SPring-8利用推進協議会　先端磁性材料研究会
第4回研究会「スピンダイナミクスと光誘起磁化過程」
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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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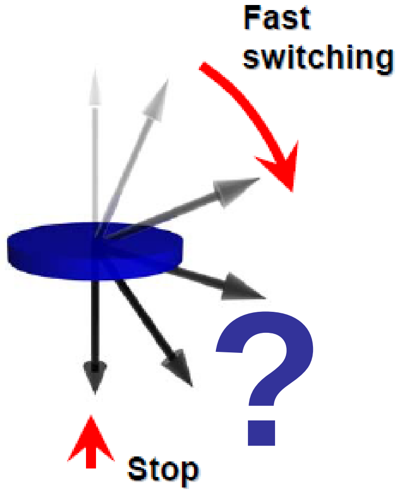
日本大学

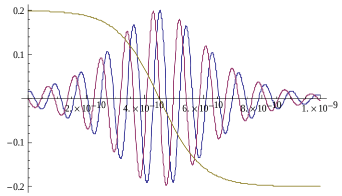
Magnetization reversal

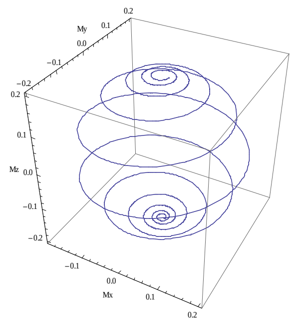


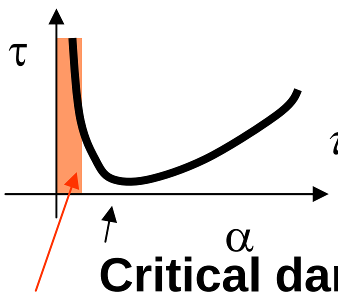
Damping term
Proportional to the dM/dt

Landau-Lifshitz-Gilbert equation

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







$$\tau = \frac{1+\alpha^2}{\alpha}\frac{1}{\omega_0} = \frac{1}{\alpha\omega}$$

Critical damping α=1

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

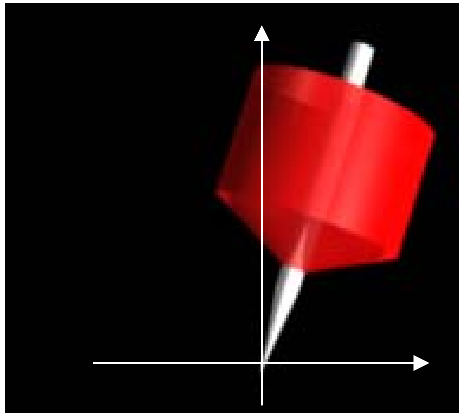
- ★ **RE-TM Ferrimagnet**
- ★ **Angular momentum compensation**

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

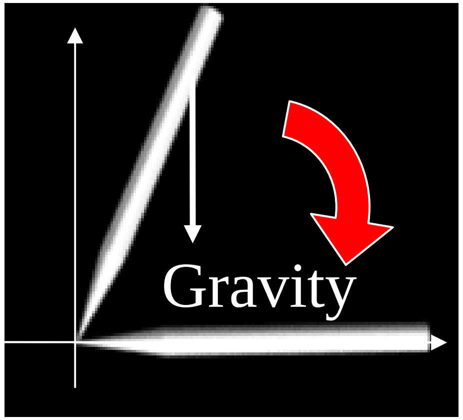
Angular momentum compensation

Spinning Top (“KO MA” in Japanese)

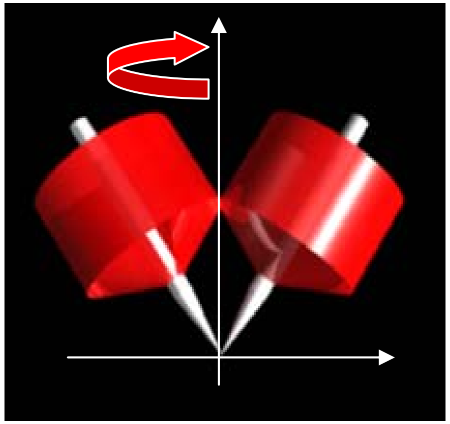
With angular momentum



Without angular momentum



Starting
precessional motion



Long time survive

Rapid fall

● Ferro magnetism

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

M L

● Ferri magnetism
sub-lattice magnetization
anti-parallel tight coupling, α, different γ

L_A M_A
M_B L_B

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

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

Magnetization dynamics in ferrimagnetics（sub-lattice）

$$\gamma_1 \neq \gamma_2$$ anti-parallel tight coupling

- phenomenological Landau-Lifshitz-Gilbert equation

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

- effective gyromagnetic ratio

Net M

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

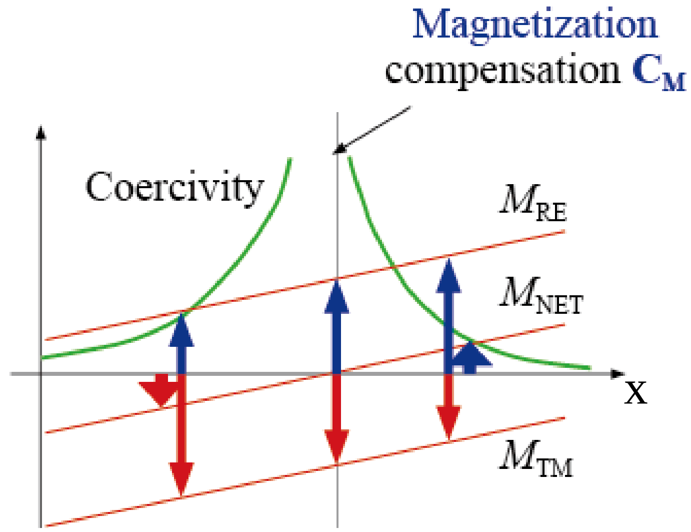
- ferromagnetic resonance (FMR) branch

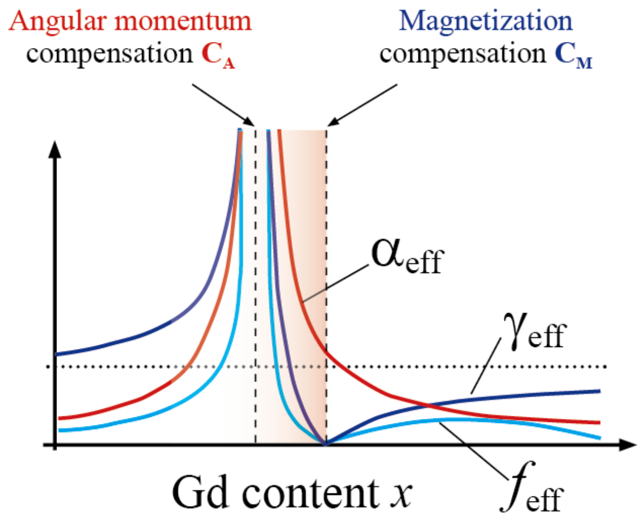
$$\omega_{FMR} = \gamma_{eff}\mathrm{H}^{eff}$$

Net angular momentum

- effective Gilbert damping parameter*

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

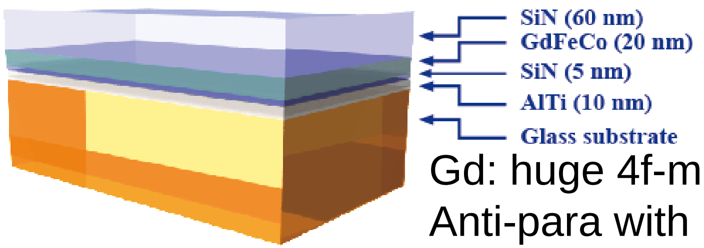




As a fast recordable media

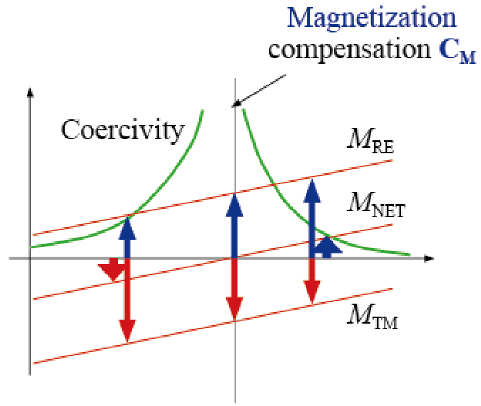
idea

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



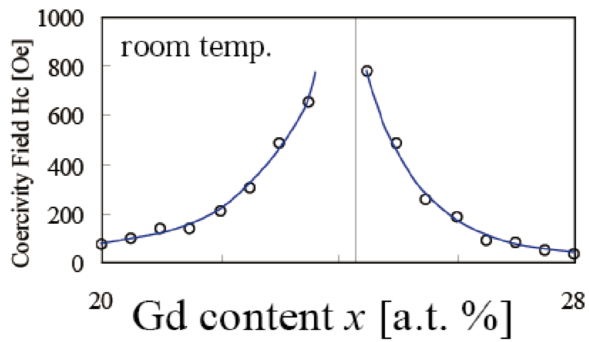
$Gd_x(Fe_{87.5}Co_{12.5})_{100-x}$

Gd: huge 4f-moment S=7/2
Anti-para with FeCo
Amorphous: uniform

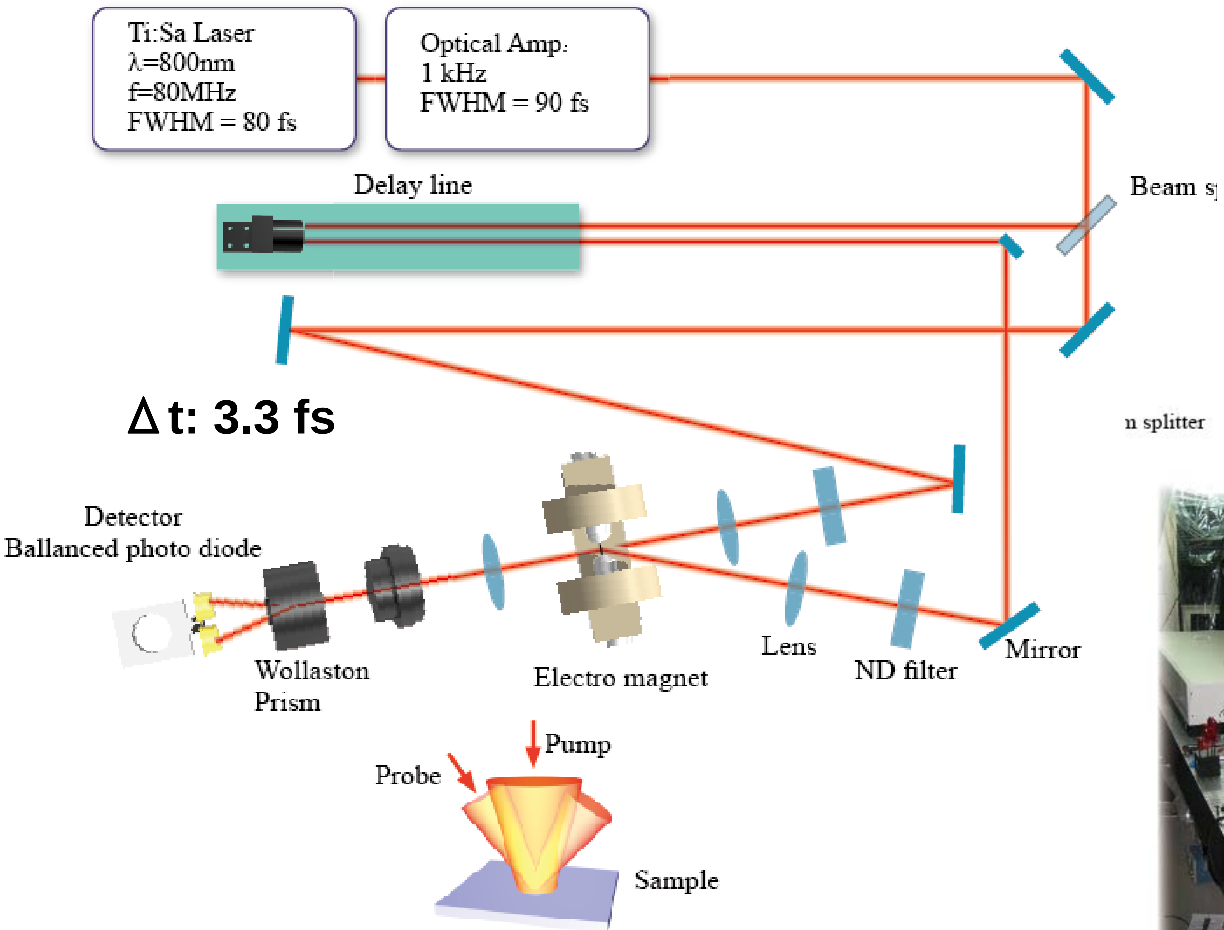


Ferrimagnetic and amorphous alloy;
Perpendiculor magnetic anisotropy;
Strong coupling between rare earth (RE) and transition (TM) component.

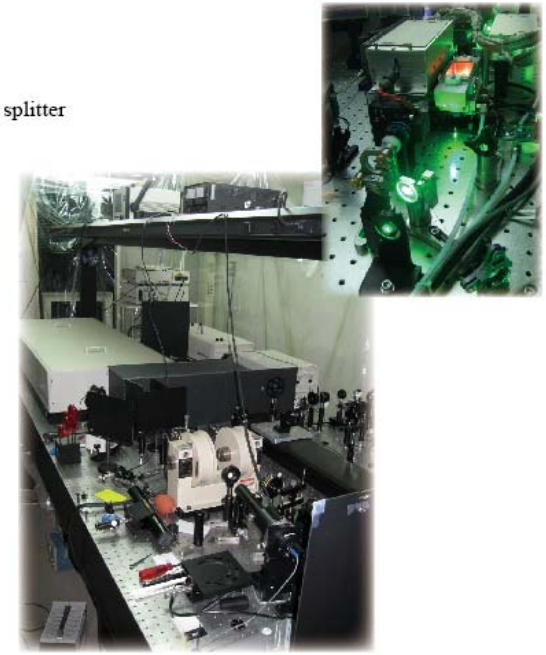
Magnetization compensation C_M **and**
Angular momentum compensation C_A
depend on the composition ratio (Gd content)



All-optical Pump probe set up



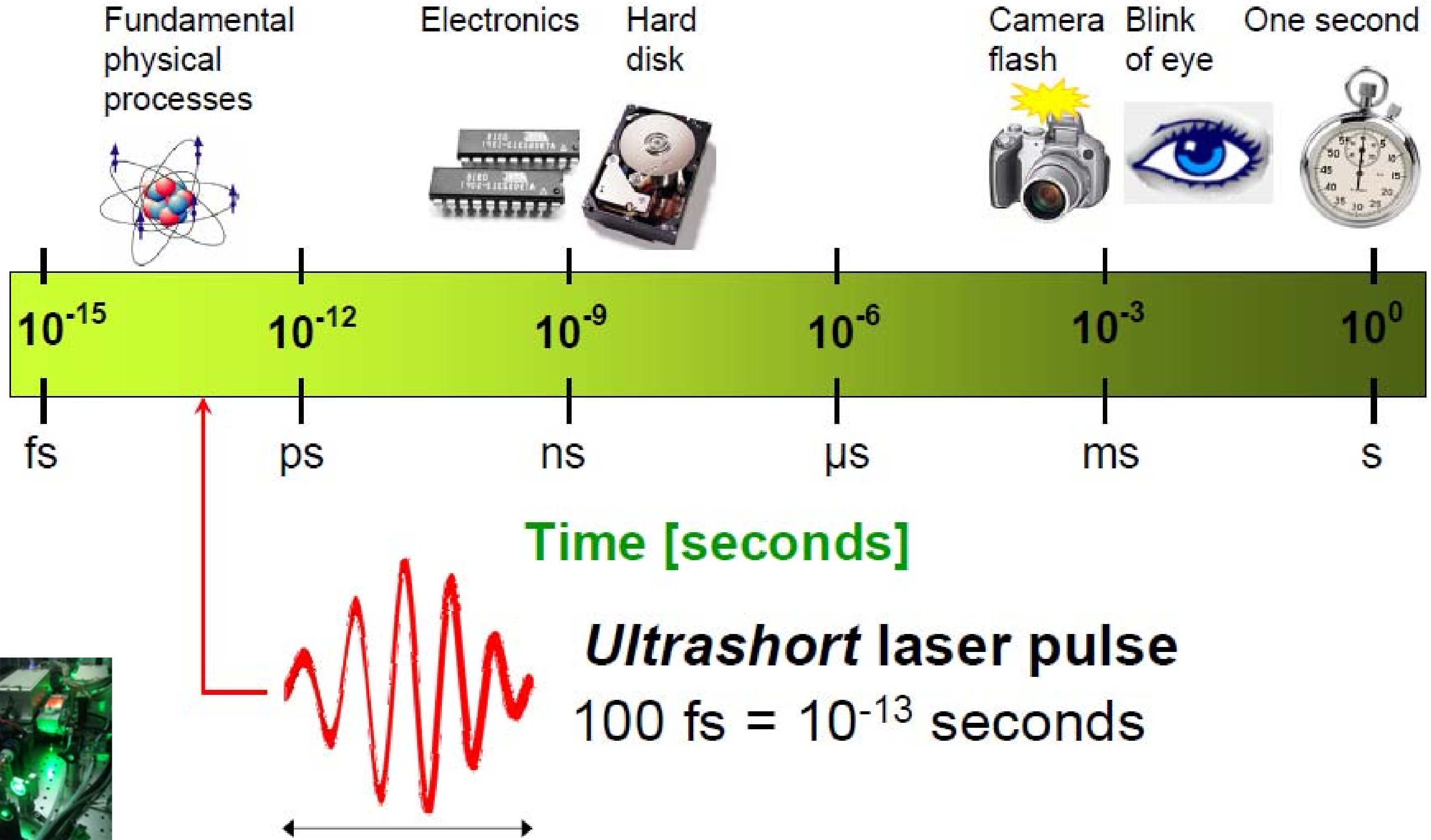
Measurements:monitering
Faraday$\Delta\theta_F/\theta_F$, Kerr $\Delta\theta_K/\theta_K$,
Transmittance$\Delta T/T$,
Reflectance $\Delta R/R$

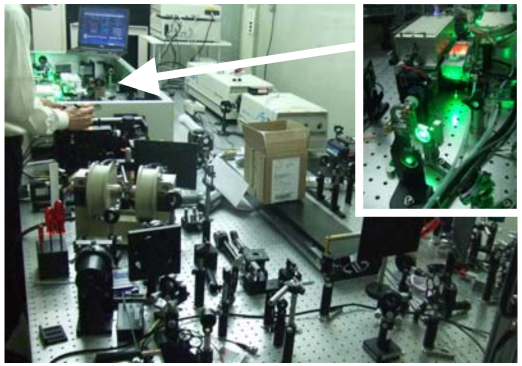


FWHM : 90fs : **420nm and 800nm**

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.

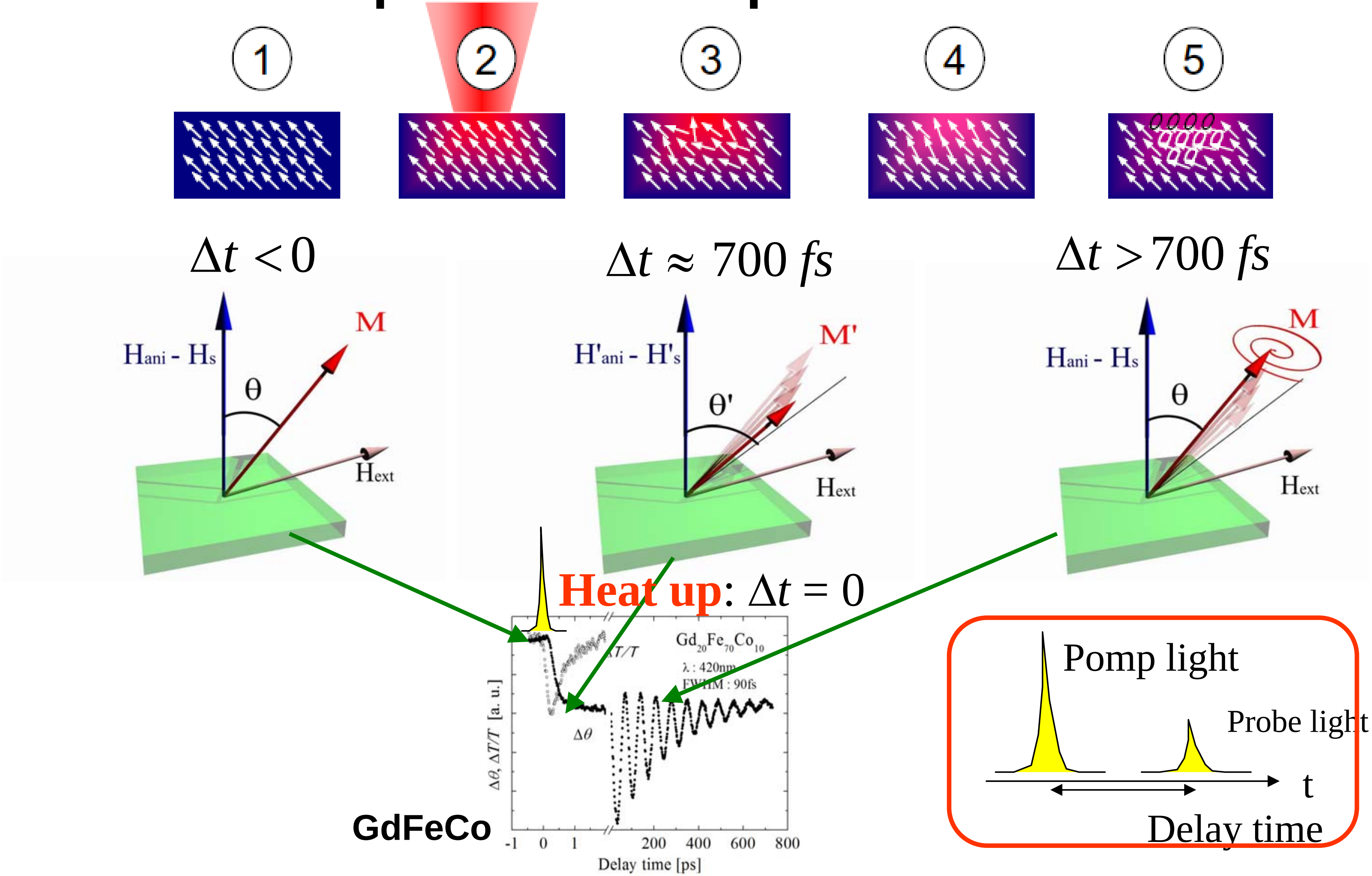
Employ femtosecond pulsed laser





Ultrafast heating
Ultrafast detection of M

Excitation of precession / spin waves

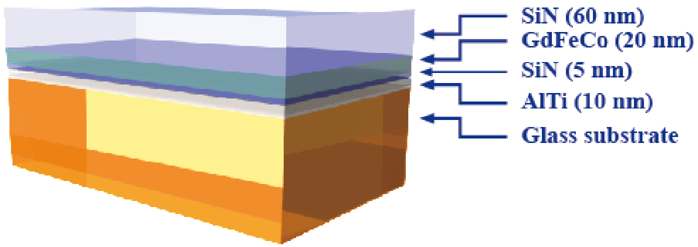


Composition dependence of precessional motion

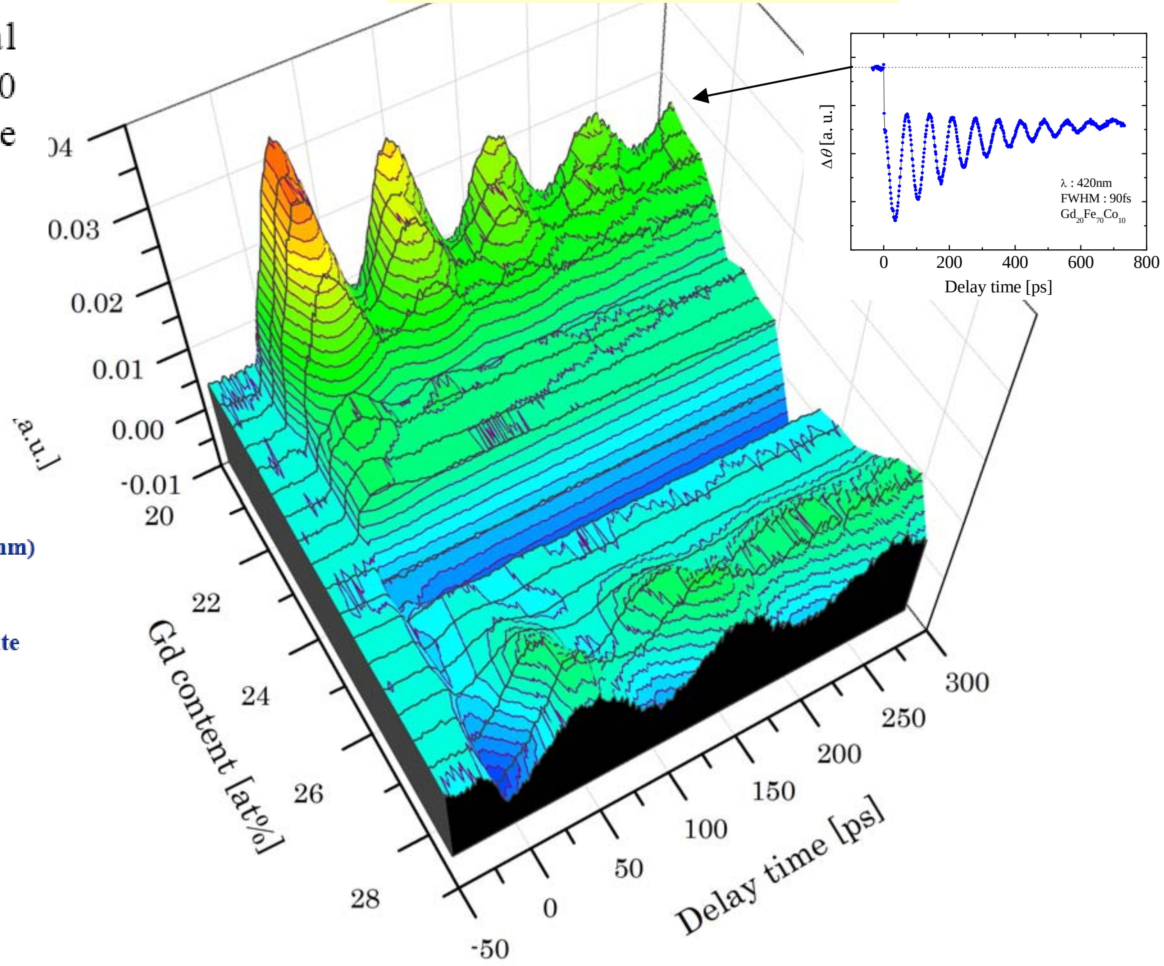
Compositional dependence of coherent precession of the magnetization in GdFeCo, measured at an external field H_{ext} = 0.42 T. Around x = 24.0 a.t. % magnetic compensation of the ferrimagnetic system occurs.

Room temperature

$$Gd_x(Fe_{87.5}Co_{12.5})_{100-x}$$

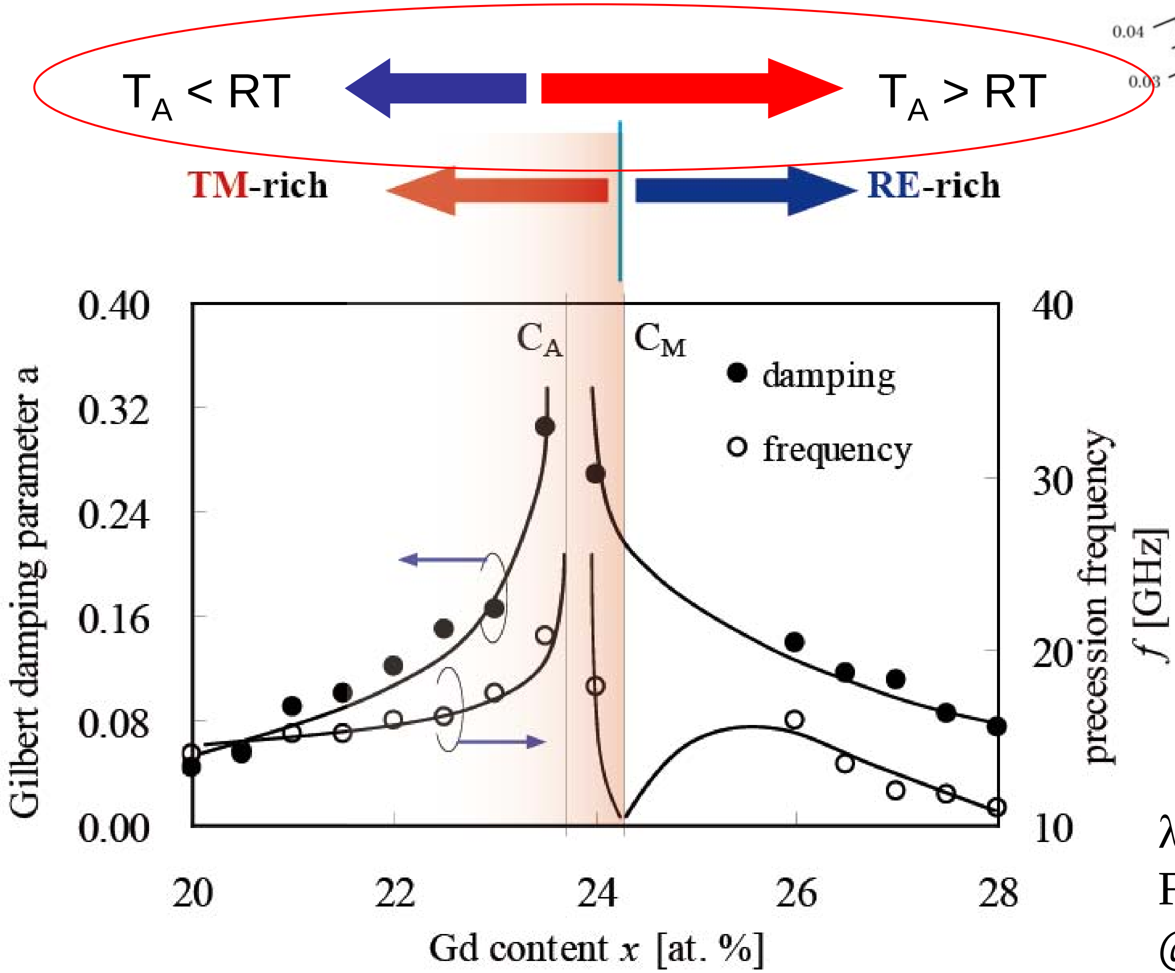


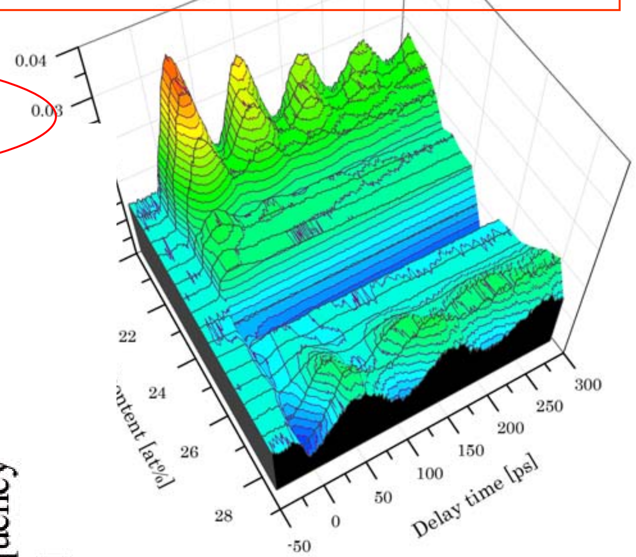
Experimental results



Composition dependence of precessional motion

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

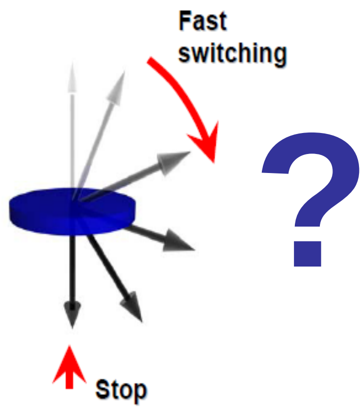




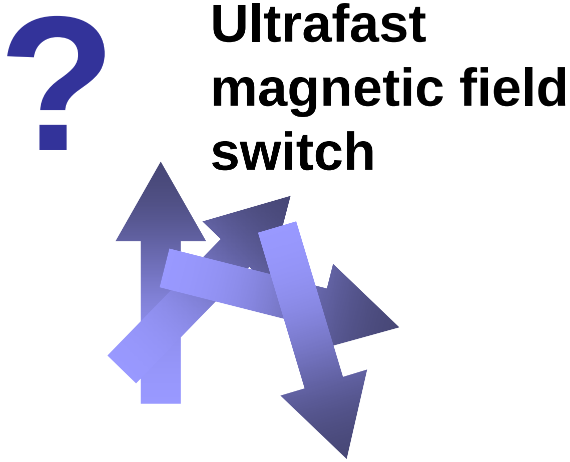
λ : **800nm**
FWHM : 90fs
@Room temp.

Does truly accelerate the magnetization reversal?

→Pump-probe measurement



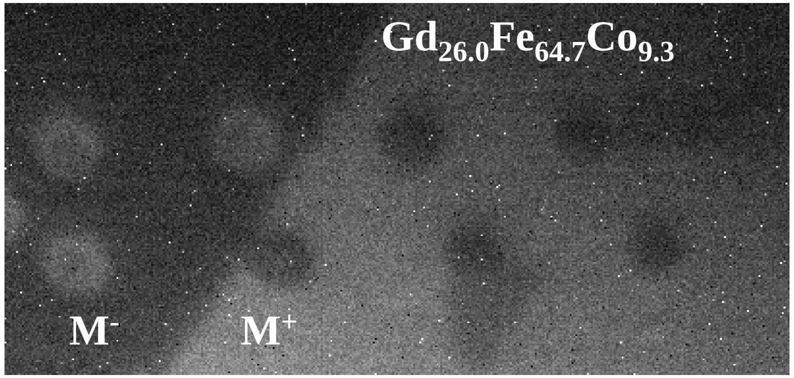
How to generate
Ultra-fast magnetic field switching?



Ultrafast demagnetization
by ultra short pule laser?

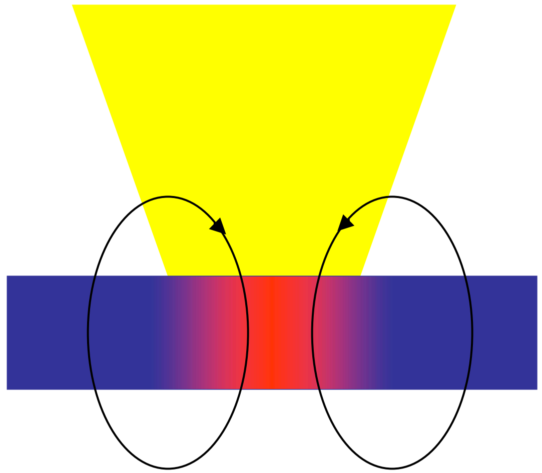
Demonstration of thermo-magnetic recording

by ultra-short single laser pulses (FWHM: 90 fs)



Polarized microscope

Rapid heating by laser

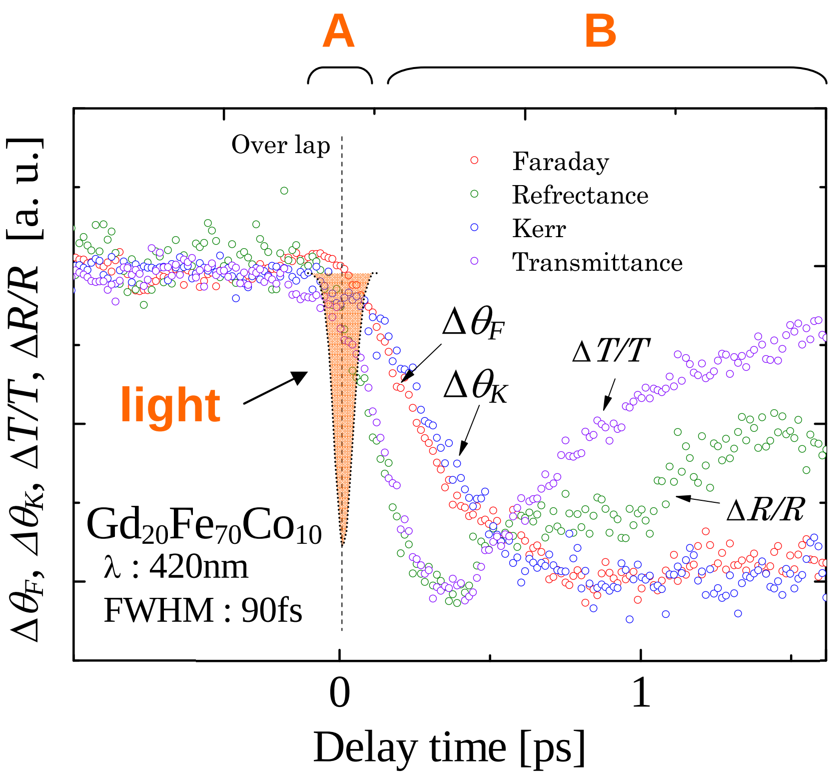


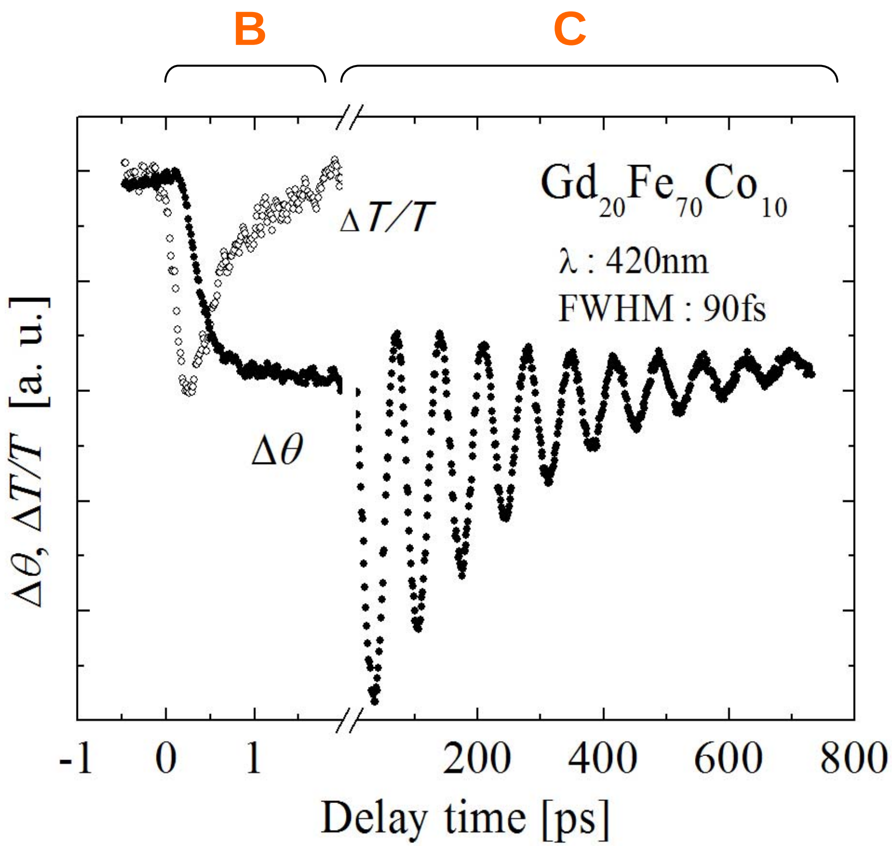
Stray field from
surrounded magnetization

Pomp-Probe measurements

Measurements:

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





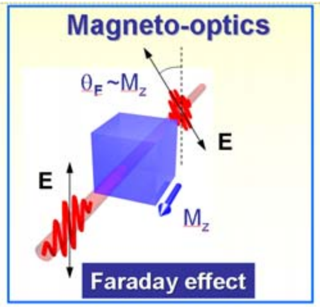
Three time region:

A ∼100fs Direct interaction: Coherent, non-thermal

B ∼few ps Charge/spin dynamics: equilibrations

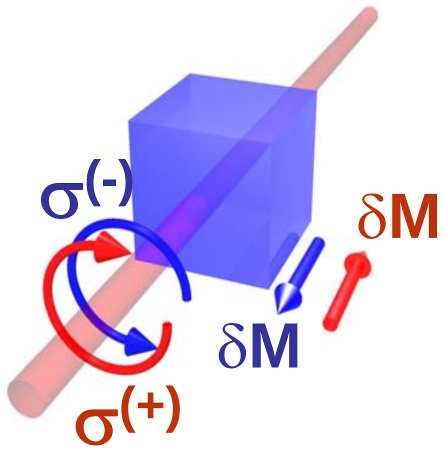
C ∼ns LLG-like motion on meta-stable state

Main part of this talk (B, C)



Faraday rotation: $\theta_F = \frac{2\pi l}{\lambda}\frac{\alpha M}{\varepsilon_0}$

Opto-magnetism



Inverse Faraday effect

$W = \varepsilon\varepsilon_0 E(\omega)E^*(\omega)$ — *Light-wave energy*

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

M – magnetization
H_{eff} - magnetic field

$$\frac{\partial W}{\partial M} = \varepsilon_0 E(\omega)E^*(\omega)\frac{\partial \varepsilon}{\partial M}$$

$$\varepsilon_{ij} = \alpha M + \beta M^3 + \ldots$$
$$\varepsilon_{jj} = \varepsilon_{jj}^{(0)} + \gamma M^2 + \varphi M^4 + \ldots$$

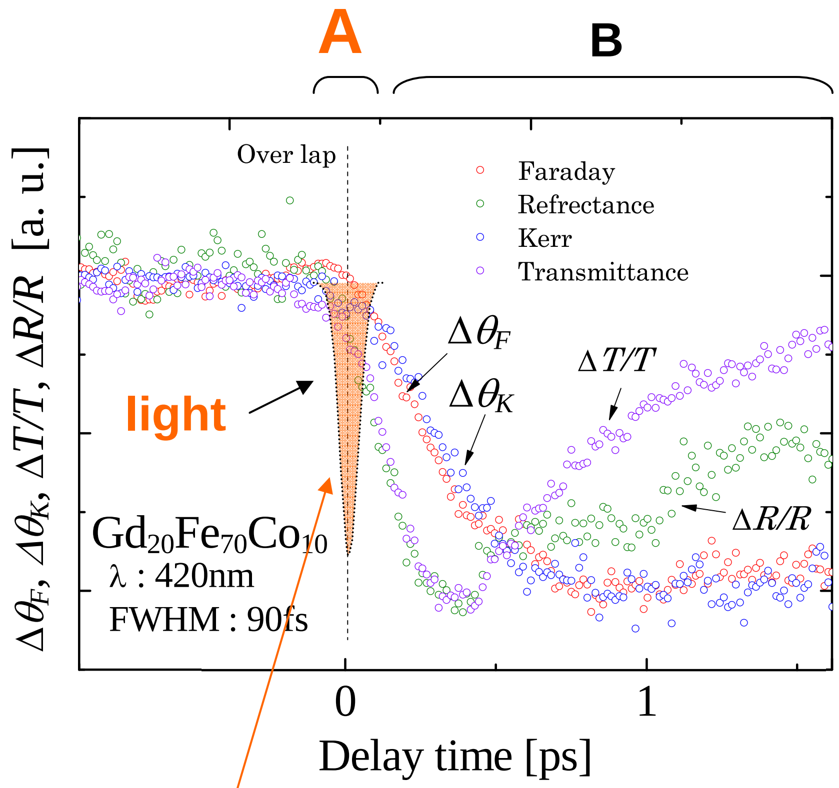
L. Onsager (1931)

$$H_{eff}(0) = \alpha\frac{\varepsilon_0}{\mu_0}E(\omega)E^*(\omega)$$

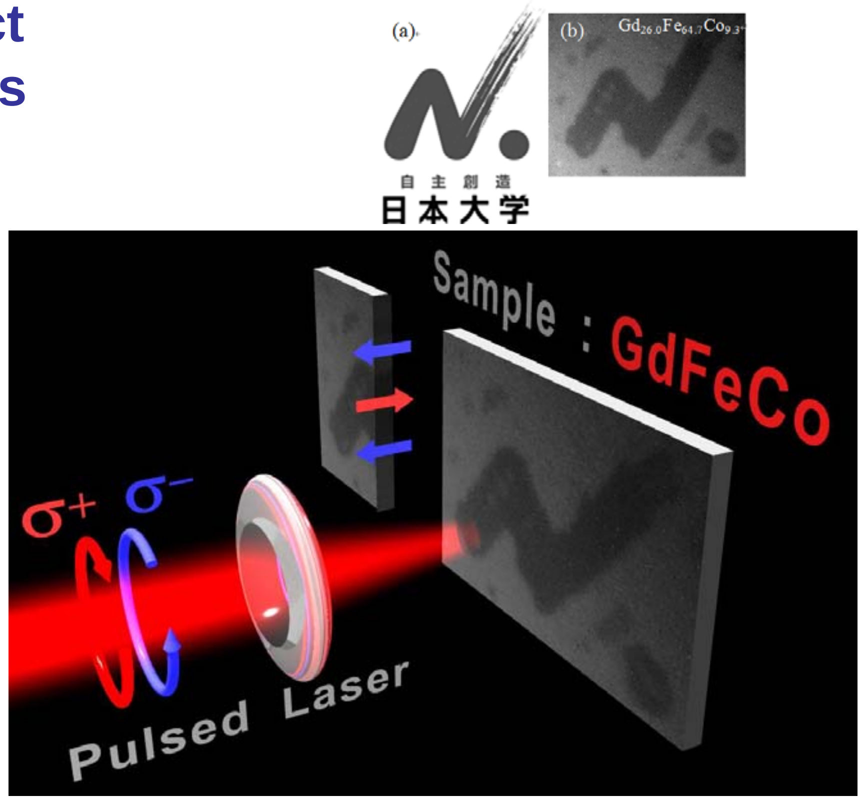
Light acts as a magnetic field

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**

Conclusions

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

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Collaborations!