Nanoantennas for light-matter coupling in multiple parallel channels

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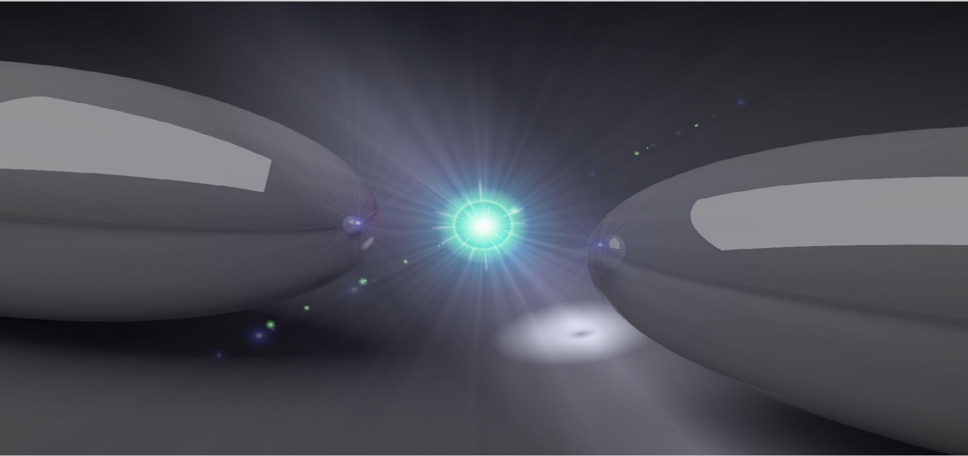
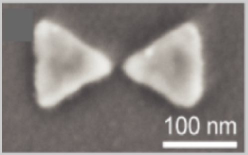
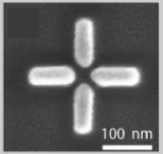
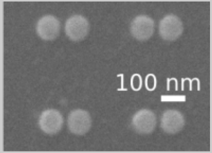
NANOLIGHT 2018, BENASQUE

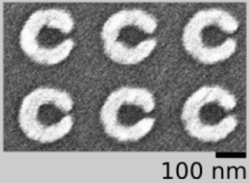


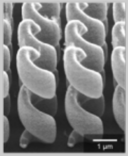
Nanoantennas are now feasible





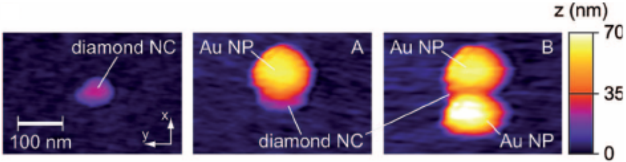


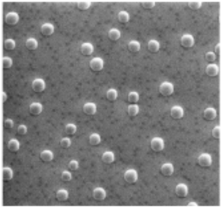


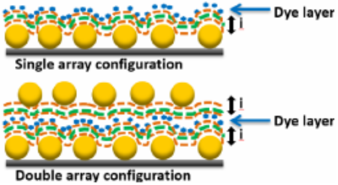


triangles: B. Roxworthy et al.,Sc.Rep.(2012); cross: Huang et al.,Nat.Commun.(2010);
dimers: S. Aćimović,ACS Nano(2009); split rings: A. Clark. et al.,J.Am.Chem.Soc.(2009);
helices: J. Gansel et al.,Science(2009); rods: courtesy of S. Maćkowski,NCU Toruń;

Quantum emitters can be positioned at nanoantenna vicinity

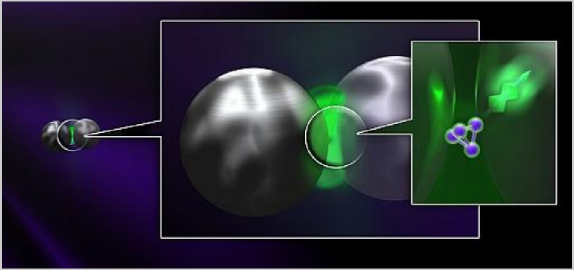




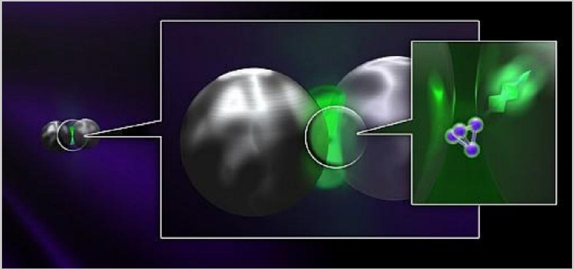


NVCs: Schietinger et al., Nano Letters (2009); QDs & In islands: courtesy of G. Khitrova, Univ. of Arizona; gold spheres & dyes: Chekini et al., J. Appl. Phys. (2015)

Nanoantennas focus light



Nanoantennas speed up light-matter interactions

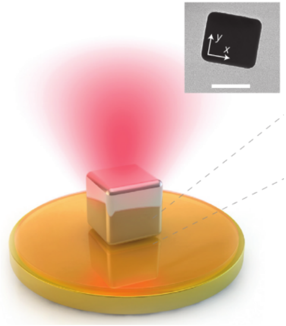


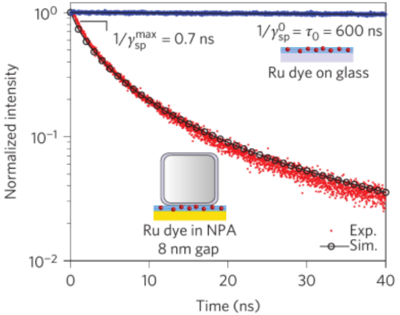
interaction

dipole approximation

$$\mathcal{V} = -\mathbf{d} \cdot \mathbf{E}$$

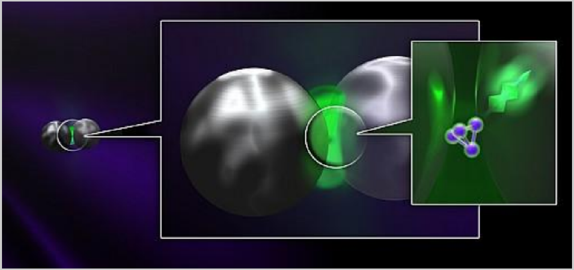
Nanoantennas modify molecular lifetime





Akselrod et al., Nature Photonics (2014)

Nanoantennas modify molecular lifetime



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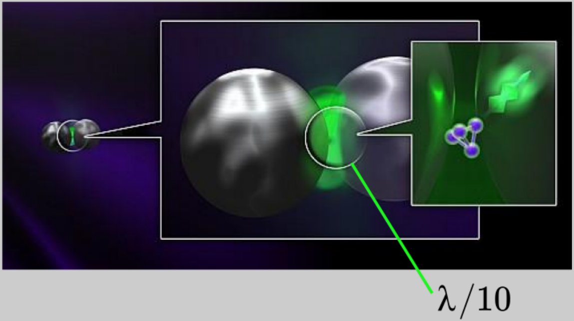
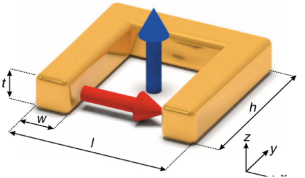


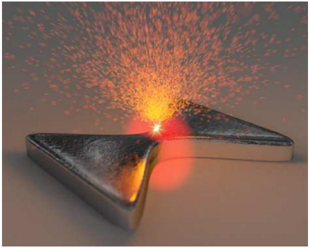
interaction
beyond dipole appr.

$$\mathcal{V} = -\mathbf{d} \cdot \mathbf{E}$$
$$-\mathbf{m} \cdot \mathbf{B} - [\mathbf{Q}\nabla] \cdot \mathbf{E}$$

multiple pathways
interference effects

State of the art



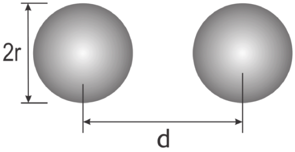


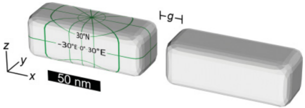
magnetic dipole
Feng et al., Opt. Lett. (2011): 2 gold patches
Schmidt et al., Opt. Expr. (2012): dielectric disks
Hein & Giessen, PRL (2013): **split ring** resonators
Mivelle et al., ACS Phot. (2015): **diabolo** nanoantenna

electric quadrupole
Filter et al., PRB (2012): **dimer** nanoantenna (2 spheres)
Kern & Martin, PRA (2012): **dimer** nanoantenna (2 nanorods), Cs atoms
Yannopapas & Paspalakis, J. Mod. Opt. (2015): core-shell arrays

combined (Green's function approach)
Tighineanu et al., PRL (2014): QD & nanowire
Cotrufo & Fiore, PRB (2015): QD & photonic crystal, nanorods
Yang & An, PRA (2016): QD & planar interface

M. Kosik, maser thesis, NCU (2017)





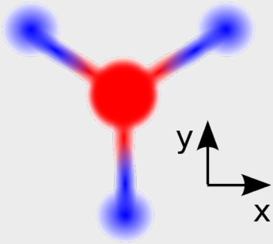
Transition rates beyond dipole approximation

$$\Gamma = \frac{2\pi}{\hbar^2} |\langle \mathrm{f} | \mathcal{V} | \mathrm{i} \rangle|^2 \rho\left(\omega_\mathrm{i} - \omega_\mathrm{f}\right)$$

$$\mathcal{V} = -\mathbf{d} \cdot \mathbf{E}\left(\mathbf{r}_\mathrm{m}\right) - \mathbf{m} \cdot \mathbf{B}\left(\mathbf{r}_\mathrm{m}\right) - [\mathbf{Q}\nabla] \cdot \mathbf{E}\left(\mathbf{r}_\mathrm{m}\right)$$

molecular properties	field distribution	transition rate
$\mathbf{d}, \mathbf{m}, \mathbf{Q}$	$\mathbf{E}(\mathbf{r}_\mathrm{m}), \mathbf{B}(\mathbf{r}_\mathrm{m})$	Γ
TDDFT (TURBOMOLE)	Maxwell's eqs. (MNPBEM, etc.)	Fermi's golden rule

Exemplary molecules



Dipole-forbidden transitions:

- OsO_3 @ 553 nm

  $m_y = 0.84\ \mu_B,\ Q_{xz} = 0.66$ B

  $m_x = 0.84\ \mu_B,\ Q_{yz} = 0.66$ B

Data source: DFT calculations, F. Weigend i M. Kühn, KIT

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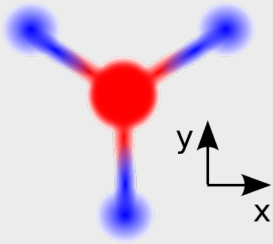

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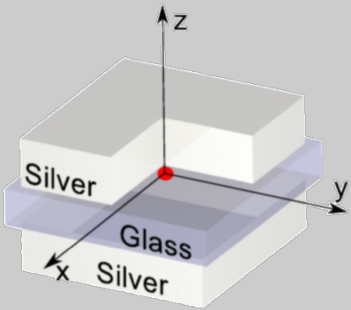
Data source: DFT calculations, F. Weigend i M. Kühn, KIT

Goal: a nanoantenna to control MD & EQ interactions

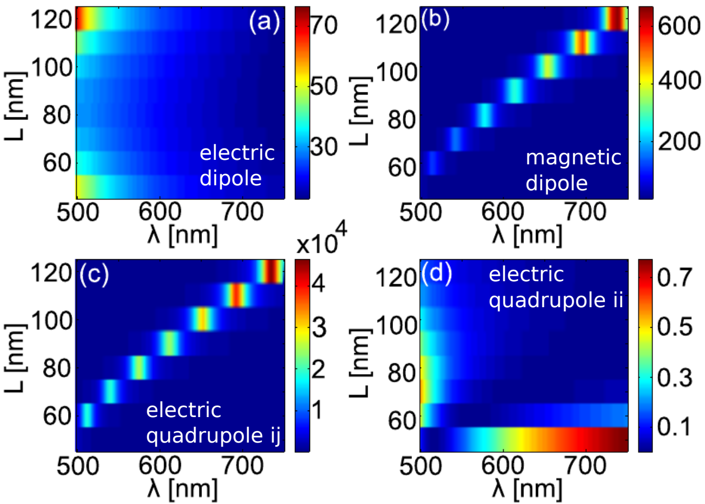
Silver nanoantenna to enhance MD & EQ interactions



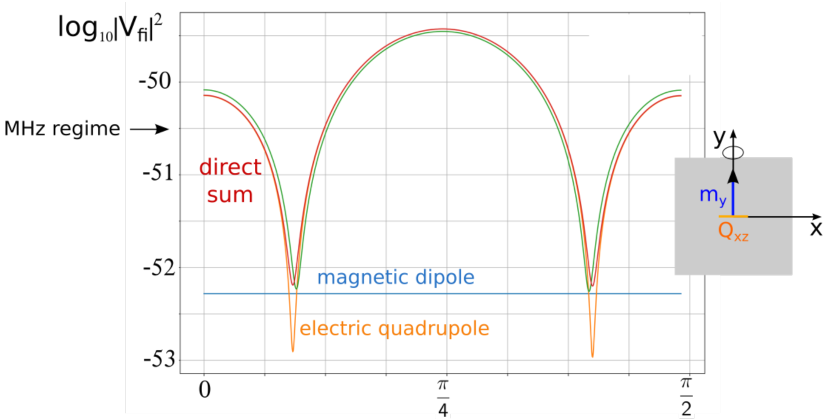
Double-patch nanoantenna:

- material: **silver** with **glass spacer**
- patch size: $L \times L \times 50$ nm
- spacer gap: 30 nm
- illumination: ED, MD, EQ
  with basic orientations
- goal: field/rate enhancement

Transition rate enhancement: isolated MD or EQ sources

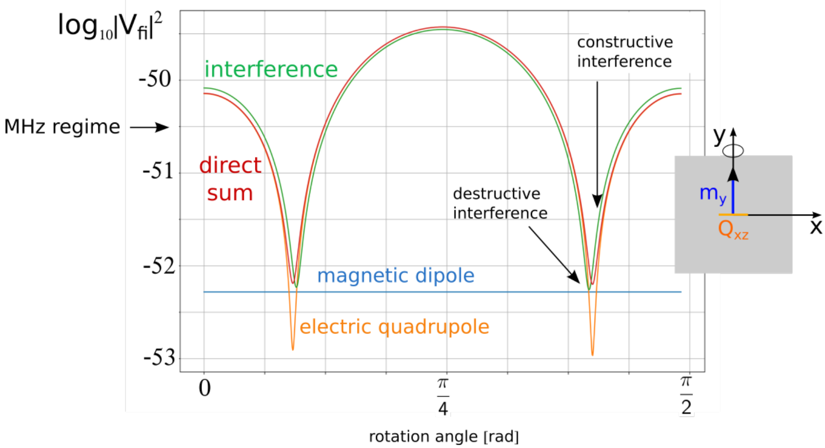


Transition rate: combined MD & EQ source

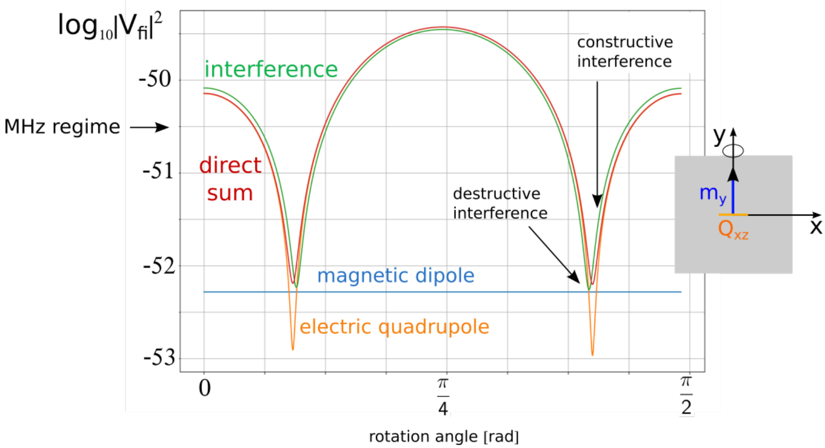


rotation angle [rad]

Transition rate: combined MD & EQ source

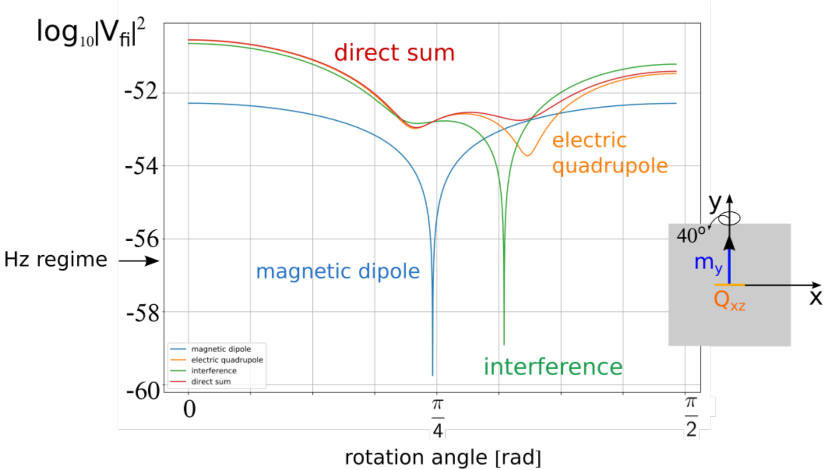


Transition rate: combined MD & EQ source



Response **stable with respect to molecular location**

Transition rate: combined MD & EQ source



7 orders of magnitude suppression due to interference

sensitive to small shifts

Conclusions & outlook

- Nanoantennas **enhance "forbidden" transitions** by even 4 orders of magnitude.
- **Interference** of parallel interaction channels: **suppression of spontaneous emission** by 7 orders of magnitude

Acknowledgements

European Funds
Smart Growth

FNP Foundation for Polish Science

European Union
European Regional Development Fund

National Science Centre
Poland

DAAD
Deutscher Akademischer Austausch Dienst
German Academic Exchange Service

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- nanophotonic devices: nanoantennas, metasurfaces, microdisks
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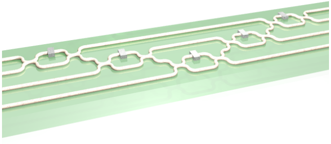
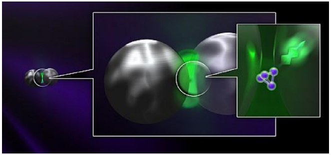
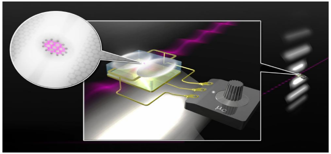
Contact: **karolina@fizyka.umk.pl**







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