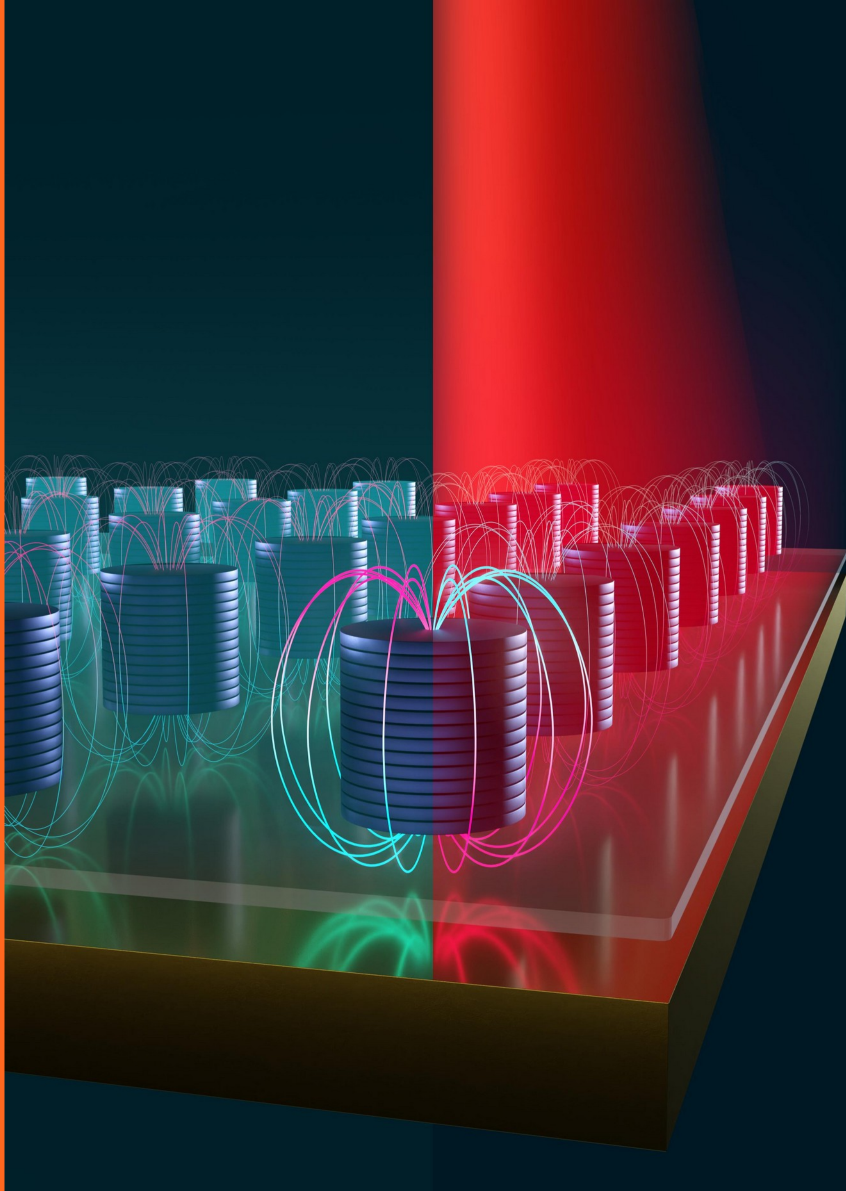
Magnetic on-off switching of a plasmonic laser

Kristian Arjas



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Magnetic on–off switching of a plasmonic laser

Francisco Freire-Fernández ✉, Javier Cuerda, Konstantinos S. Daskalakis, Sreekanth Perumbilavil, Jani-Petri Martikainen, Kristian Arjas, Päivi Törmä ✉ & Sebastiaan van Dijken ✉

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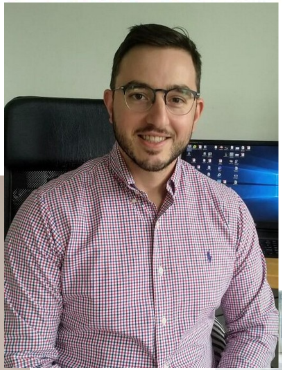
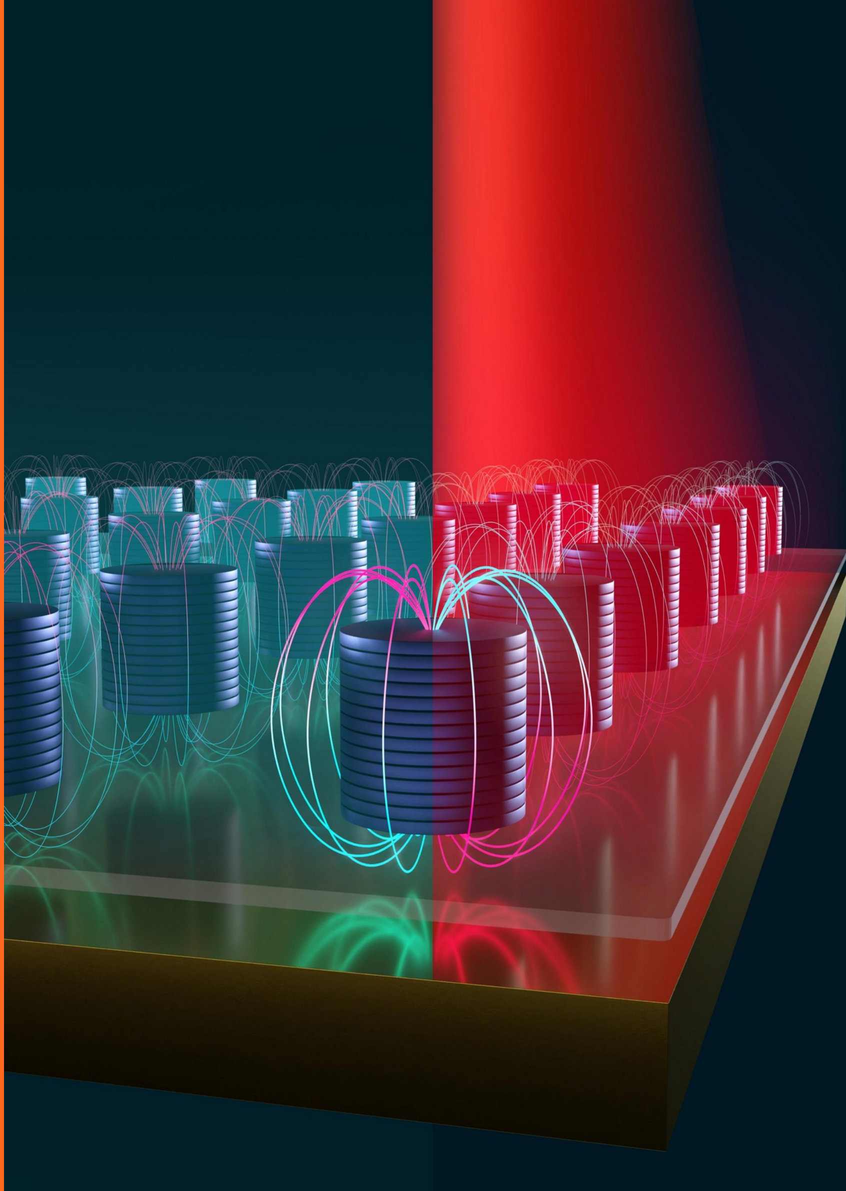




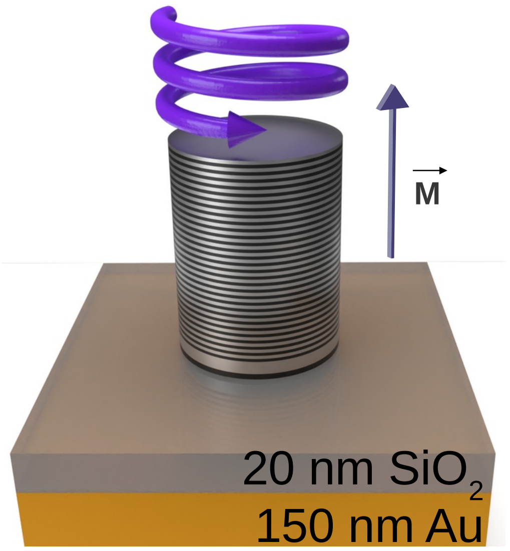

Outline

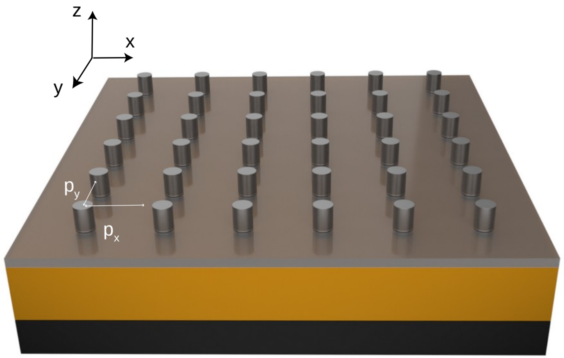
- Description of the system
- Measurements
- Chiral doublets
- Mechanism



The system

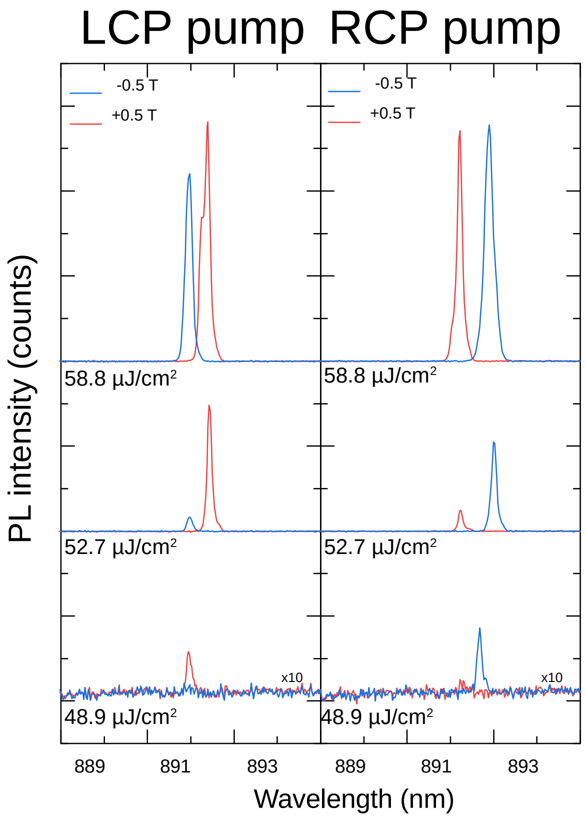
- Co/Pt cylinders in Square/Rectangular arrays
  - Placed on Au substrate
  - External magnetic field
  - System immersed in organic dye



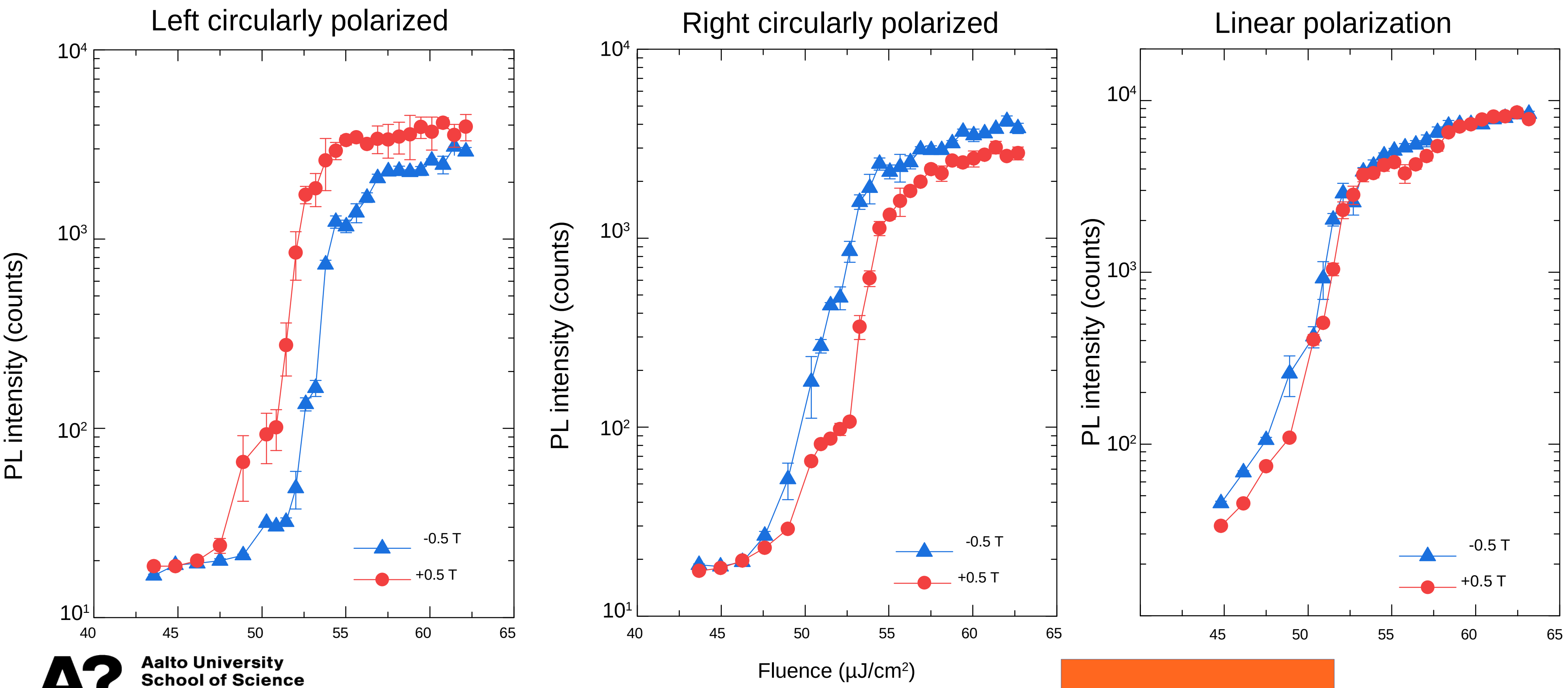


Optical response of the system

- System is excited at 800nm
  - 200fs pulses
  - RCP/LCP pumping
  - Normal incident angle (Γ-point)
- Photoluminescence (PL) is measured



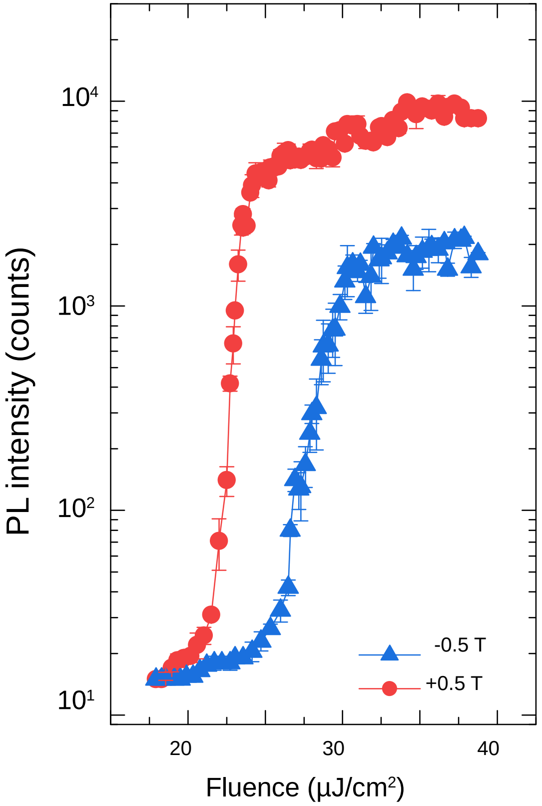
Measurements, Square array



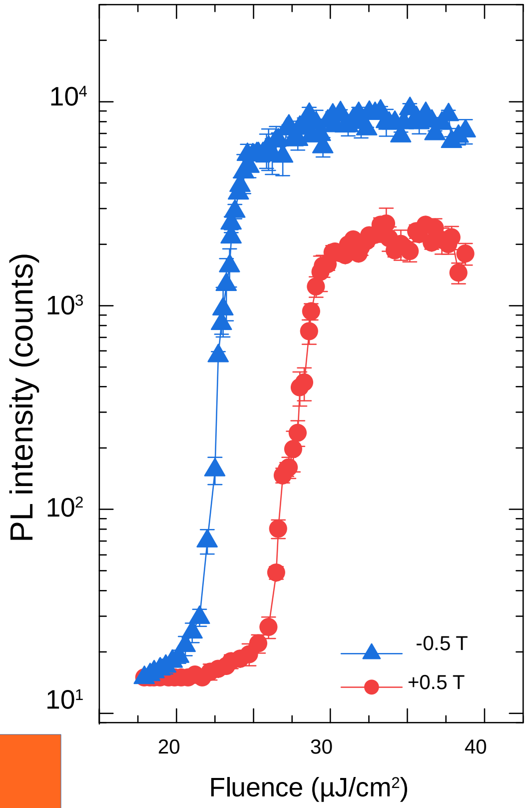
$p_x = p_y = 590nm$

Measurements, Rectangular array

Left circularly polarized



Right circularly polarized



p_x = 590nm
p_y = 530nm

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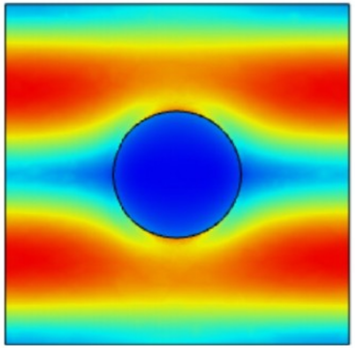
Possible explanations

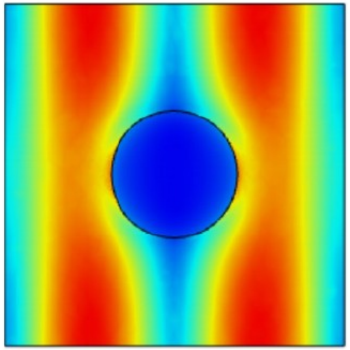
Phenomenon	Effects
• MCD (<1%)	• Increased absorption – Increased excitation • Effect linear • Cannot explain 4-20% effect

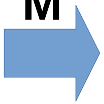
Modes of Square lattice

896 nm

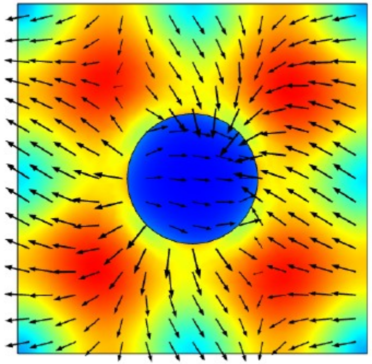


896 nm

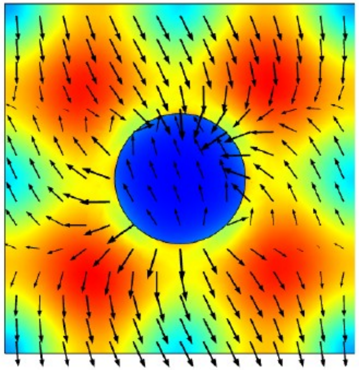




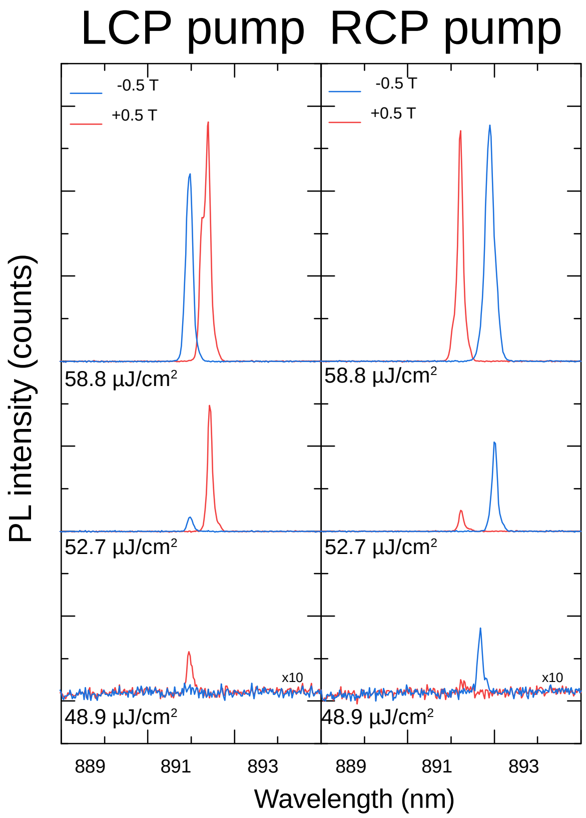
895.8 nm



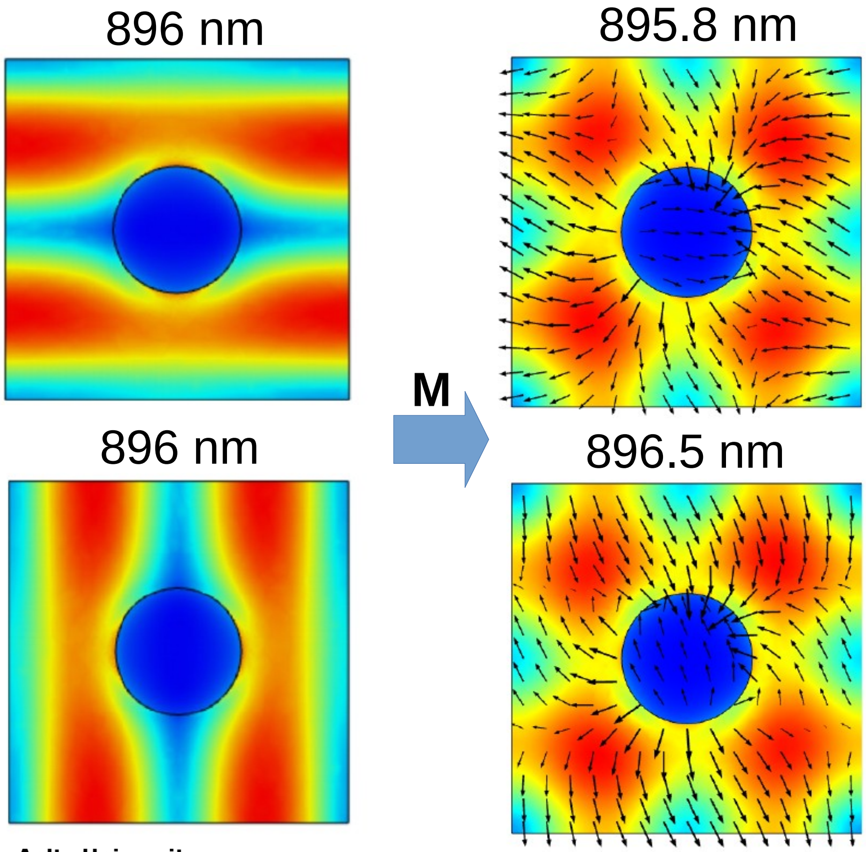
896.5 nm



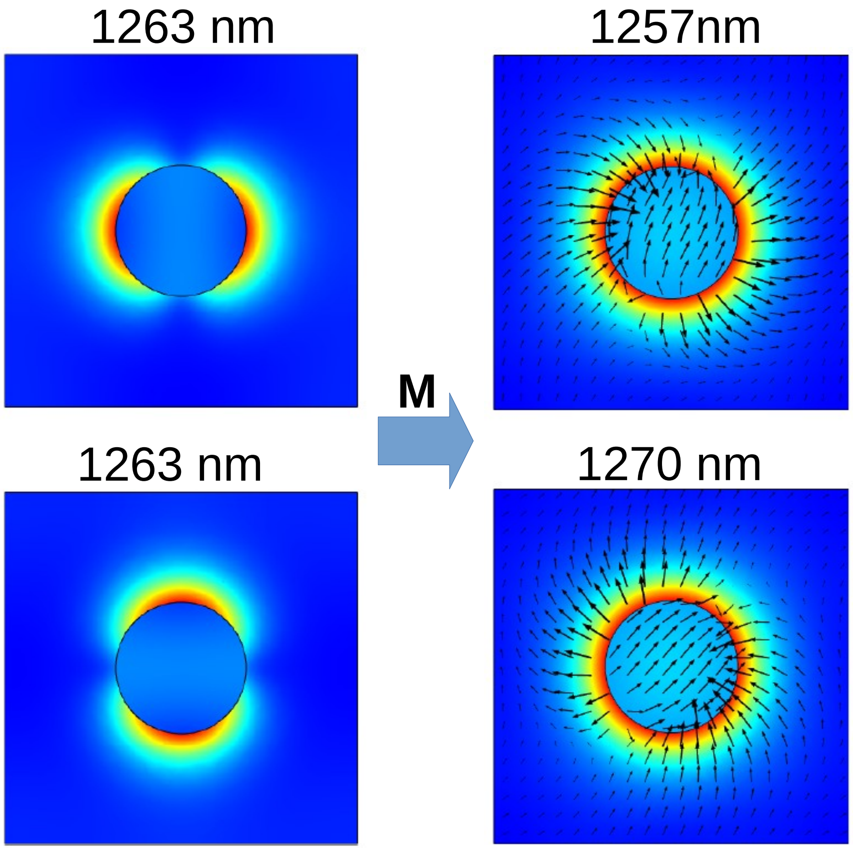
Lasing mode



Modes of Square lattice

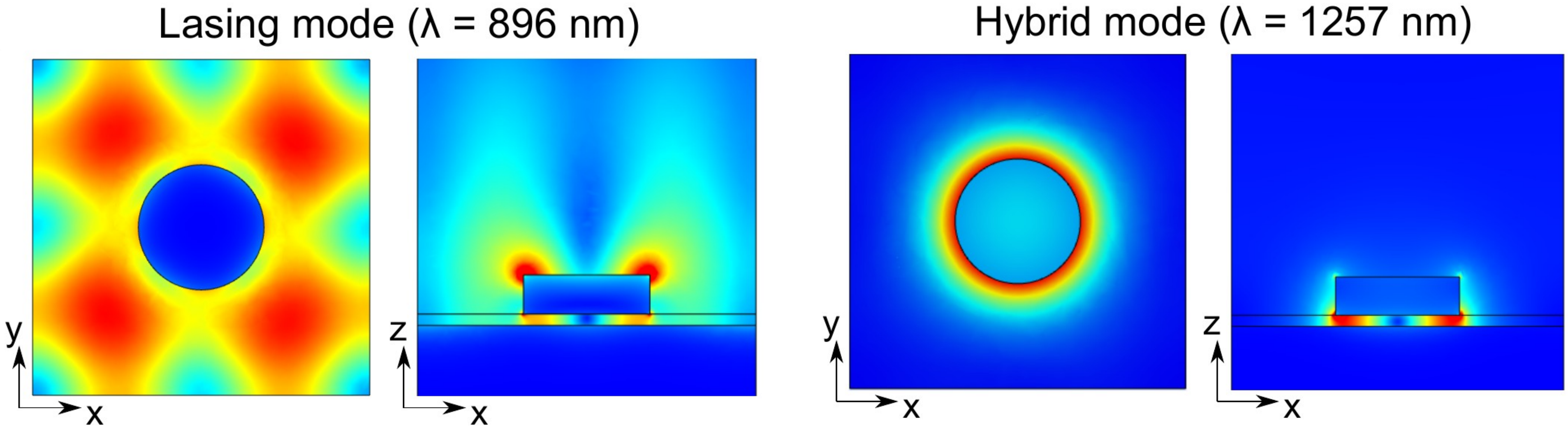


Lasing mode

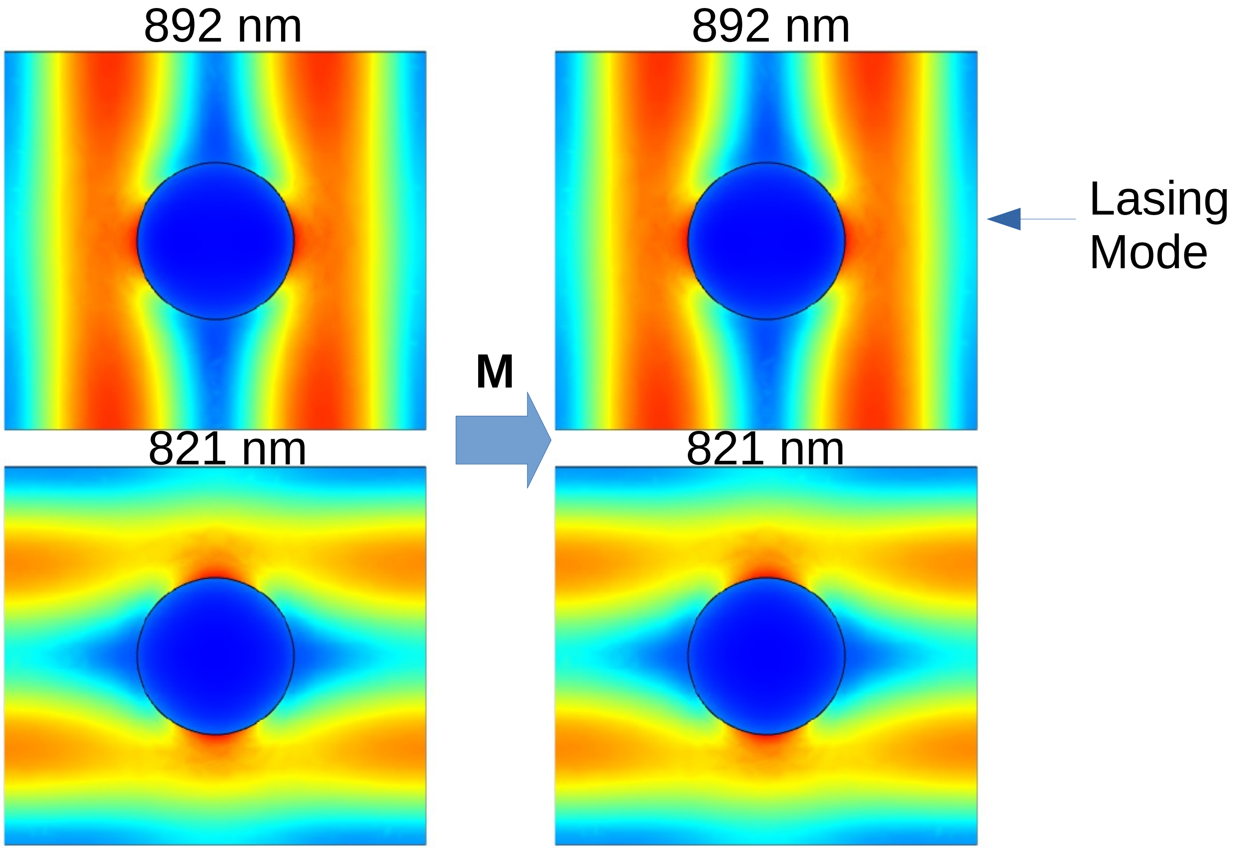


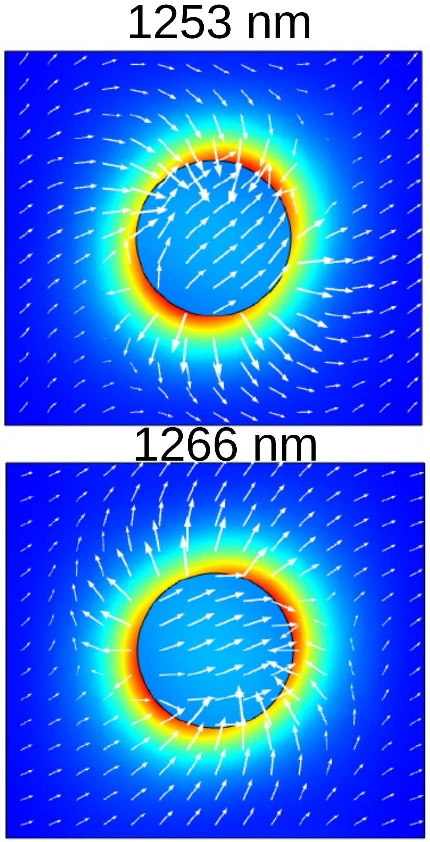
“Hybrid” mode

Modes of Square lattice



Modes of Rectangular Lattice





Hybrid modes

Possible explanations

Phenomenon	Effects
• ~~MCD (<1%)~~ • Different λ, τ_{cav}	• Effects non-linear • Difference small • Cannot explain stronger effect in Rectangular array

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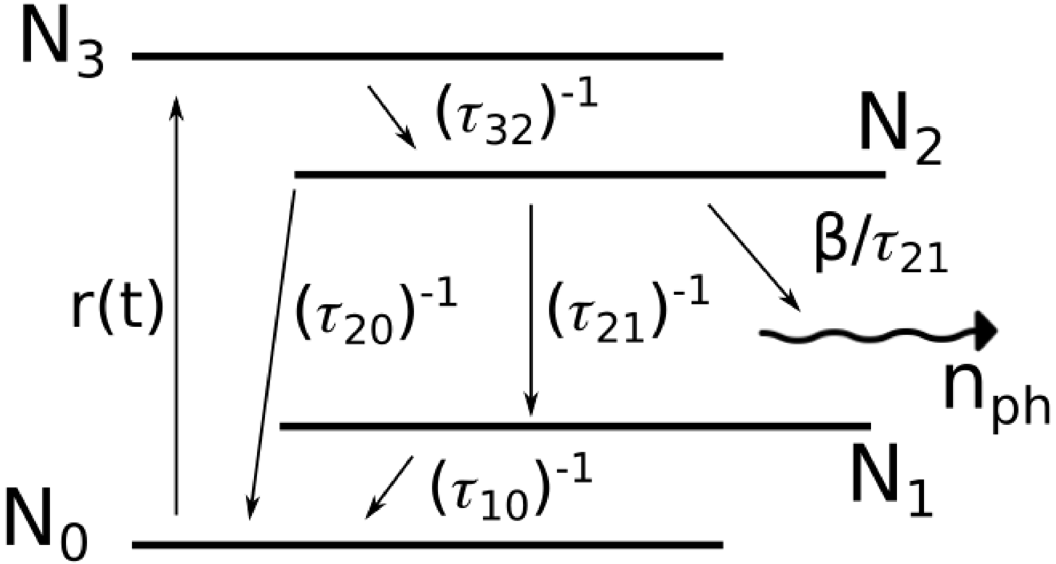
Lasing dynamics

- Lasing described with standard 4-level model



$$\frac{dn_{ph}}{dt} = \beta n_{ph}\frac{(N_2 - N_1)}{\tau_{21}} + \beta\frac{N_2}{\tau_{21}} - \frac{n_{ph}}{\tau_{cav}}$$

Lasing dynamics

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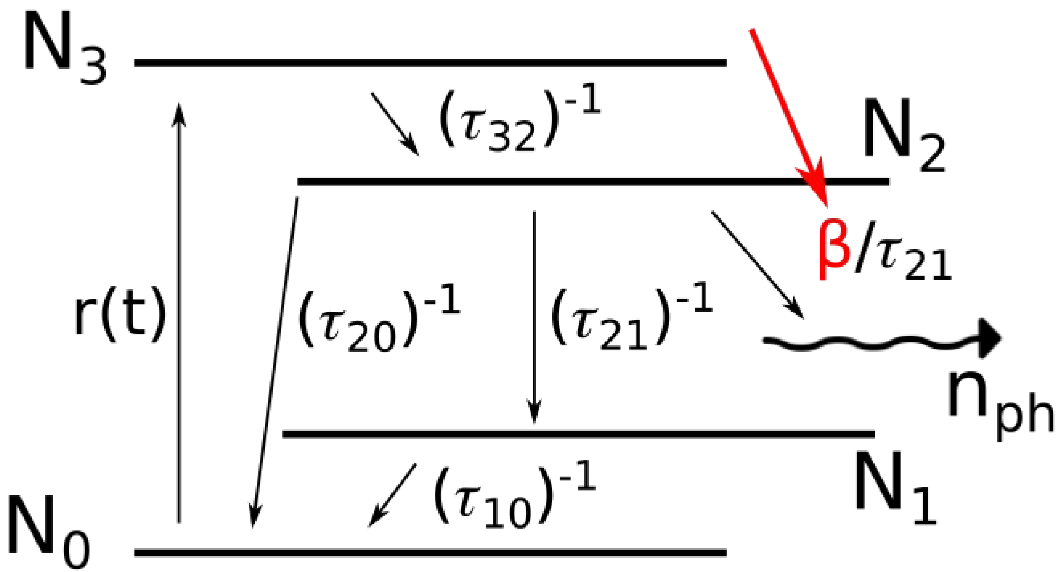
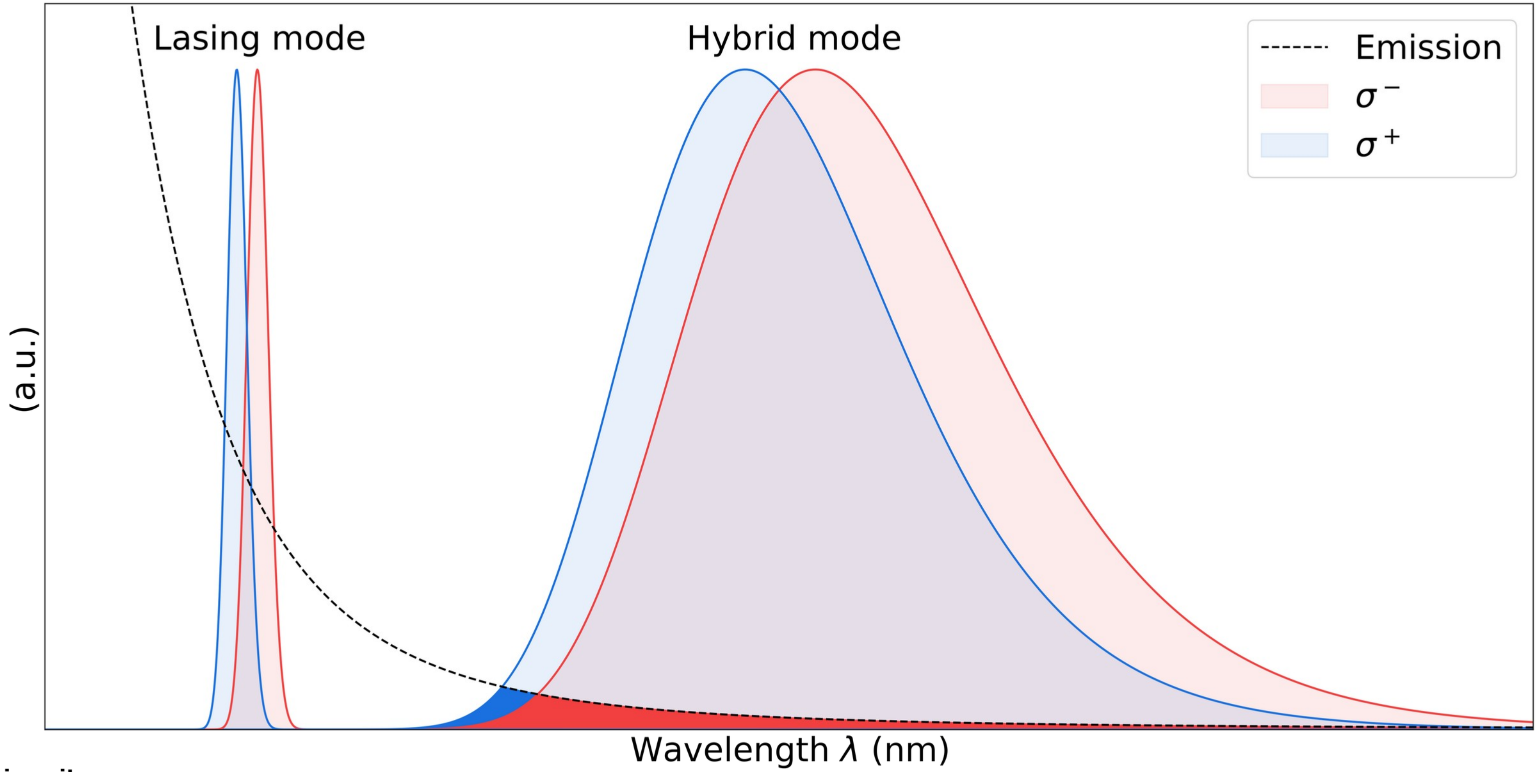


$$\frac{dn_{ph}}{dt} = \beta n_{ph}\frac{(N_2 - N_1)}{\tau_{21}} + \beta\frac{N_2}{\tau_{21}} - \frac{n_{ph}}{\tau_{cav}}$$

Possible explanations

Phenomenon	Effects
• ~~MCD (<1%)~~ • ~~Different λ, τ_{cav}~~ • Different β	• Amount of available gain affected • Effect highly non-linear

Mode-structure of system



Estimation of β

- β is proportional decay rate

$$\beta_i = \frac{\gamma_i}{\gamma_{tot}}$$

Estimation of β

- β is proportional decay rate
- Decay rates estimated from mode structure as

$$\beta_i = \frac{\gamma_i}{\gamma_{tot}}$$

$$\gamma_i = \int_0^{E_{cutoff}} p(E)\alpha^2\sigma_i(E)dE$$

Normalized Emission spectrum

Projection to LCP/RCP basis

Lorentzian fit based on FEM

Estimation of β

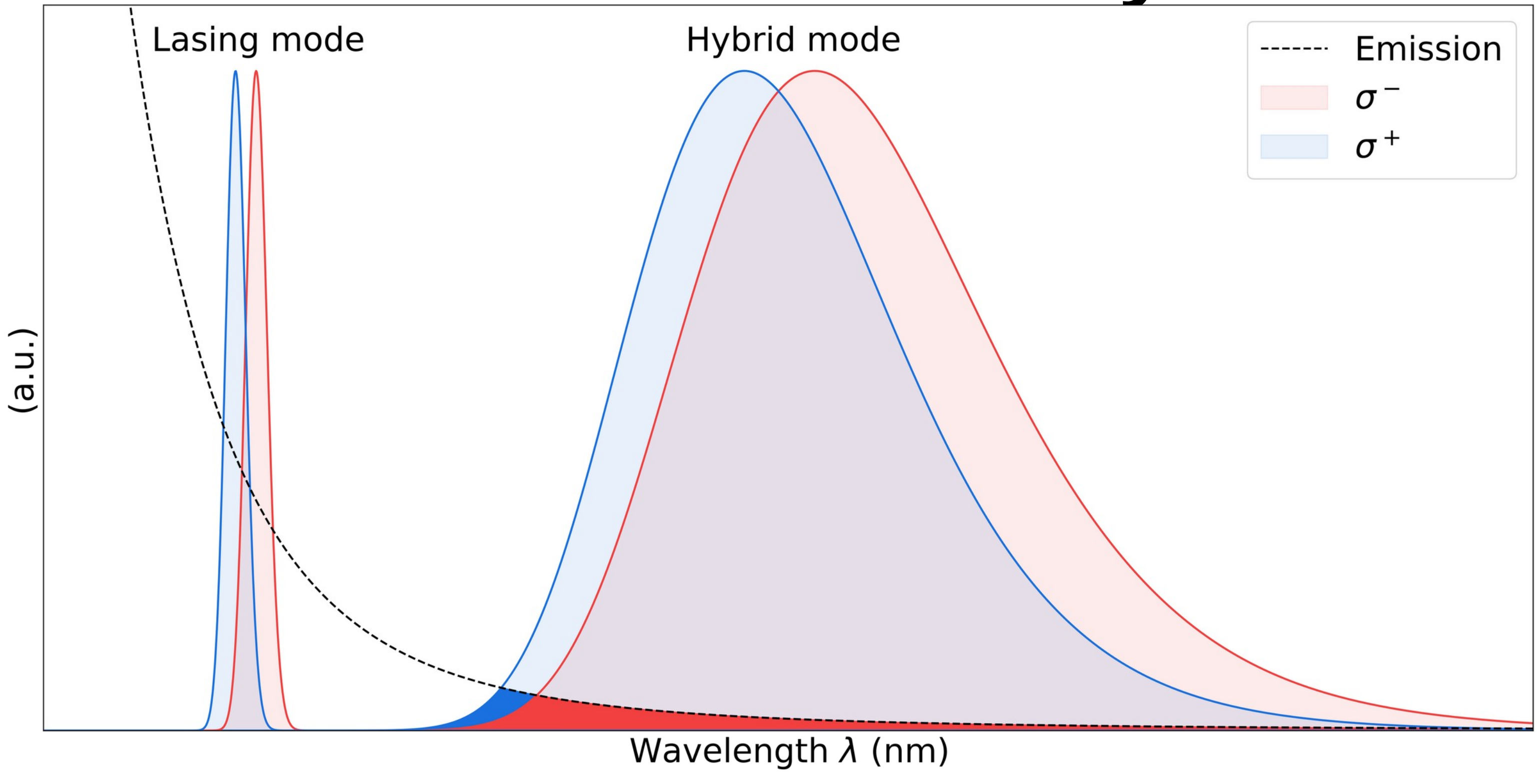
- β is proportional decay rate

$$\beta_i = \frac{\gamma_i}{\gamma_{tot}}$$

- Decay rates estimated from mode structure
- Approximating difference β in as

$$\frac{\beta_- - \beta_+}{\beta_+} \simeq \frac{\gamma_{-,hybrid}}{\gamma_L}\left(1 - \frac{\gamma_{-,hybrid}}{\gamma_{+,hybrid}}\right)$$

Mode-structure of system



$\Delta\beta$ ~ 1-2% (Square)
$\Delta\beta$ ~ 2-4% (Rectangular)

Estimated Threshold shift

- Simulating threshold curves for different β
  - β as a free parameter
  - τ_{cav} from FEM

$$\frac{dn_{ph}}{dt} = \beta n_{ph} \frac{(N_2 - N_1)}{\tau_{21}} + \beta \frac{N_2}{\tau_{21}} - \frac{n_{ph}}{\tau_{cav}}$$

Estimated Threshold shift

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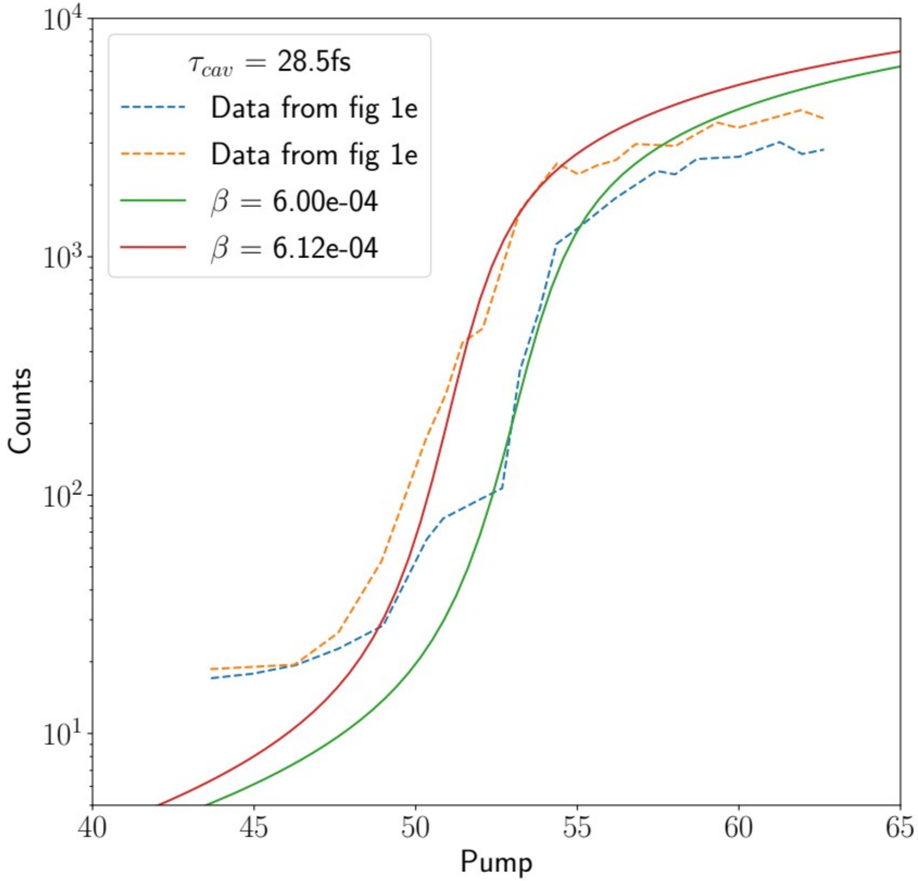
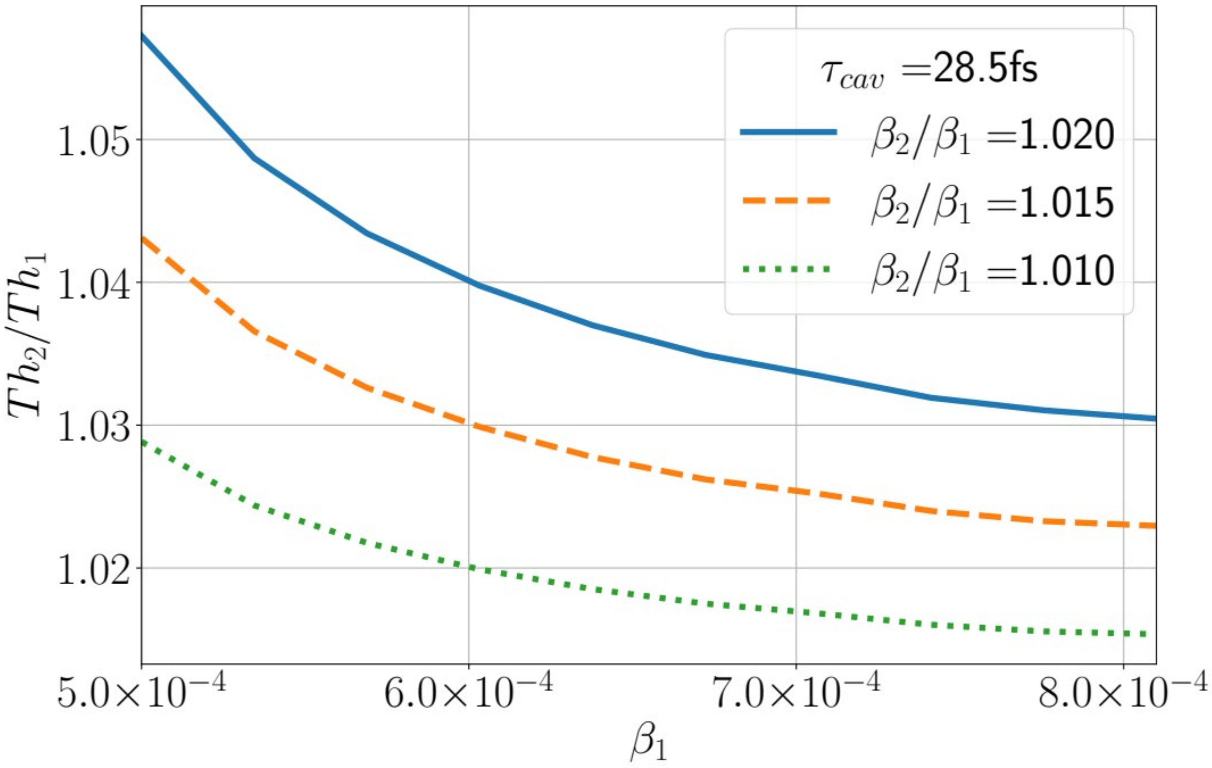
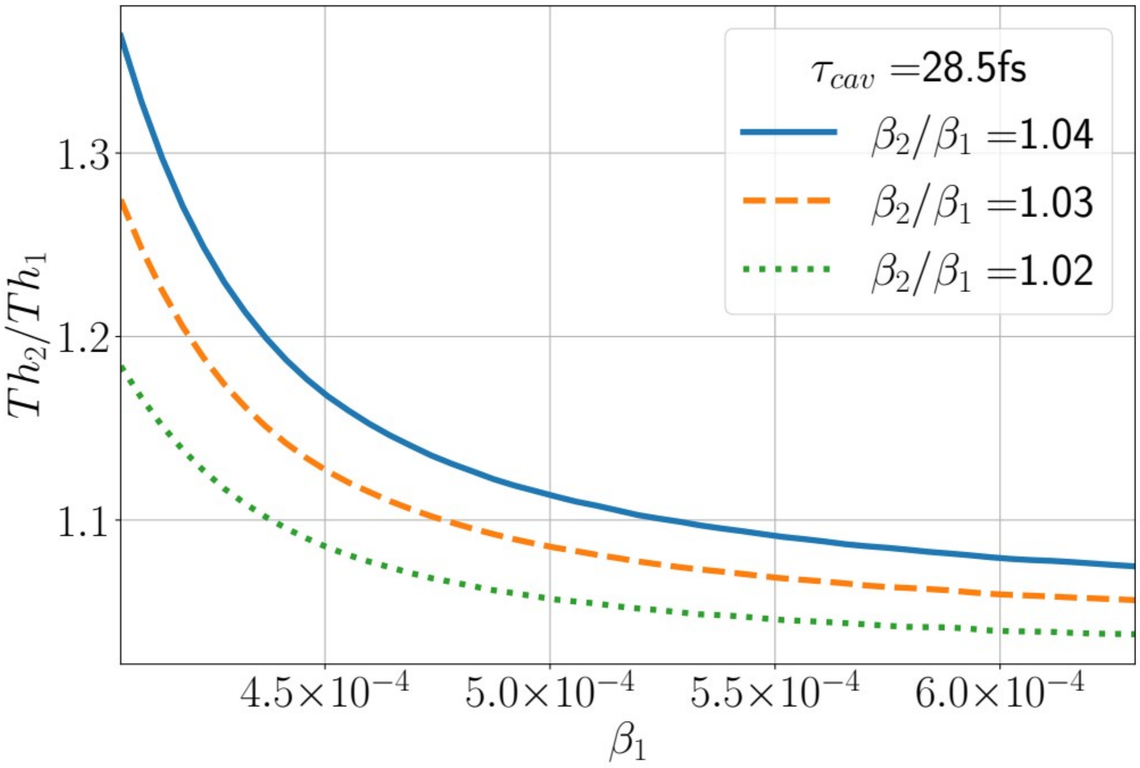


Estimated Threshold Shift



Square lattice

Estimated Threshold Shift



Rectangular lattice

Why the effect is stronger for Rectangular lattice?

- Maximize difference in β w.r.t. magnetic field

Why the effect is stronger for Rectangular lattice?

- Maximize difference in β w.r.t. magnetic field
  - Emphasize hybrid modes in comparison to lasing

$$\gamma_i = \int_0^{E_{cutoff}} p(E)\alpha^2\sigma_i(E)dE$$

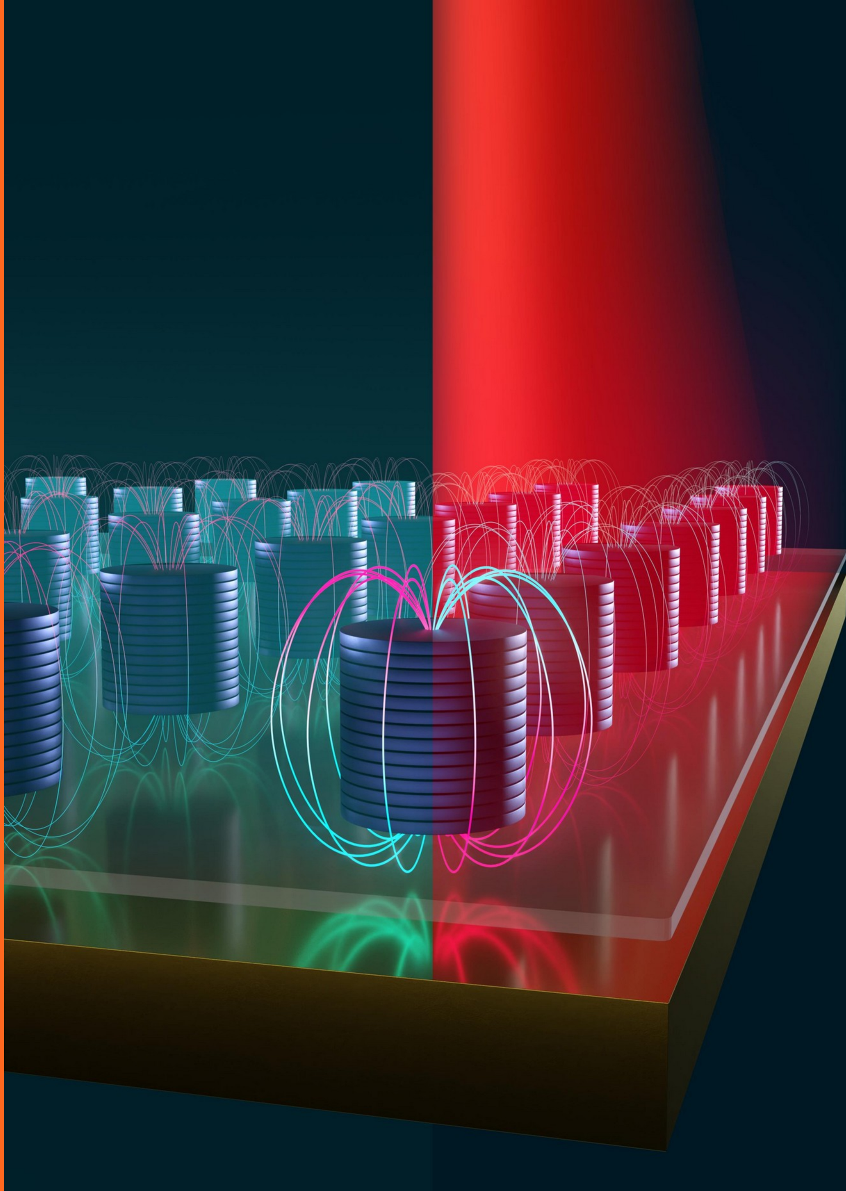
0.5 for linear mode

$$\frac{\beta_- - \beta_+}{\beta_+} \simeq \frac{\gamma_{-,hybrid}}{\gamma_L}\left(1 - \frac{\gamma_{-,hybrid}}{\gamma_{+,hybrid}}\right)$$

Conclusion

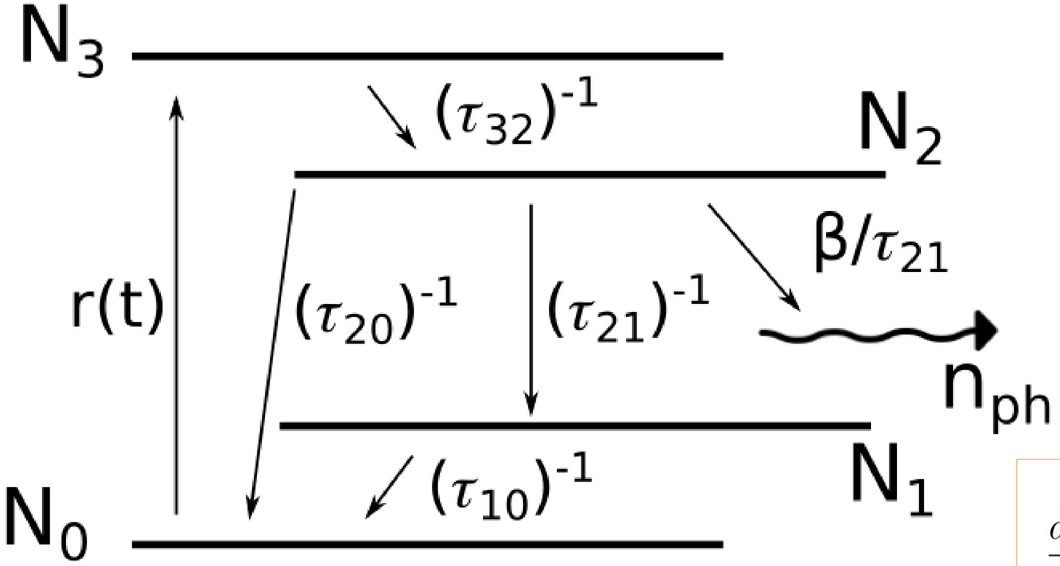
- Magnetically controlled plasmonic laser
- Auxiliary hybrid modes
- Direct observation of chiral doublet

Thank you



Lasing dynamics, full equations

- Lasing described with standard 4-level model



$$\frac{dN_3}{dt} = r(t)(N_0 - N_3) - \frac{N_3}{\tau_{32}}$$
$$\frac{dN_2}{dt} = -\beta n_{ph}\frac{(N_2 - N_1)}{\tau_{21}} - \frac{N_2}{\tau_{21}} - \frac{N_2}{\tau_{20}} + \frac{N_3}{\tau_{32}}$$
$$\frac{dN_1}{dt} = \beta n_{ph}\frac{(N_2 - N_1)}{\tau_{21}} + \frac{N_2}{\tau_{21}} - \frac{N_1}{\tau_{10}}$$
$$\frac{dN_0}{dt} = -r(t)(N_0 - N_3) + \frac{N_2}{\tau_{20}} + \frac{N_1}{\tau_{10}}$$

$$\frac{dn_{ph}}{dt} = \beta n_{ph}\frac{(N_2 - N_1)}{\tau_{21}} + \beta\frac{N_2}{\tau_{21}} - \frac{n_{ph}}{\tau_{cav}}$$

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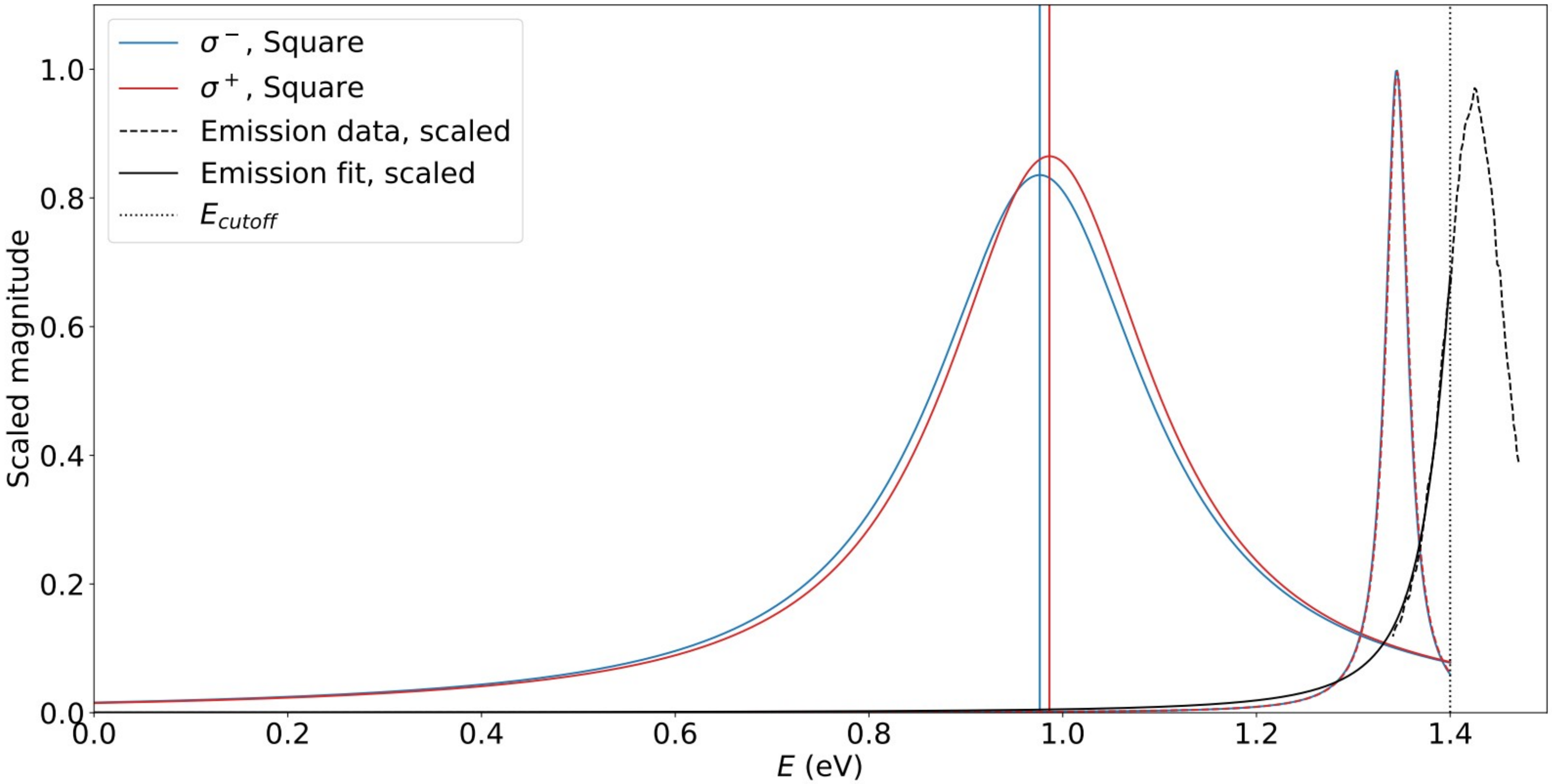
Estimation of β (in scale)



$\Delta\beta$ ~ 1-2% (Sq)
$\Delta\beta$ ~ 2-4% (Re)

Why the effect is stronger for Rectangular lattice?

- Maximize difference in β w.r.t. magnetic field
  - Emphasize hybrid modes in comparison to lasing
  - Increased energy of hybrid modes

1270nm -> 1266nm
1257nm -> 1253nm

Why the effect is stronger for Rectangular lattice?

- Maximize difference in β w.r.t. magnetic field
  - Emphasize hybrid modes in comparison to lasing
  - Increased energy of hybrid modes
  - Maximize the absorption of lattice