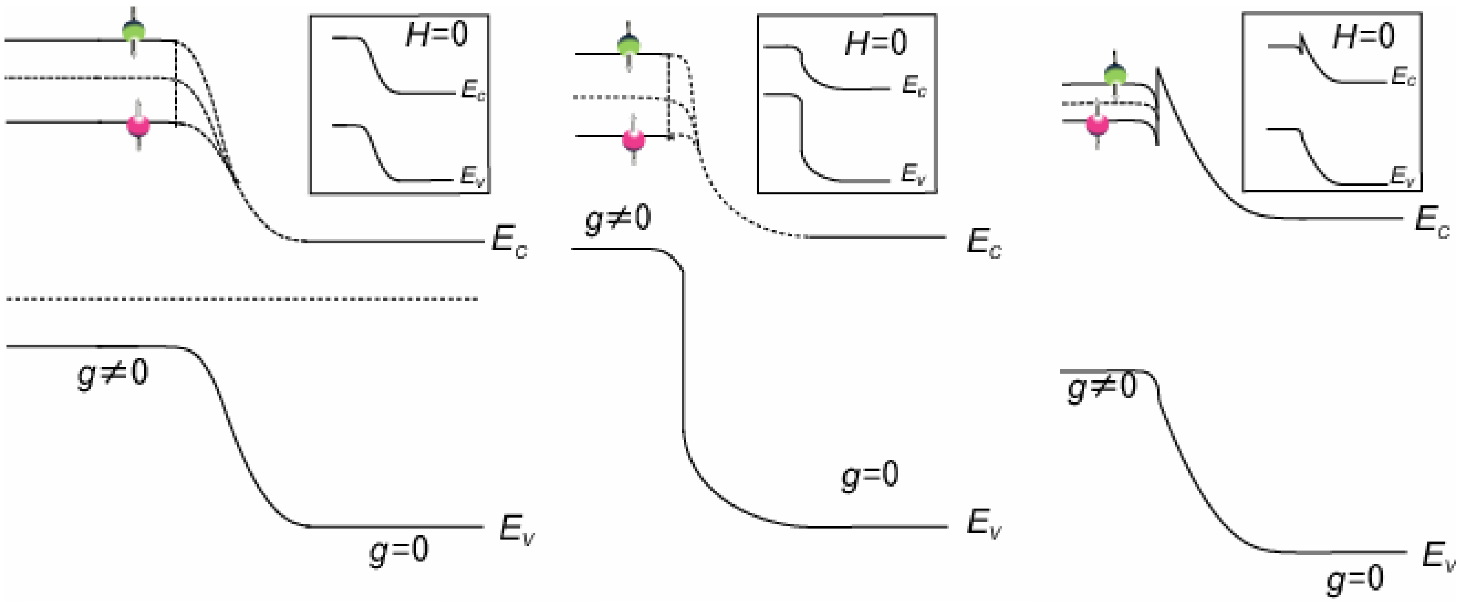
Amount of current depends on spin polarization of carriers.

I. Zutic, *et.al* PRL (2002)

g-factor engineering (*Ⅲ*- *V* *SC*)



H.Kosaka.*et.al*. Elecron.Lett.**37**,464,(2001)



graded *g*, homo *p*-*n* graded *g*, hetero *p*-*n* abrupt Δ*g*, hetero *p*-*n*

For = For(↑) + For(↓)

Back = Back(↑) + Back(↓)

For – Back = {For(↑) – Back(↑)} + {For(↓) – Back(↓)}

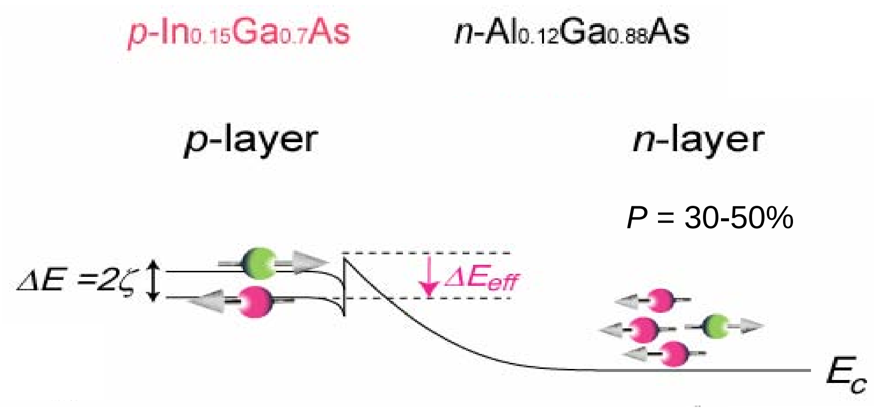
$\Delta(\sigma^- - \sigma^+)$ = {ΔFor(↑) – ΔBack(↑)} – {ΔFor(↓) – ΔBack(↓)}

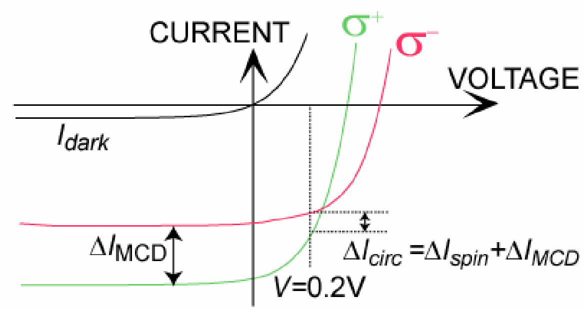
= {ΔFor(↑) – ΔFor(↓)} – {ΔBack(↑) – ΔBack(↓)}

ΔFor(↑) = ΔFor(↓). Therefore, we need ΔBack(↑) ≠ ΔBack(↓) to get non-zero Δ.

in the end of 2006

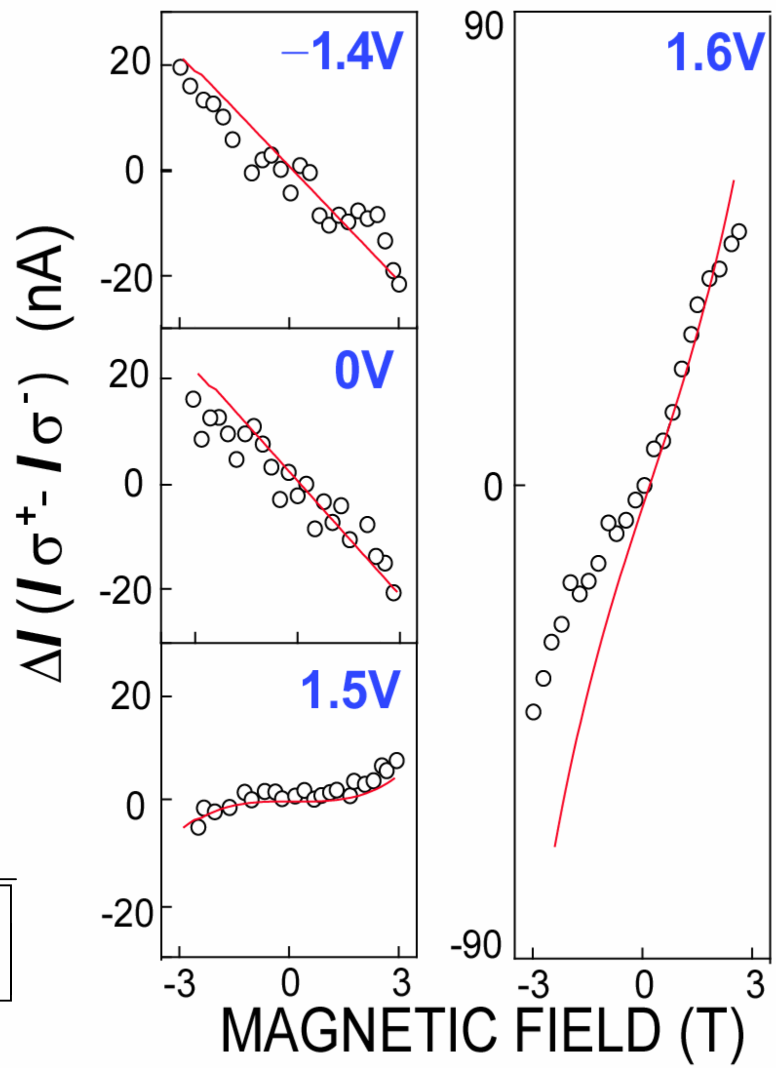
SPIN PHOTODIODE





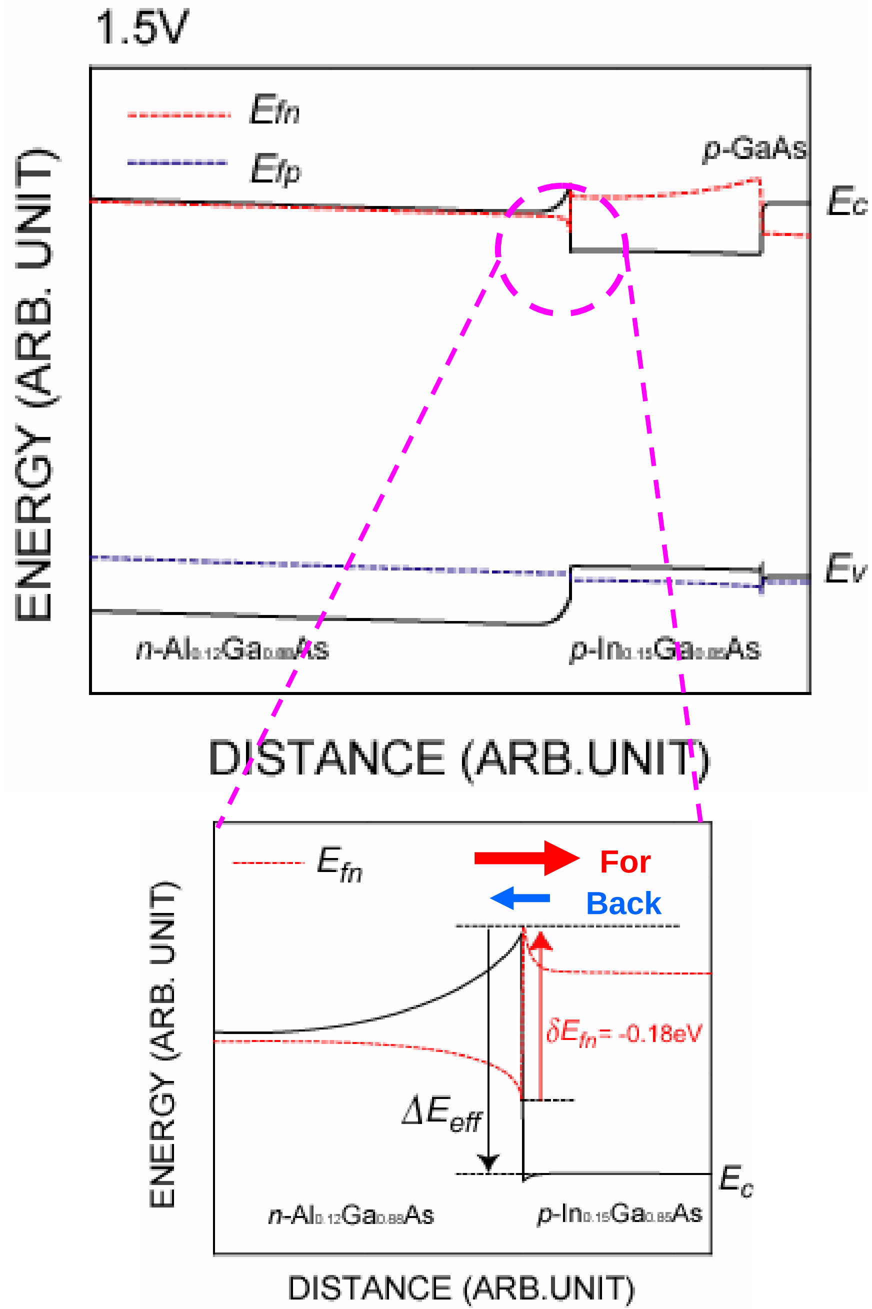
$$\beta = \frac{\exp\left(\frac{-2\Delta E_{eff}}{kT}\right)}{\left[\frac{D_e}{\nu_R L_e} + \exp\left(-\frac{(\Delta E_{eff}+\zeta)}{kT}\right)\right]\cdot\left[\frac{D_e}{\nu_R L_e} + \exp\left(-\frac{(\Delta E_{eff}-\zeta)}{kT}\right)\right]}$$

($\beta P = 0.7\%$)



T. Kondo, *et.al.* JJAP **45**, 26.L663 (2006)

Current injection (non-equilibrium condition) and hetero-spin transport factor β



We need ΔBack(↑) ≠ ΔBack(↓) to get non-zero Δ.

With carriers flowing forward, $E_{F,p}$ is pushed upward, giving rise to an increase in backward flow.

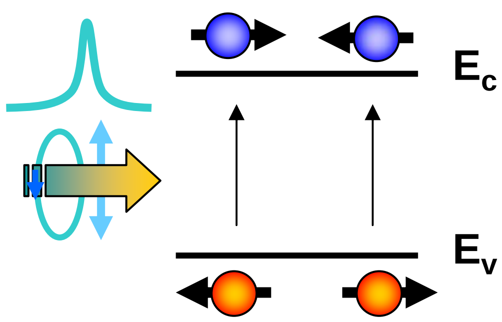
Consequently, hetero-spin transport factor β is increased.

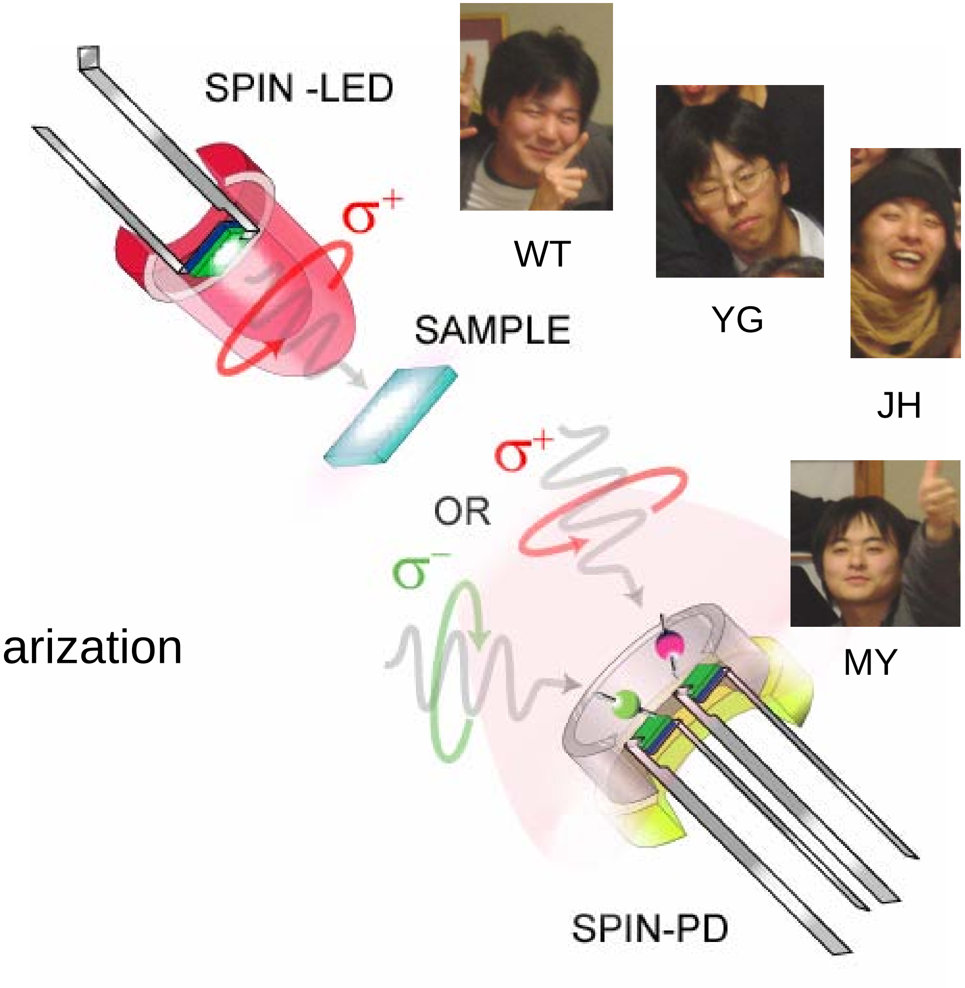
$|\Delta\text{Back}(\uparrow) - \Delta\text{Back}(\downarrow)|$ is increases..

Effect of hot electrons !

JH

Spin - Photonics





σ^+ and σ^- ⟺ spins

Extract information from the state of polarization

Chemical synthesis and analysis

- pharmaceutics

- foods and ingredients

Bio-technology

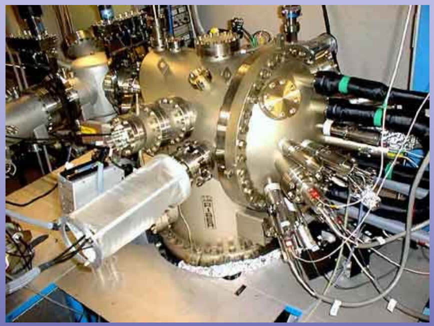
Information processing with quantum

Diffusion is great !

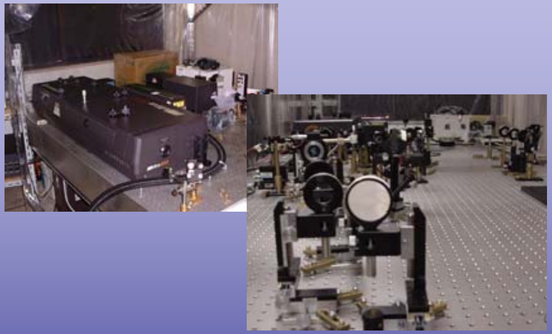
(Depletion region would not cause problems)

Hot carriers help spin transport across heterojunction !

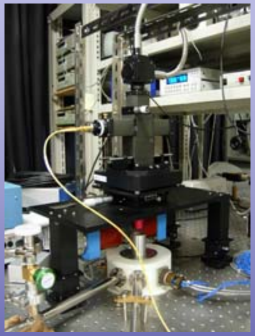
(Dynamic enhancement of β)



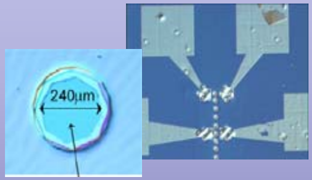
Think and grow

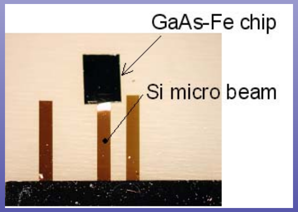


Act and test



Show and discuss





Summary :

1. precession induced by the optical excitation
   (non-thermal effect, insight into f.m.s.c)
2. spin transport in SC
   (diffusion, heterojunctions)

<u>Co-workers</u>

Y. Kitamoto (associate professor, Tokyo Tech.)

S. Sugahara (associate professor, Tokyo Tech.)

Y. Hashimoto (research scientist, Tokyo Tech.)

J. Hayafuji and S. Kobayashi (doctor course students, Tokyo Tech.)