Magneto-Optical Kerr Effects of Magnetic Garnet Thin Films Incorporating Gold Nanoparticles:

A Possible Coupling between Localized Surface Plasmons and Magneto-Optical Effects

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Introduction

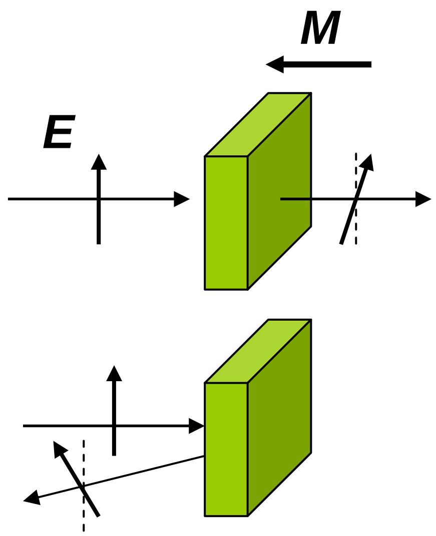
Magneto-Optical (MO) effects:

Linearly polarized light interacts with magnetized materials

The plane of polarization of light is rotated.

Transmission: MO Faraday effects

Reflection: MO Kerr effects



Coupling between MO Kerr effects and surface plasmon polariton (SPP)

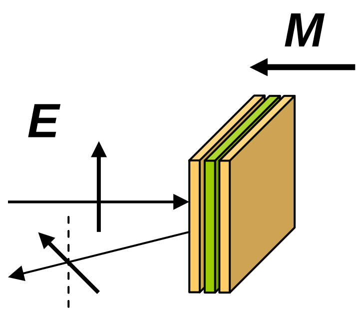
Au/Co/Au multi-layers in ATR geometry

Enhancement of MO Kerr FOM

Traveling SPP coupled to MO effect

Surface-enhanced MO media ?

*V. I. Safarov et al., PRL **73**, 3584 (1994).*



Motivation

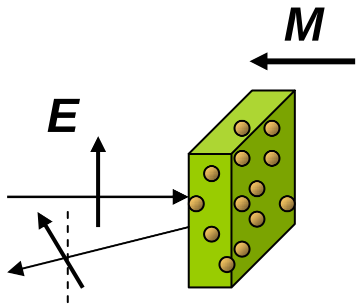
MO medium + noble metal nanoparticles (MO inactive) , e.g., Au

Little is known about

MO Kerr effects coupled with localized SPP in the visible region

*Theoretical: V.A.Kosobukin, SPIE Proceeding **2535**, 9 (1995).*

*Theoretical: M.Abe and T.Suwa, PRB **70**, 235103 (2004).*



Localized SPP

Direct excitation by traveling light wave

Large specific surface

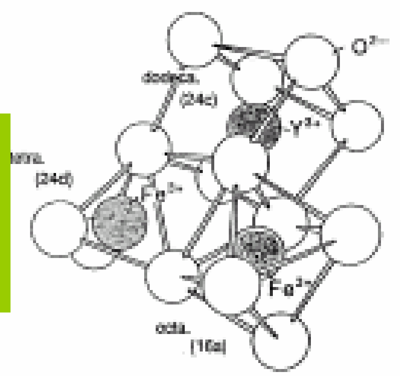
Localized SPP influence MO effects

Novel MO effects of composite materials

$Y_3Fe_5O_{12}$: yttrium iron garnet (YIG)

Ferrimagnet

Transparent in visible region



Present study:

Preparation and MO Kerr study of

YIG films incorporating Au nanoparticles

Preparation

Film deposition: Co-sputtering method

4 inch ϕ YIG target, Au chips

Ar gas 20mTorr

Deposition rate ~6nm/min

Film thickness: 200-500nm

on quartz substrates

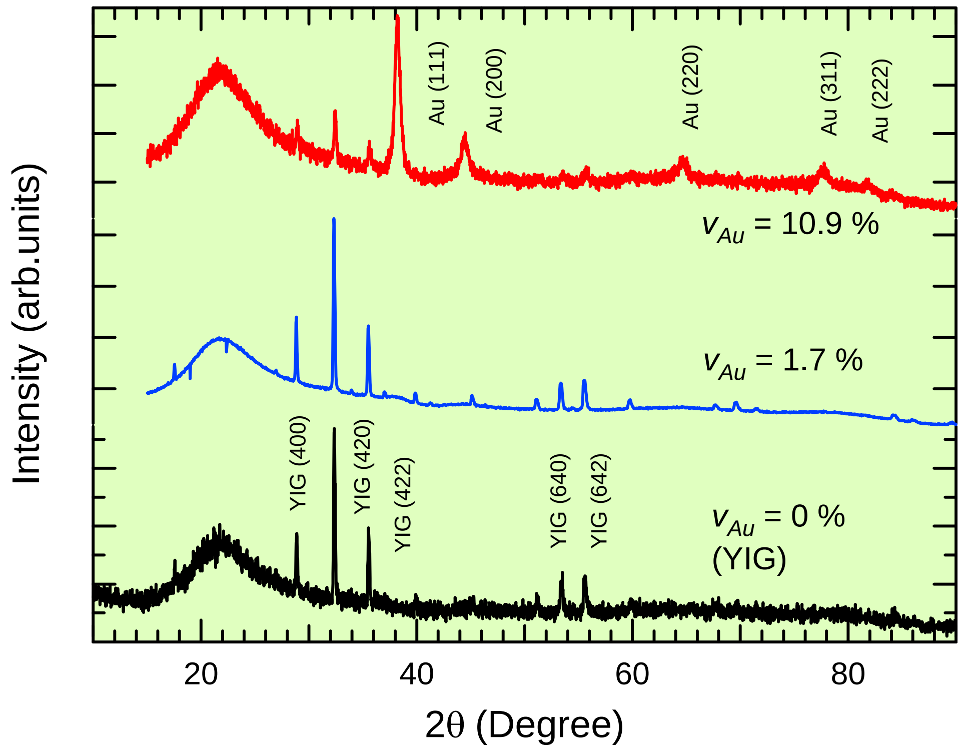
Au volume fraction (v_{Au}) evaluated by EPMA

v_{Au}= 0, 1.7, 10.9 %

Post annealing: 900°C 30min in N_2 gas

X-ray diffraction profiles

* $\lambda_{CuK\alpha}$ = 1.54 Å
* after annealing

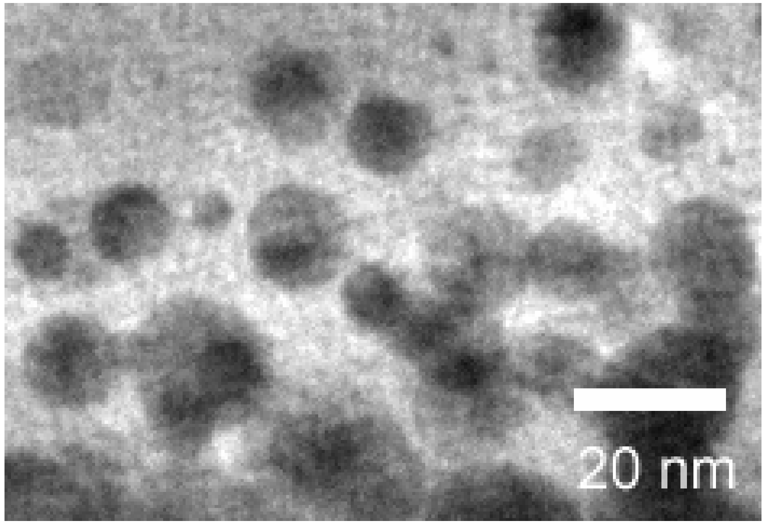


fcc-Au is grown and coexist with crystalline YIG in a film with v_{Au} = 10.9%

TEM observation

* at 200 kV

Cross-sectional transmission electron microscopy (TEM)

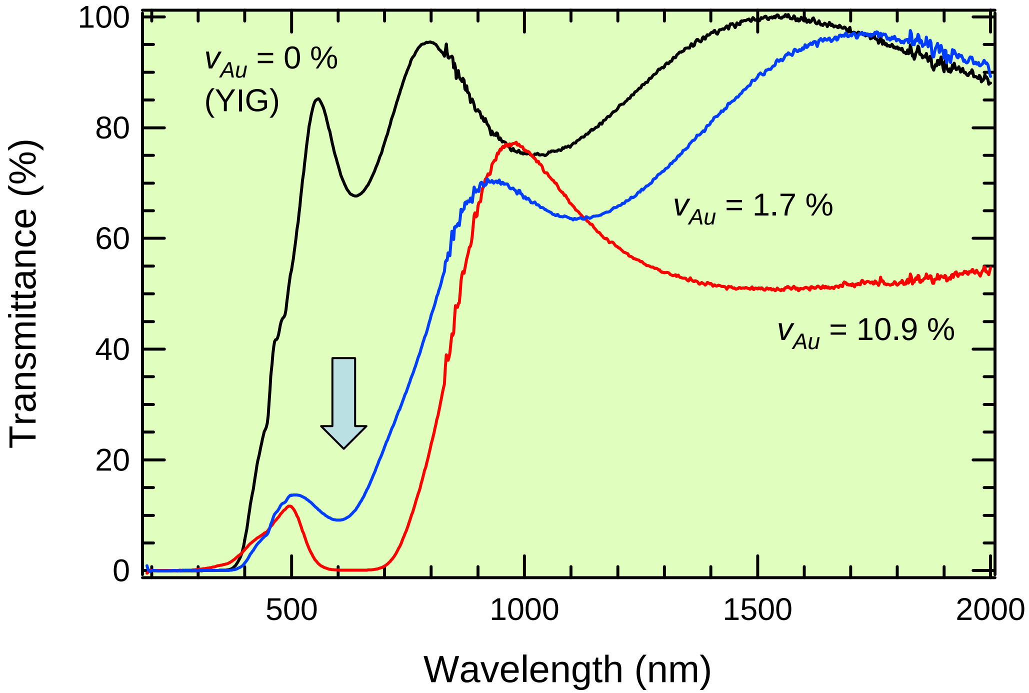


v_{Au}= 10.9%

Spherical Au nanoparticles 12 nm in average diameter
are embedded randomly in YIG matrices

UV-Vis. transmission spectra

* using a double-beam-type spectrometer



Below 500nm: Strong absorption due to CT-type transition in YIG

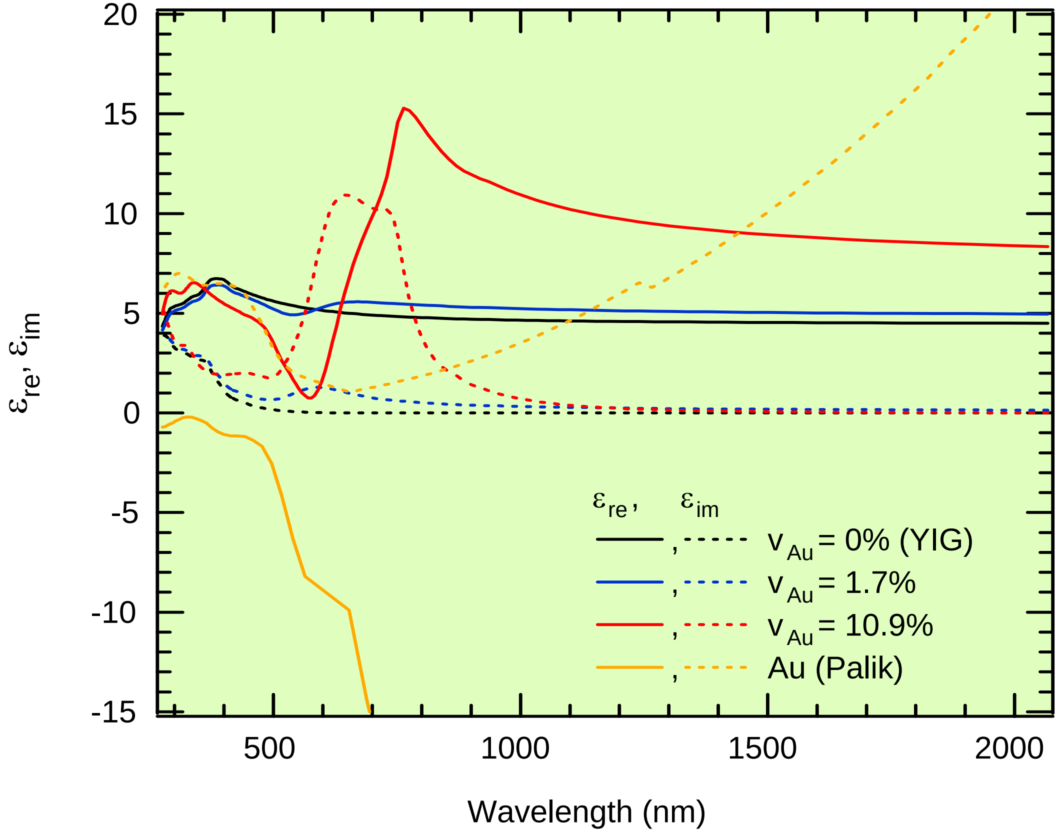
Above 500nm: Almost transparent for YIG

Incorporation of Au results in a strong absorption around 600nm

SPP of Au nanoparticles

Spectroscopic ellipsometry

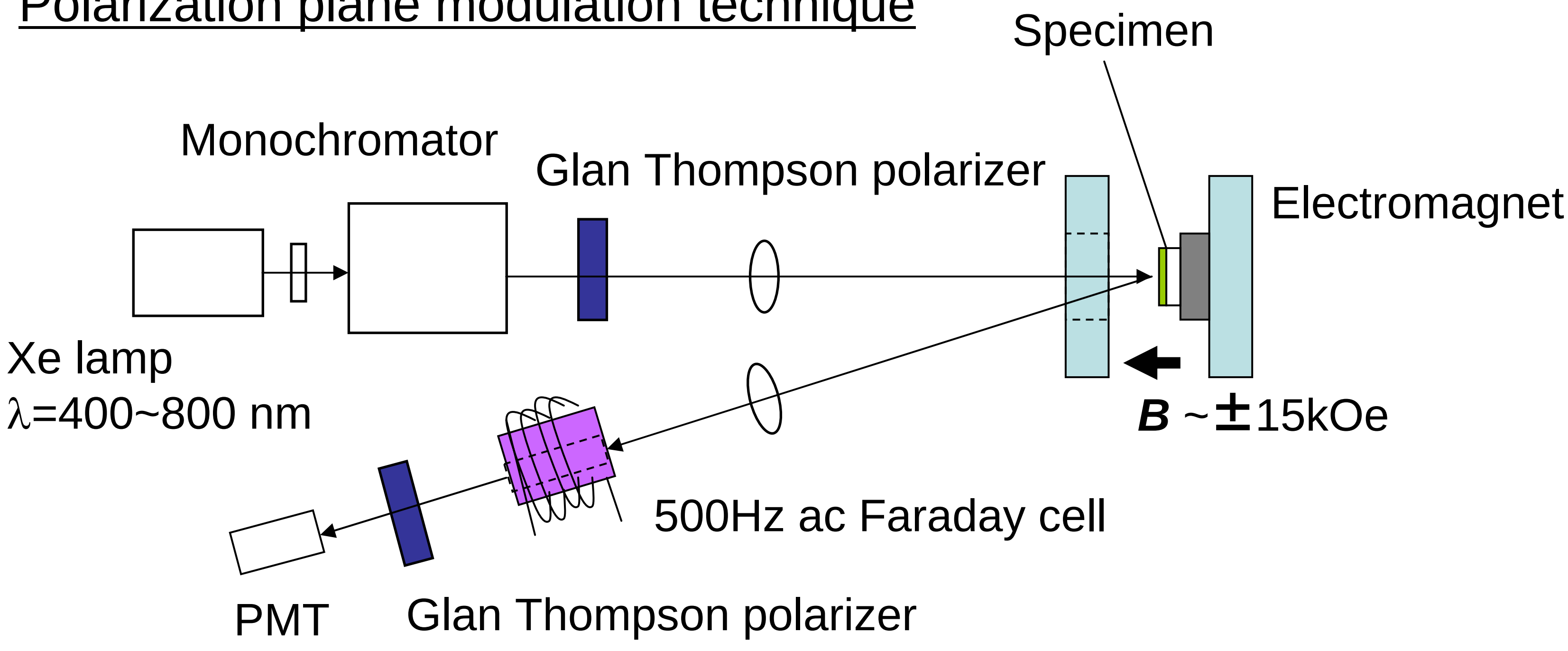
* using Horiba UVISEL NIR



We observe dispersion of ε due to SPP of Au nanoparticles in YIG

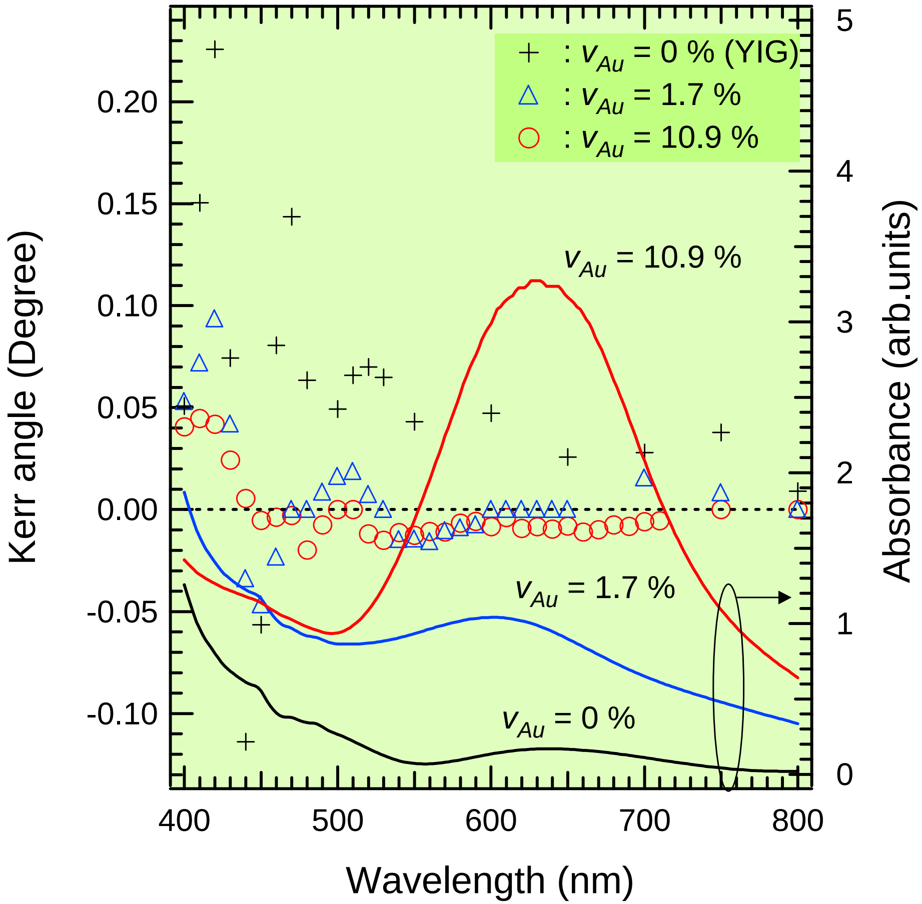
Polar MO-Kerr effect measurements

Polarization plane modulation technique



Faraday cell between two polarizers compensates
the rotation of polarization plane due to Kerr effects of the specimen
High angle resolution about 0.001°

Polar MO-Kerr spectra



v_{Au} = 1.7%:
With Au nanoparticles
Negative Kerr rotation angle around 550nm

v_{Au} = 10.9%:
Increase in v_{Au}
Red shift of the region of Anomalous negative Kerr rotation

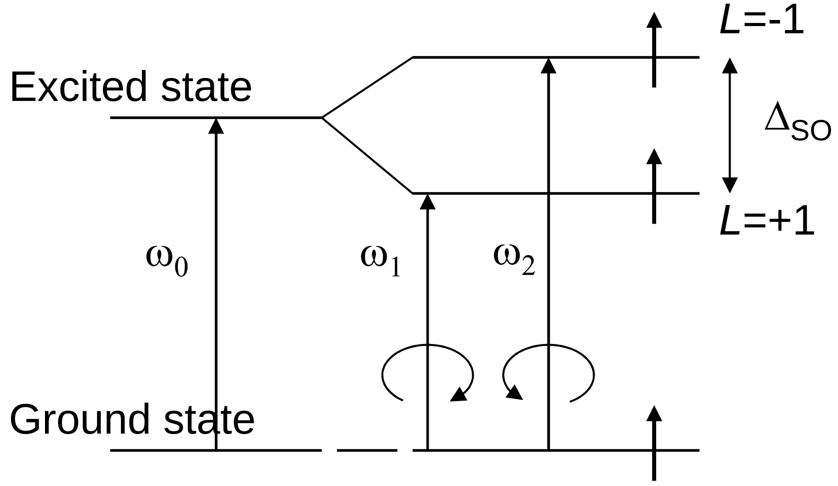
Correlation between the region of negative Kerr rotation and SPP wavelength of Au nanoparticles
A possible coupling between SPP and MO effects

CT-type transition

*F. J. Kahn et al., Phys.Rev.**186**, 891 (1969).*

Optical transition related to *d* electron in YIG:
Charge transfer (CT) type transition, crystal field (CF) type transition

1. CT-type transition: transition from *p* level to *d* level



$$\varepsilon'_{xy} = \frac{Ne^2 f_0 \Delta_{SO}}{2m\varepsilon_0\omega\tau} \cdot \frac{\omega_0 - \omega}{\left\{(\omega_0 - \omega)^2 + \gamma^2\right\}^2}$$

$$\varepsilon''_{xy} = -\frac{Ne^2 f_0 \Delta_{SO}}{4m\varepsilon_0\omega} \cdot \frac{(\omega_0 - \omega)^2 - \gamma^2}{\left\{(\omega_0 - \omega)^2 + \gamma^2\right\}^2}$$

MO effects:
Oscillator strength f_0, spin-orbit splitting Δ_{SO}, frequency ω

Possible origin

1. Charge transfer (CT) type transition around 490 nm is dominant in MO property of YIG in visible region

The **effective SO coupling** of excited state in CT transition is modified by localized SPP accompanied by an enhanced electric field

$$H_{SO} = \left[\frac{\hbar}{4m_0c^2} \right] \{ \nabla V \times \vec{p} \} \cdot \vec{\sigma}$$

Negative Kerr rotation angle

cf: Modification of SO coupling constant in Bi_x: $Gd_{3-x}Fe_5O_{12}$

Takeuchi, JJAP ***14****, 1903 (1975).*

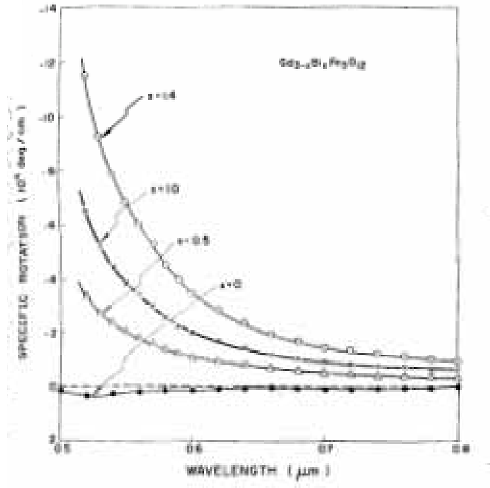


Fig. 1. Faraday rotation spectra of $Gd_{3-x}Bi_xFe_5O_{12}$.

2. Enhancement of oscillator strength of crystal field (CF) type transition in YIG at 610 nm by relieving **the parity constrain**

Summary

- We have prepared YIG thin films containing small amount of Au nanoparticles.

- UV-visible transmission spectra shows strong absorption around 600 nm, which is caused by SPP of Au nanoparticles.

- Polar MO-Kerr spectra shows negative Kerr angle around 600nm, indicating the near-field coupling between MO Kerr effect and SPP.

- Possible origin for negative Kerr angle:
  1. Modification of spin-orbit coupling in CT-type transition by SPP with an enhanced electric field,
  2. Enhancement of oscillator strength of CF-type transition in YIG by SPP as an electric dipole