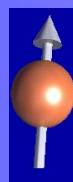


SPring-8利用推進協議会 先端磁性材料研究会
第4回研究会「スピンドYNAMICSと光誘起磁化過程」
2010.8.5 総評会館201会議室, Japan



超短パルス・レーザーを用いた磁化ダイナミクス計測と 円偏光誘起磁化反転

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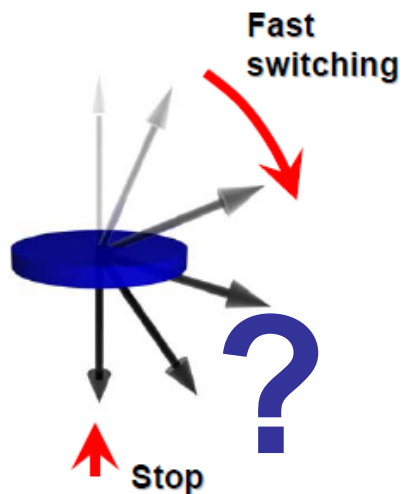
²PRESTO, Japan Science and Technology Agency , Japan

e-mail: atsuka@ecs.cst.nihon-u.ac.jp





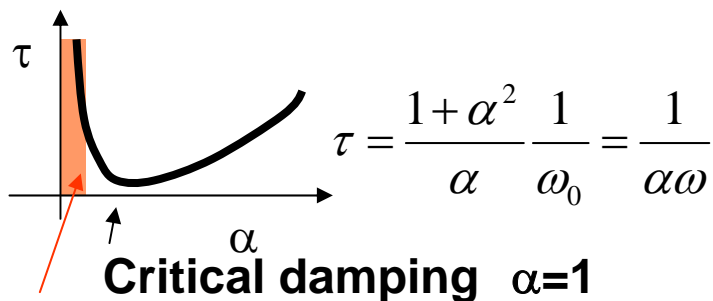
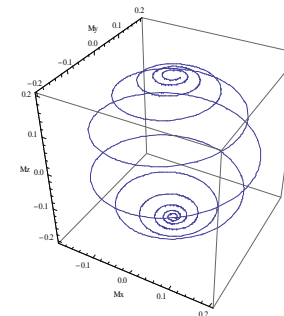
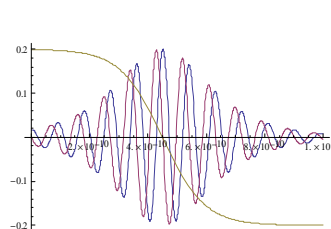
Magnetization reversal



*Damping term
Proportional to the dM/dt*

Landau-Lifshitz-Gilbert equation

$$\frac{dM}{dt} = -\gamma(M \times H^{eff}) + \frac{\alpha}{M} \left(M \times \frac{dM}{dt} \right)$$



Conventional recording media

Low damping

(CoCrPt ~ 0.04 Inaba)



Magnetization reversal

How to gain the speed?

Idea

Interplay of ultra fast heating and large temperature dependence of magnetic resonance

★ ➤ RE-TM Ferrimagnet

★ ➤ Angular momentum compensation



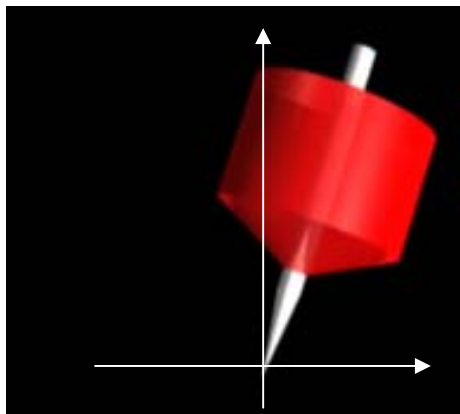
High-speed and strongly damped **precessional switching** triggered with ultrafast heating of a GdFeCo



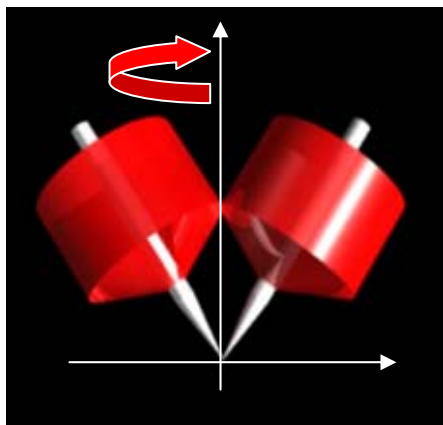
Angular momentum compensation

Spinning Top (“KO MA” in Japanese)

With angular momentum

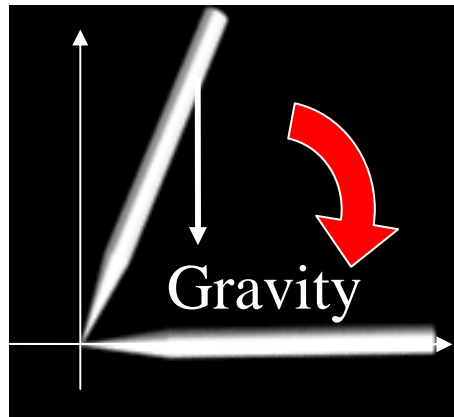


Starting precessional motion



Long time survive

Without angular momentum



Rapid fall

● Ferro magnetism

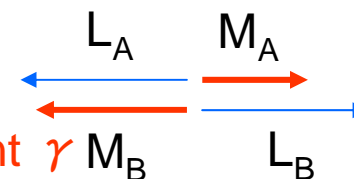
$$\mathbf{L} = -\mathbf{M} / \gamma$$



● Ferri magnetism

sub-lattice magnetization

anti-parallel tight coupling, α , different γ



$$\mathbf{L}_{net} = -(\mathbf{M}_{RE} / \gamma_{RE} - \mathbf{M}_{TM} / \gamma_{TM})$$

$$\mathbf{M}_{net} = \mathbf{M}_{RE} - \mathbf{M}_{TM}$$



Magnetization dynamics in ferrimagnetics (sub-lattice)

$$\gamma_1 \neq \gamma_2 \quad \text{anti-parallel tight coupling}$$

- phenomenological Landau-Lifshitz-Gilbert equation

$$\frac{d\mathbf{M}}{dt} = -|\gamma|(\mathbf{M} \times \mathbf{H}^{eff}) + \frac{\alpha}{M} \left(\mathbf{M} \times \frac{d\mathbf{M}}{dt} \right)$$

- effective gyromagnetic ratio

$$\gamma_{eff}(x) = \frac{M_{RE}(x) - M_{TM}(1-x)}{\left(\frac{M_{RE}(x)}{|\gamma_{RE}|} - \frac{M_{TM}(1-x)}{|\gamma_{TM}|} \right)} = \frac{M_{Net}}{A_{Net}}$$

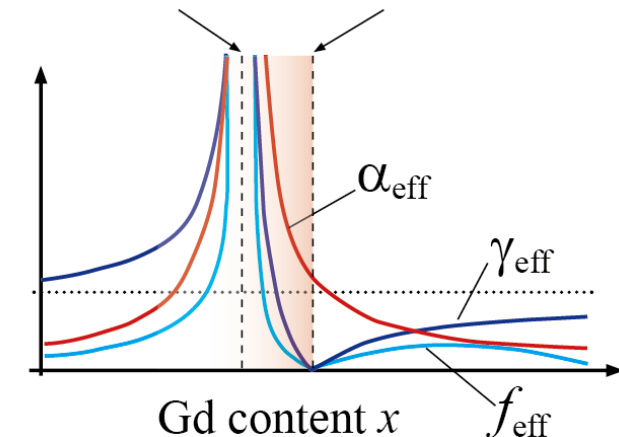
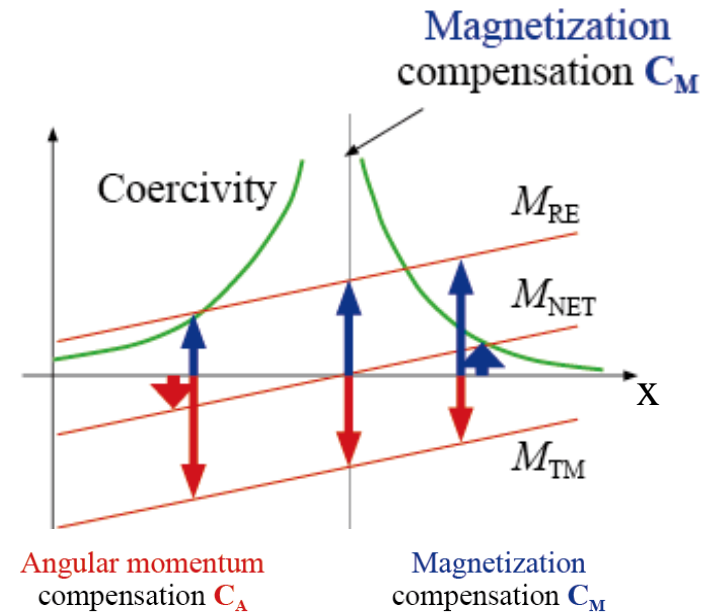
Net M

- ferromagnetic resonance (FMR) branch

$$\omega_{FMR} = \gamma_{eff} H^{eff} \quad \text{Net angular momentum}$$

- effective Gilbert damping parameter*

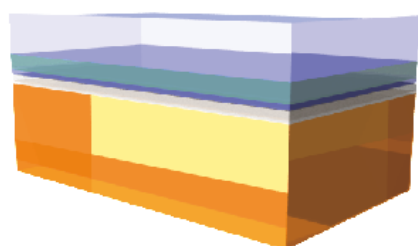
$$\alpha_{eff}(x) = \frac{\left(\lambda_{RE}/|\gamma_{RE}|^2 \right) + \left(\lambda_{TM}/|\gamma_{TM}|^2 \right)}{\left(\frac{M_{RE}(x)}{|\gamma_{RE}|} - \frac{M_{TM}(1-x)}{|\gamma_{TM}|} \right)} = \frac{A_0}{A_{Net}}$$



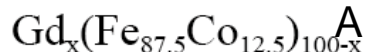


As a fast recordable **media**,
acceleration of dynamic response
with adequate net magnetization
is realized by controlling net **angular momentum**.

idea

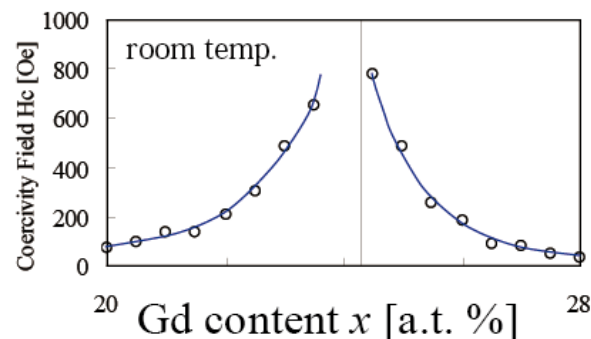
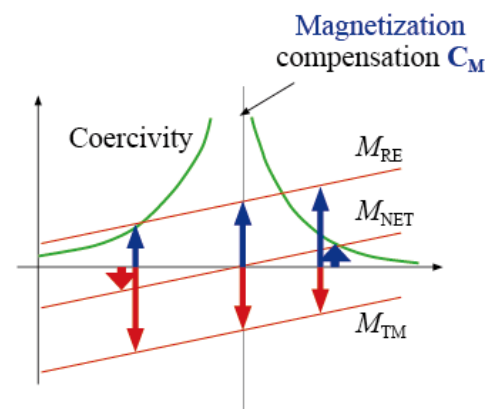


SiN (60 nm)
GdFeCo (20 nm)
SiN (5 nm)
AlTi (10 nm)
Glass substrate
Gd: huge 4f-moment $S=7/2$
Anti-para with FeCo
Amorphous: uniform



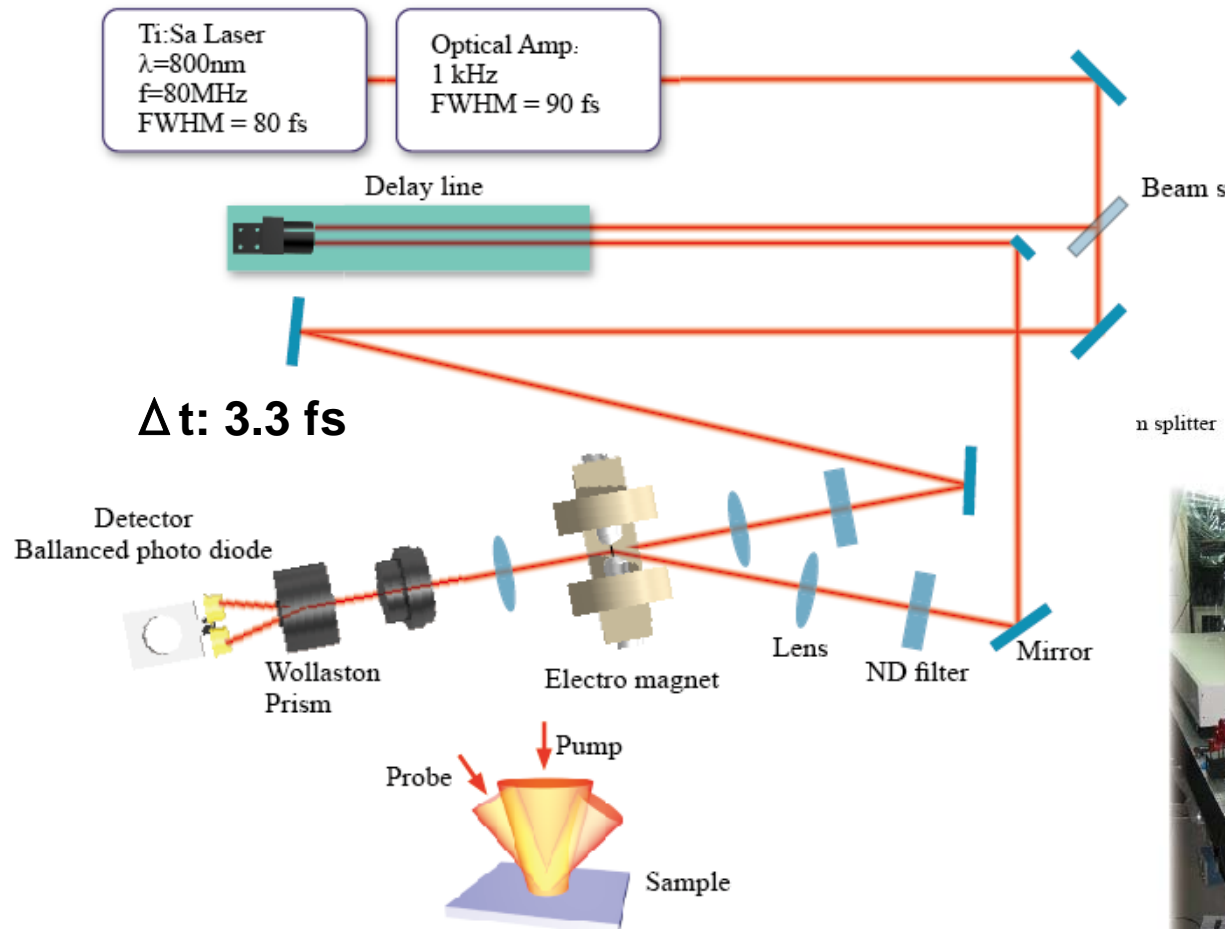
Ferrimagnetic and amorphous alloy;
Perpendicular magnetic anisotropy;
Strong coupling between rare earth (RE) and
transition (TM) component.

Magnetization compensation C_M and
Angular momentum compensation C_A
depend on the composition ratio (Gd content)

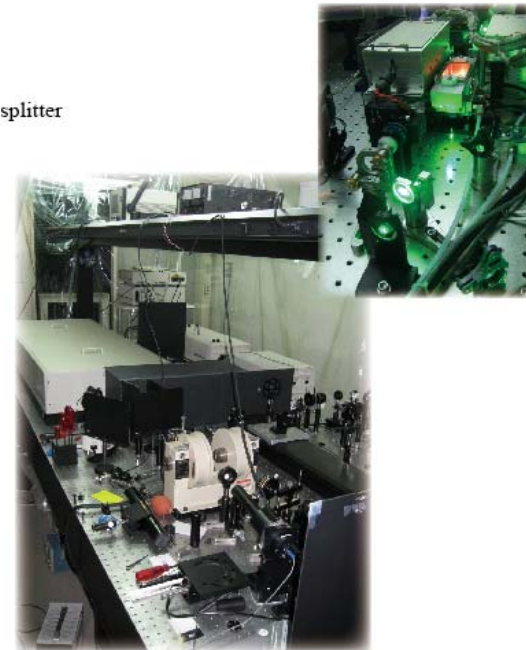




All-optical Pump probe set up



Measurements: monitoring
 Faraday $\Delta\theta_F/\theta_F$, Kerr $\Delta\theta_K/\theta_K$,
 Transmittance $\Delta T/T$,
 Reflectance $\Delta R/R$

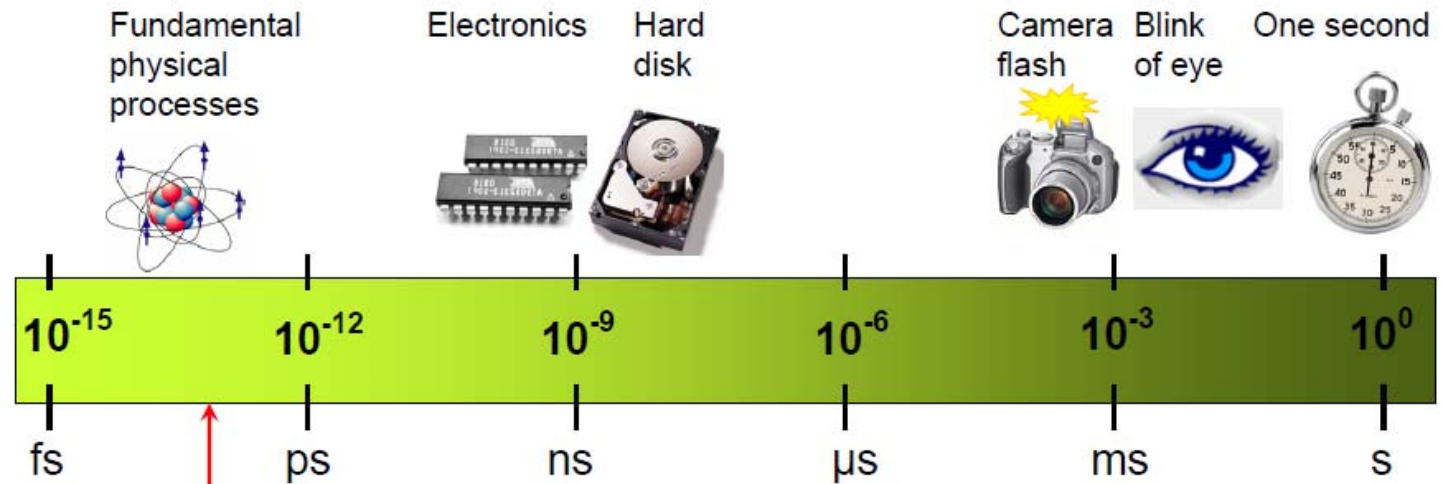


FWHM : 90fs : **420nm and 800nm**

Note that only the magnetization of the transition metal subsystem is probed by the linear Faraday-effect at laser wave length of 800 nm. It makes possible to measure the magnetic dynamics near magnetic compensation point.



Employ femtosecond pulsed laser



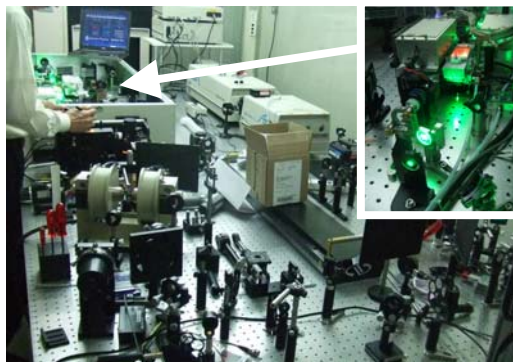
Time [seconds]

Ultrashort laser pulse

100 fs = 10^{-13} seconds

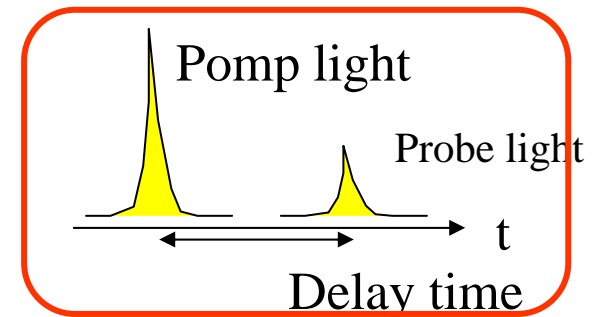
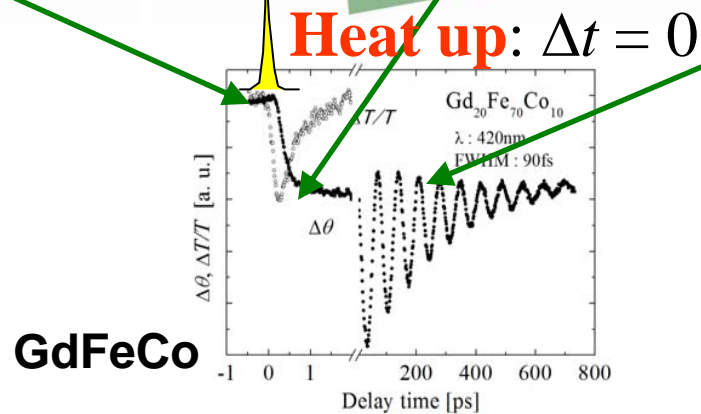
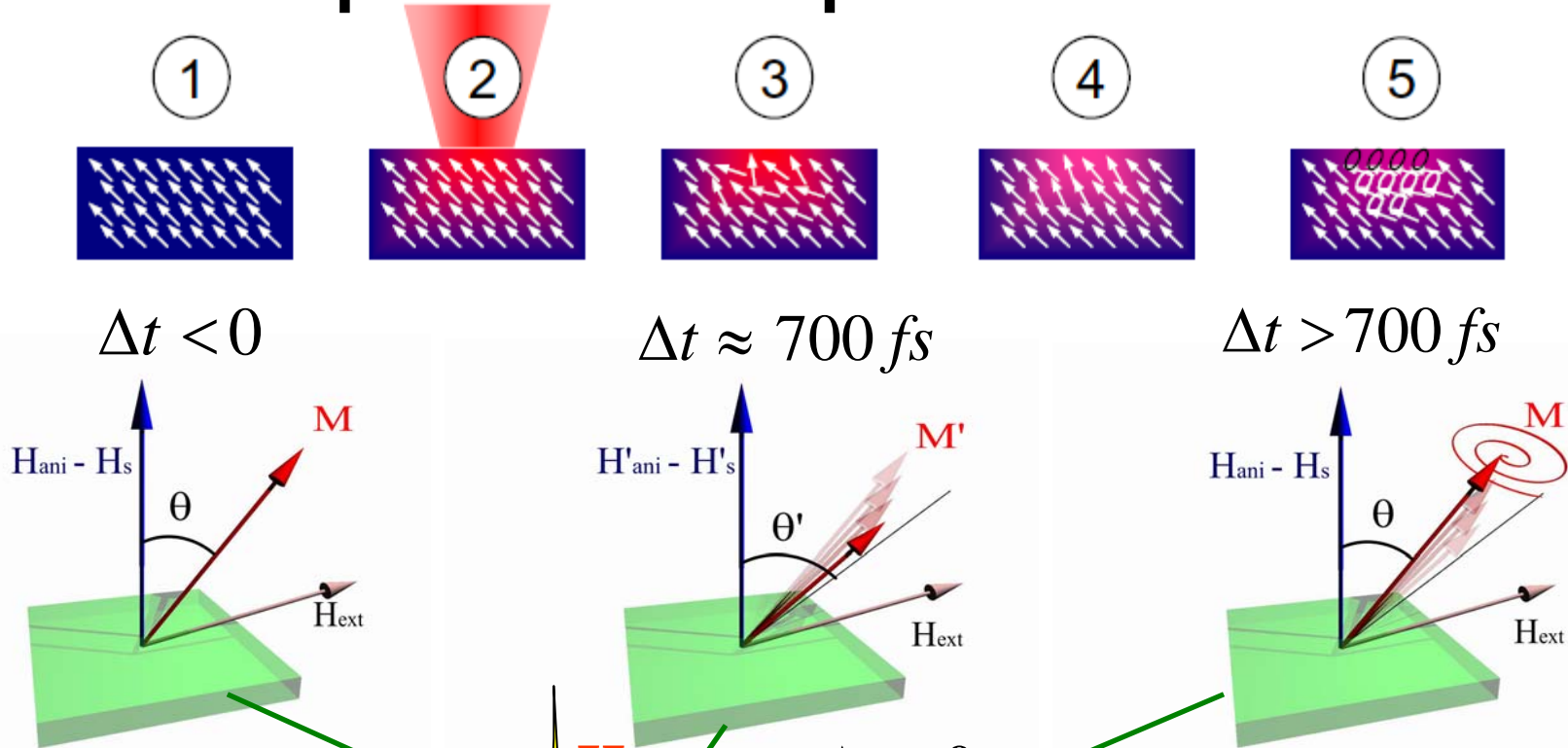


Ultrafast heating
Ultrafast detection of M





Excitation of precession / spin waves

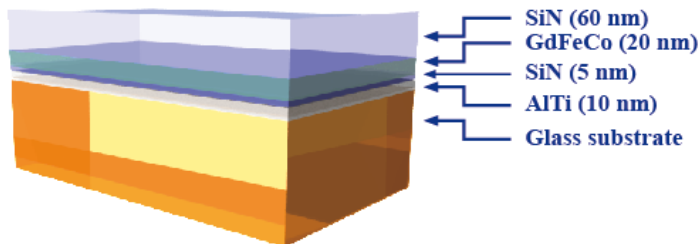
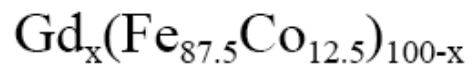




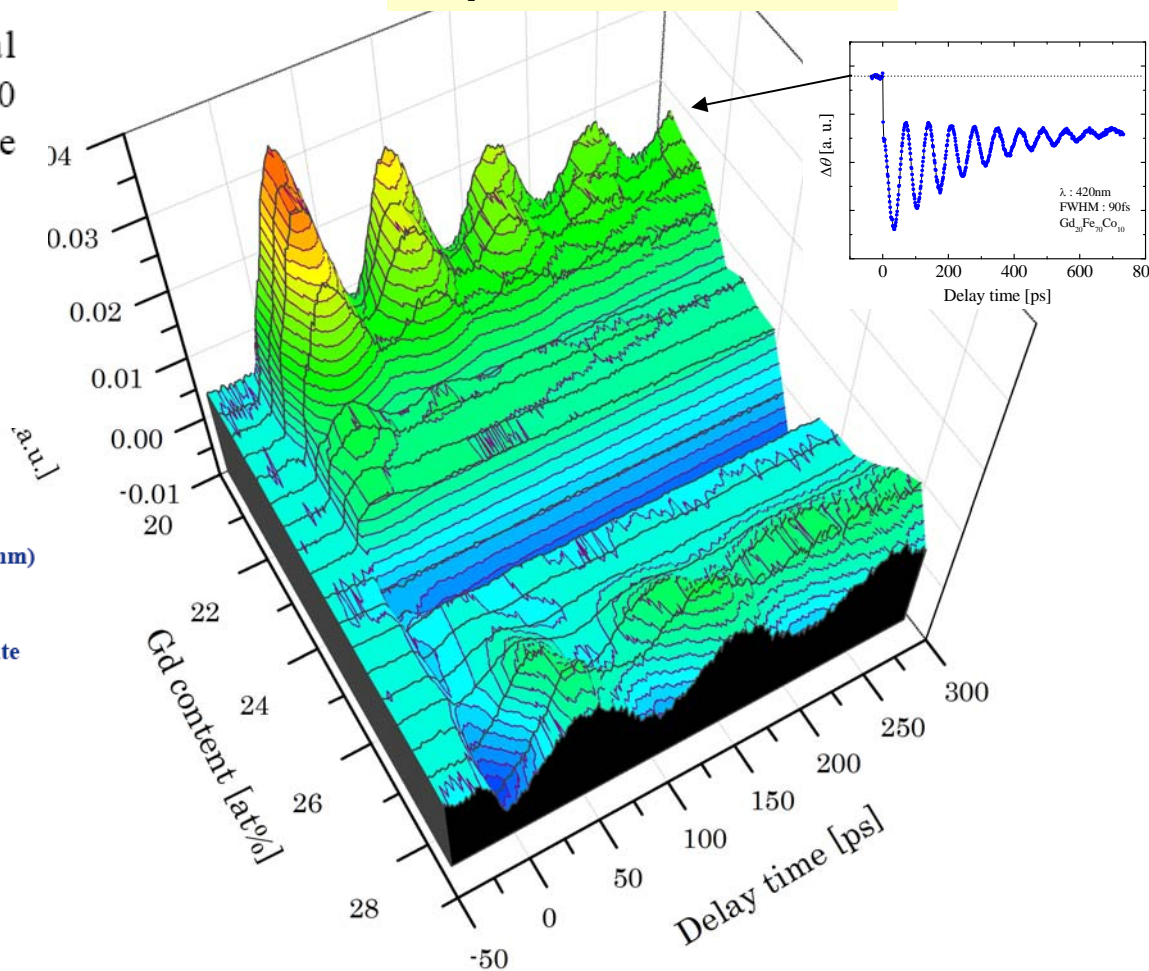
Compositional dependence of coherent precession of the magnetization

in GdFeCo, measured at an external field $H_{\text{ext}} = 0.42$ T. Around $x = 24.0$ a.t. % magnetic compensation of the ferrimagnetic system occurs.

Room temperature

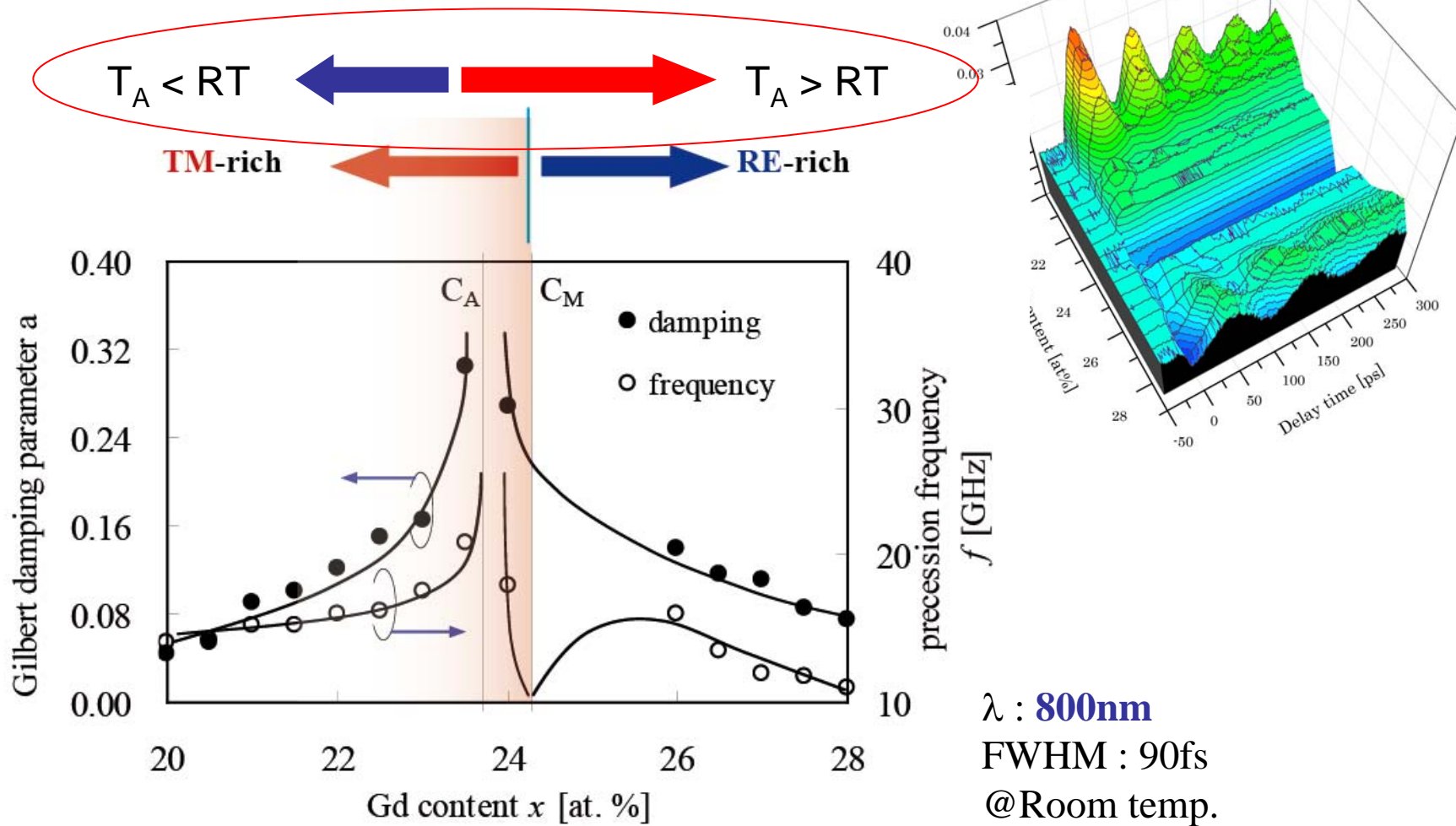


Experimental results





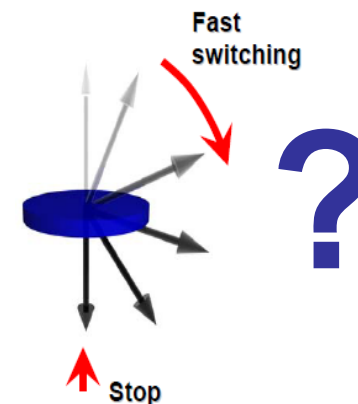
Divergent tendency of precession frequency and damping was appeared closing to compensation composition ratio





Does truly accelerate the magnetization reversal?

→ Pump-probe measurement

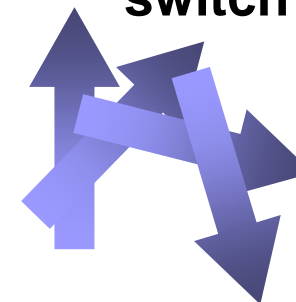


How to generate Ultra-fast magnetic field switching?



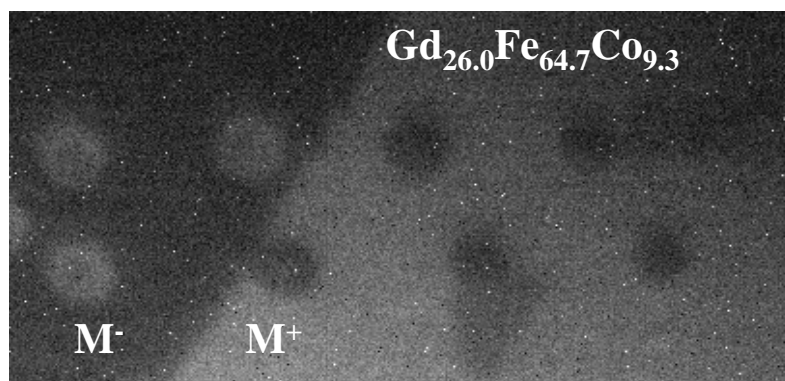
Ultrafast magnetic field switch

Ultrafast demagnetization by ultra short pulse laser?



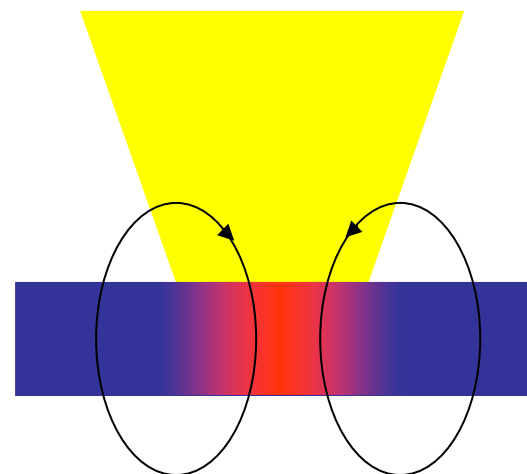


Demonstration of thermo-magnetic recording by ultra-short single laser pulses (FWHM: 90 fs)



Polarized microscope

Rapid heating by laser

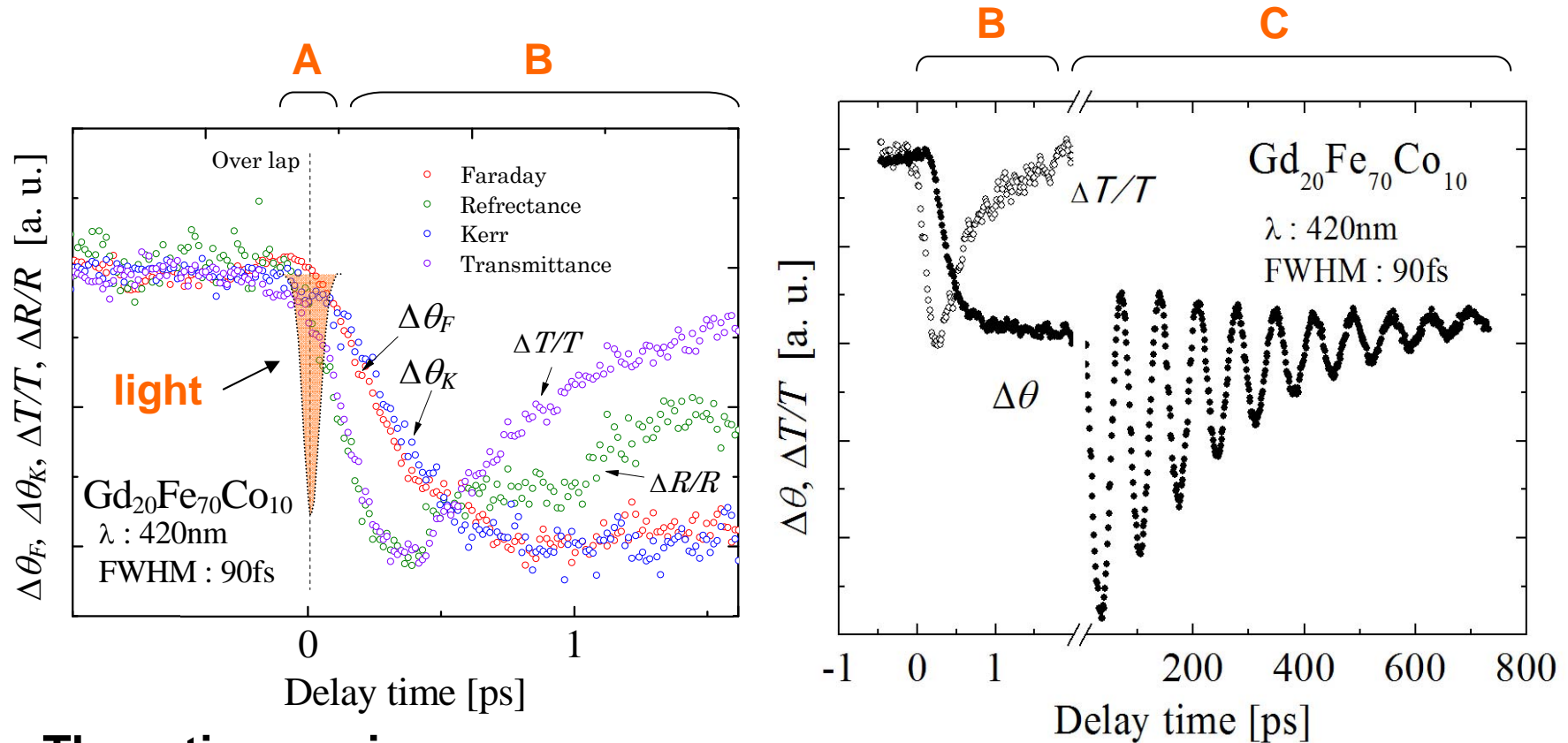


Stray field from surrounded magnetization



Measurements:

Faraday $\Delta\theta_F/\theta_F$, Kerr $\Delta\theta_K/\theta_K$, Transmittance $\Delta T/T$, Reflectance $\Delta R/R$



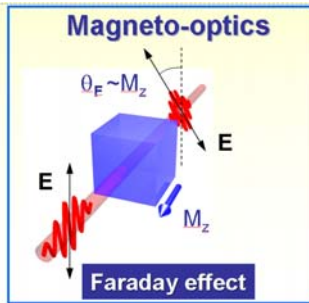
Three time region:

A $\sim 100\text{fs}$ Direct interaction: Coherent, non-thermal

B $\sim \text{few ps}$ Charge/spin dynamics: equilibrations

C $\sim \text{ns}$ LLG-like motion on meta-stable state

Main part of this talk



Faraday rotation: $\theta_F = \frac{2\pi l}{\lambda} \frac{\alpha M}{\epsilon_0}$



$W = \epsilon \epsilon_0 E(\omega) E^*(\omega)$

Light-wave energy

$H_{eff}(0) = \frac{1}{\mu_0} \frac{\partial W}{\partial M(0)}$

M - magnetization

H_eff - magnetic field

$\frac{\partial W}{\partial M} = \epsilon_0 E(\omega) E^*(\omega) \frac{\partial \epsilon}{\partial M}$

$\epsilon_{ij} = \alpha M + \beta M^3 + \dots$

$\epsilon_{jj} = \epsilon_{jj}^{(0)} + \gamma M^2 + \varphi M^4 + \dots$



L. Onsager (1931)

Opto-magnetism

Inverse Faraday effect

$H_{eff}(0) = \alpha \frac{\epsilon_0}{\mu_0} E(\omega) E^*(\omega)$

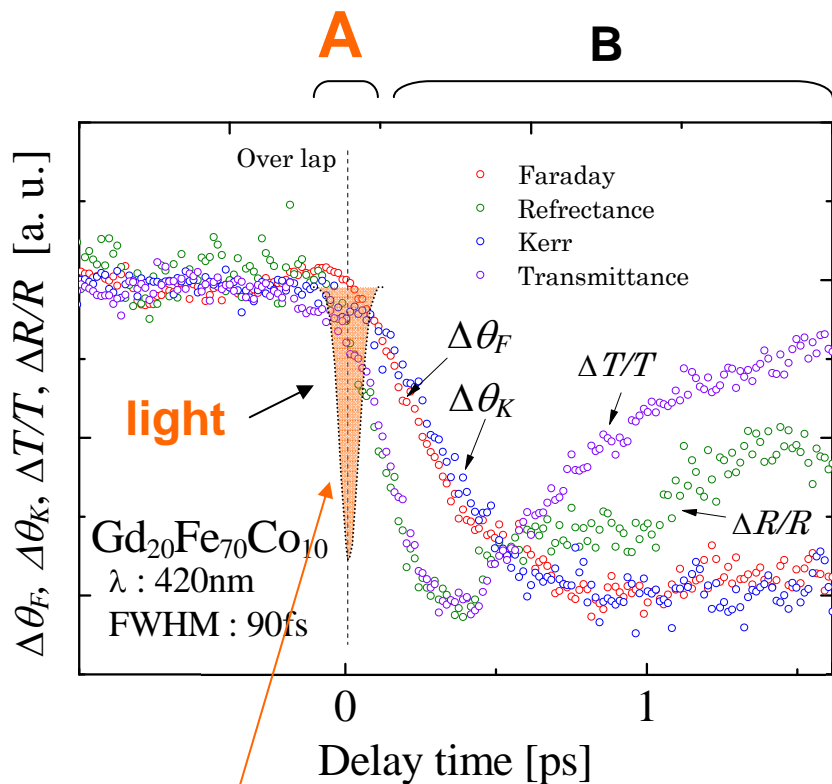
Light acts as a magnetic field

L. P. Pitaevskii, *Sov. Phys. JETP* **12**, 1008 (1961).

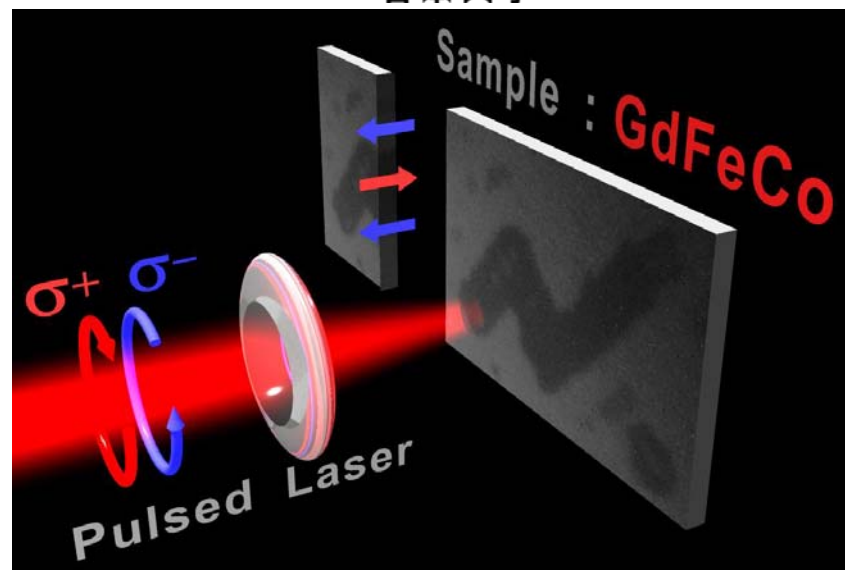
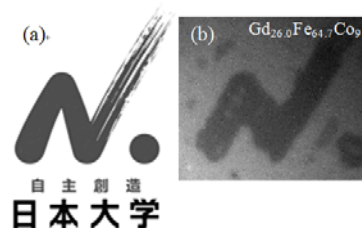
J. P. van der Ziel et al, *Phys. Rev. Lett.* **15**,190 (1965).



A Direct interaction: non-thermal effect Deference with B and C process



Ultra-fast pass light to spins



Information writing on GdFeCo media

**Magnetization reversal depend on
Angular momentum of light**

➡ Non-thermal effect



RE-TM **ferrimagnetic** alloy (GdFeCo) with femtosecond pulsed laser (FWHM~90fs)

- Ultrafast demagnetization of TM and RE components around 1ps
- Divergent tendency of precession frequency and damping (~ 0.32) was appeared closing to **angular momentum compensation**
- Precessional switching can be triggered by ultra-short pulse laser
- **Angular momentum compensation** is a vital point for the magnetization switching speed of magnetic and magneto optical data storage devices!
- Demonstrate that magnetic information can be recorded by non-thermal way, with combination of inverse Farady like effect, ultrafast heating across compensation temperature



Acknowledgements

This work is partially supported by a grant-in-aid from the Nihon university Multidisciplinary Research Grant for (2009).

Collaborations!

