Current Topics in Nanophotonics

General Information — Summer Semester 2020

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Contents

I. Administrative aspects

Welcome to the seminar **Current Topics in Nanophotonics**, this semester delivered online via zoom!

Let us introduce the team:

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Assessment:

- one 60 minute presentation on a nanophotonics subfield, delivered in groups of two (possibly one group of three)
- four topics to choose from, presentation should provide a general introduction to the topic plus examples of frontier research
- topics:
  nanophotonics with 2D materials (Lucca); chiral nanophotonics (Leo);
  ultrafast dynamics in nanomaterials (Rodrigo); phonon-polaritons and hyperbolic materials (Andrea)

Suggested timetable of the seminar:

Week	Event
29 April	Introduction to the seminar
6 May	Assignment of topics, discussion of possible masters projects with us
13 May	Topical breakout sessions
20 May	Topical breakout sessions
27 May	Topical breakout sessions
3 June	Presentation
10 June	Presentation
17 June	Presentation
24 June	Presentation
1 July	Feedback
8 July	Social-distancing lab tour (if possible) Masters project discussion

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

2D materials for nanophotonics

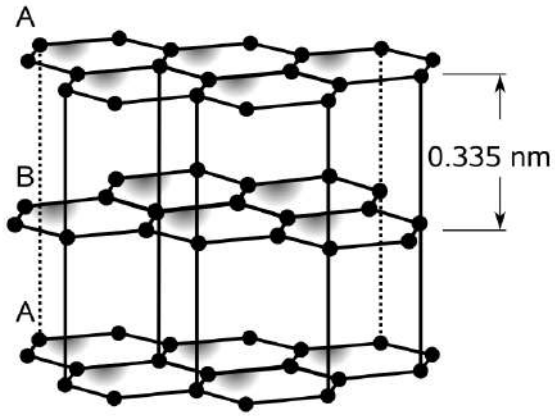
Lucca Kühner

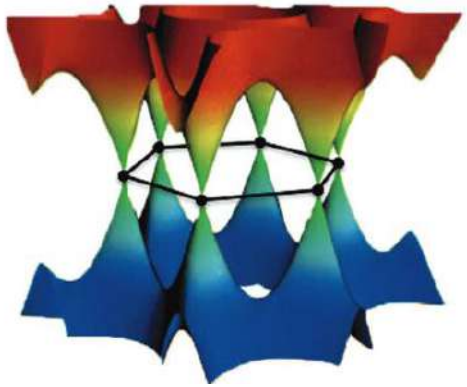
Current topics in nanophotonics

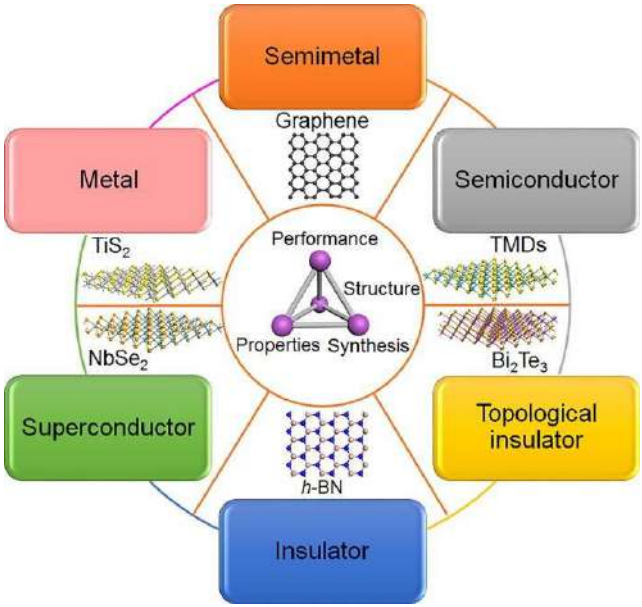
29th April 2020

2D materials

Graphite structure



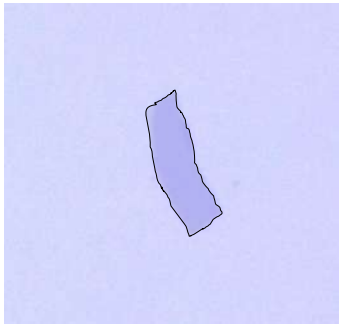


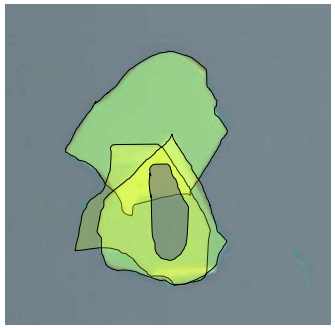


P. Schmidt-Wellenburg et al., *arXiv:***0708.1371** (2007)

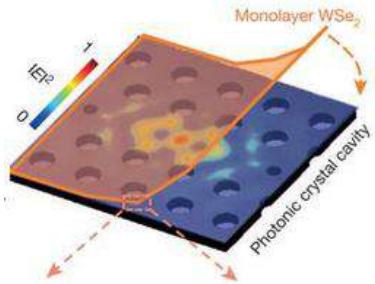
X. Li et al., *Appl. Phys. Rev.* **4** (2017)

Aspects of 2D materials

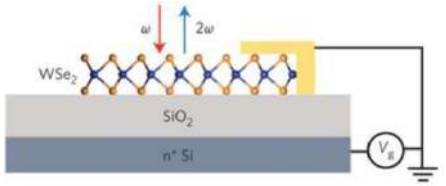




Fabrication

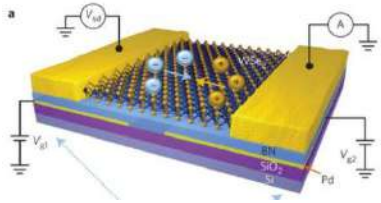


Wu et al., *Nature* **520** (2015)

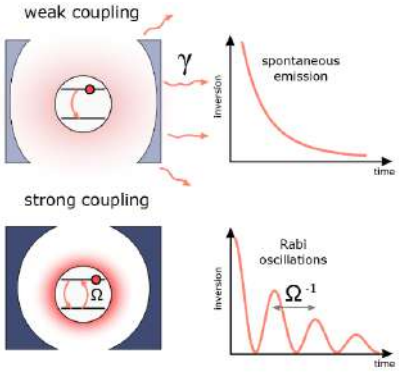


K. Seyler et al., *Nature Nanot.* **10** (2015)

Optoelectronics

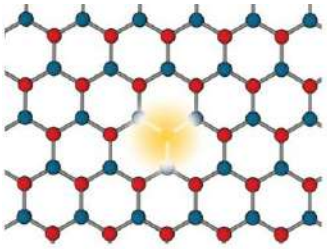


J. Ross et al., *Nature Nanot.* **9** (2014)



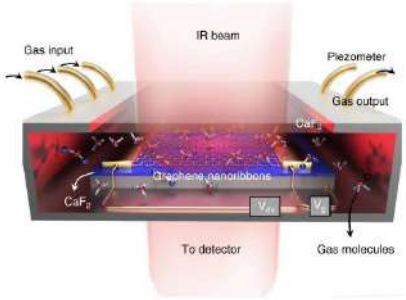
D. Baranov et al., *ACS Phot.* **5** (2018)

Quantum optics

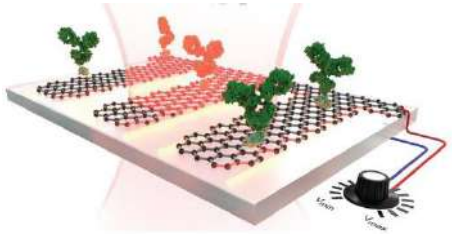


Aharonovich et al., *Science* **358** (2017)

Sensing



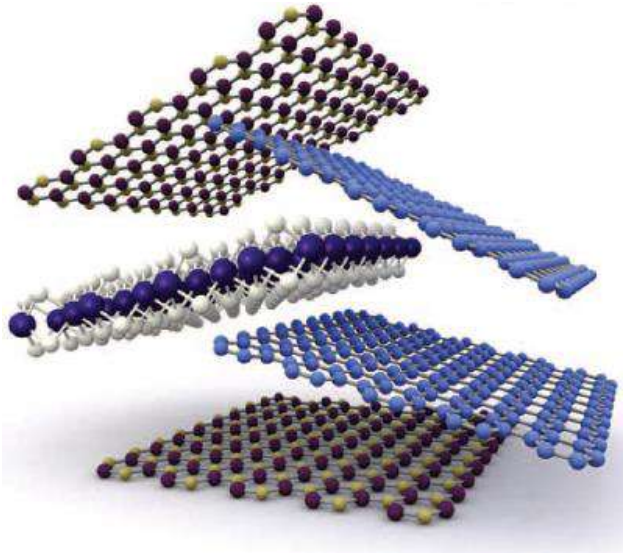
H. Hu et al., *Nature Com.* **10** (2019)

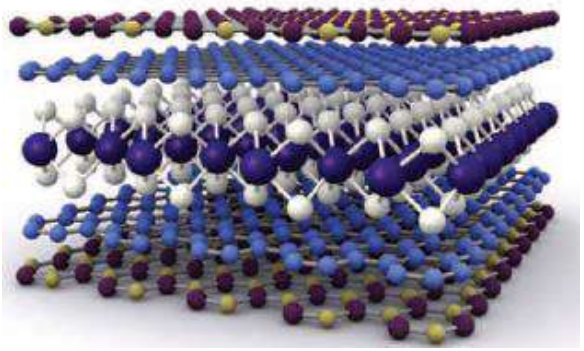


D. Rodrigo et al., *Science* **349** (2015)

Van der Waals heterostructures

Stacking of different materials





Design of artificial materials

K. Novoselov et al., *Science* **353** (2017)

Chirality and chiral optics

Fakultät für Physik der LMU München - LS S. Maier, 29. April 2020

Basic aspects of chirality:

- A chiral object cannot be superimposed to its mirror image by solely translational and rotatoinal transformations
- Nature is chiral; there are plenty of examples (DNA, proteins of all living organisms...)
- Fact: differential interaction strengths between matter and Left Circularly Polarized Light (LCPL) / RCPL
- Differential absorption of LCPL/RCPL → circular dichroism; Differential refraction for LCPL/RCPL → rotatory dispersion
- However, the effect is subtle: use of chiral (hybrid) plasmonic systems for enhancing twisted light-matter interactions
- Mechanism: Chiral molecule/object "communicates" chirality to nearby structures via interaction between electronic clouds
- Frequent approaches for achieving strong CD response using plasmonic nanostructures:
  - Achiral metal nanostructures + chiral molecules
  - Chiral metal nanostructures (paradigm: helix)

Constitutive relations:

$$\mathbf{D}_\omega = \varepsilon(\omega,\mathbf{r})\mathbf{E}_\omega + i\xi(\omega,\mathbf{r})\mathbf{B}_\omega$$

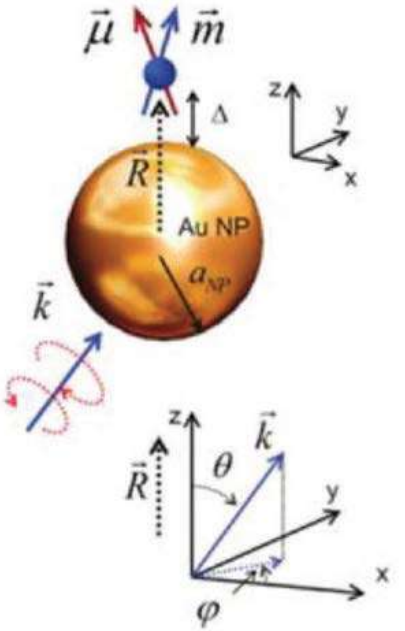
$$\mathbf{H}_\omega = \frac{1}{\mu}\mathbf{B}_\omega + i\xi(\omega,\mathbf{r})\mathbf{E}_\omega$$

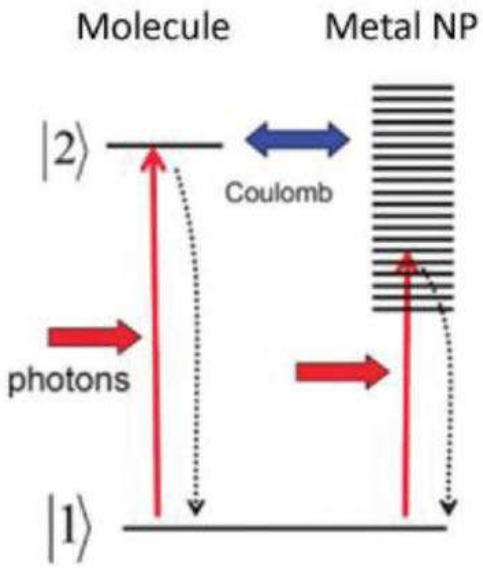
Chiral properties of the medium

$$\mathrm{CD}_{\mathrm{molecule}} = a(\omega)\mathrm{Im}\left[\hat{P}\mu_{12}\cdot\mathbf{m}_{21}\right]$$

$$\mathrm{CD}_{\mathrm{plasmon}} \propto \mathrm{Im}(\varepsilon_{\mathrm{metal}})\cdot f_{\mathrm{resonant}}\cdot\mathrm{Im}\left[\hat{K}\mu_{12}\cdot\mathbf{m}_{21}\right]$$

$$\mathrm{CD} = \mathrm{CD}_{\mathrm{molecule}} + \mathrm{CD}_{\mathrm{plasmon}}$$





PROGRESS REPORT *Adv. Mater.* **2018**, 1801790

ADVANCED MATERIALS
www.advmat.de

Plasmonic Chirality

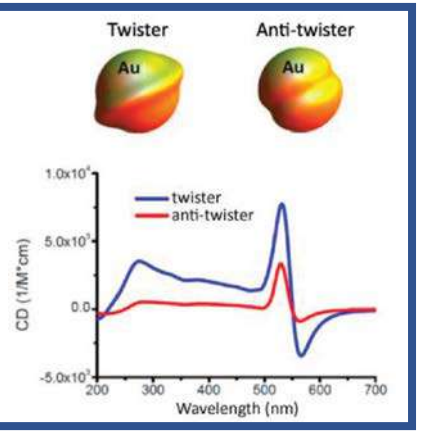
Plasmonic Chirality and Circular Dichroism in Bioassembled and Nonbiological Systems: Theoretical Background and Recent Progress

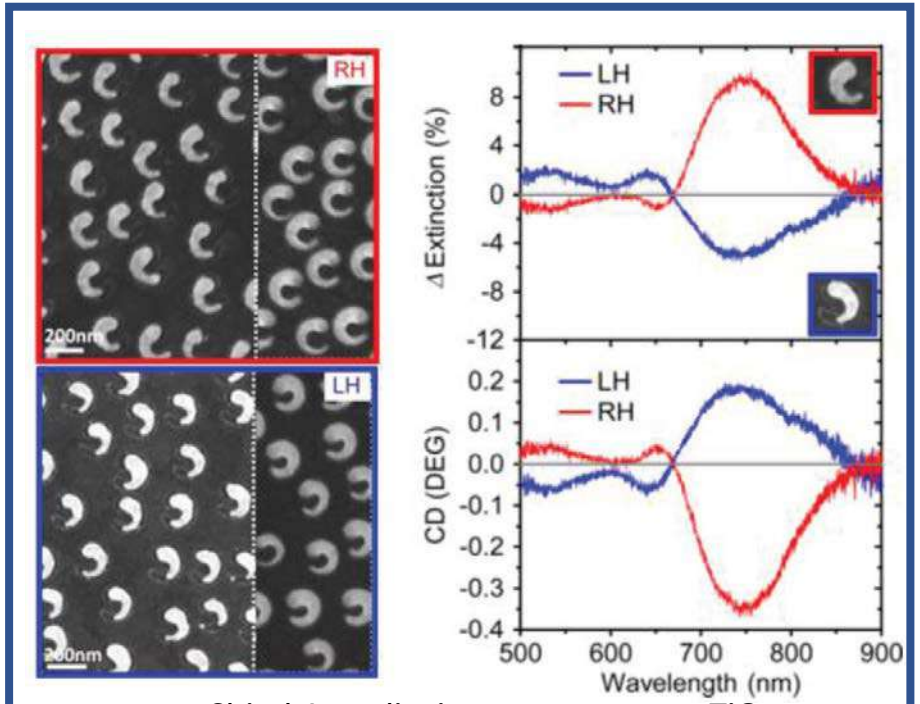
- Chiral metal nanoparticles/nanocrystals:

$$CD = \langle Q_{k+} - Q_{k-} \rangle$$

$$Q_k = \int_{NC} \langle \boldsymbol{j}.\boldsymbol{E} \rangle dV = \left(\frac{\omega}{2\pi}\right) Im(\varepsilon_{NC}) \int_{NC} \boldsymbol{E}_\omega.\boldsymbol{E}_\omega^* dV$$

(Joule heat generated in the metal due to light absorption)



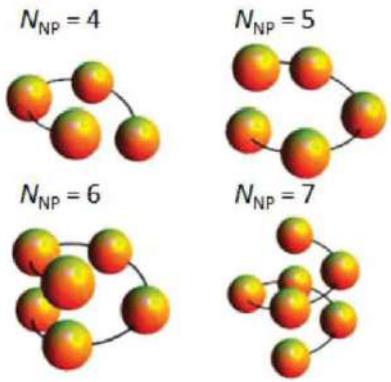


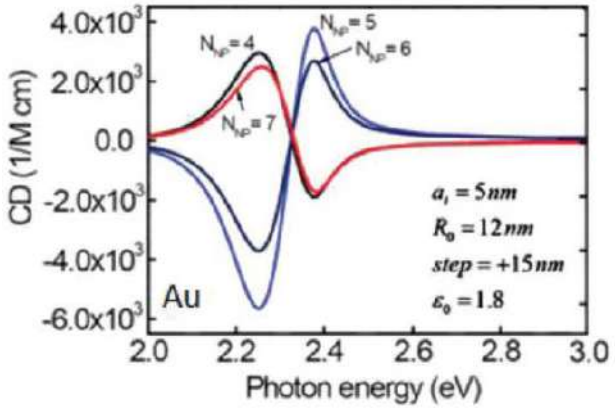
Chiral Au split ring resonators on TiO_2:
chiral shape leads to $\vec{\mu}$ not // $\vec{m}$

- Interacting plasmonic nanoparticles:

- Chiral arrangement of Localized Surface Plasmons induced by interactions between nanoparticles in a chiral scaffold. Paradigm: DNA

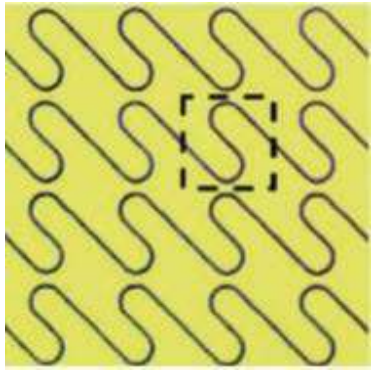
$$CD_{plasmon-plasmon} \propto a^{12}/R^8$$



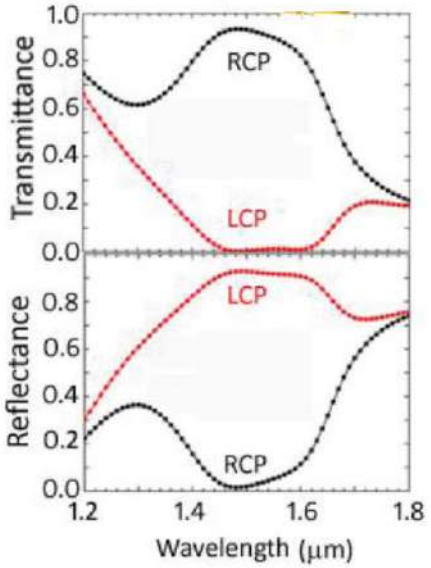


- Chiral plasmonic metasurfaces and metamaterials:

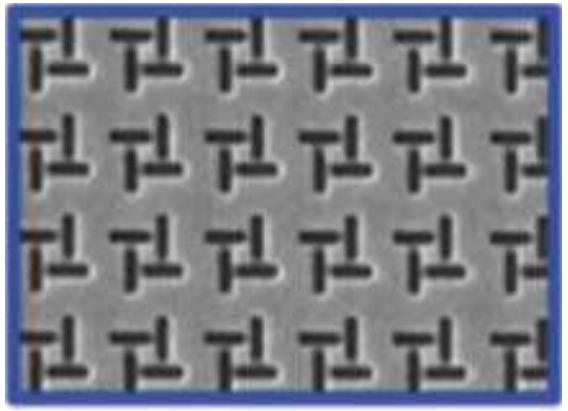
  - Litographically fabricated metal structures

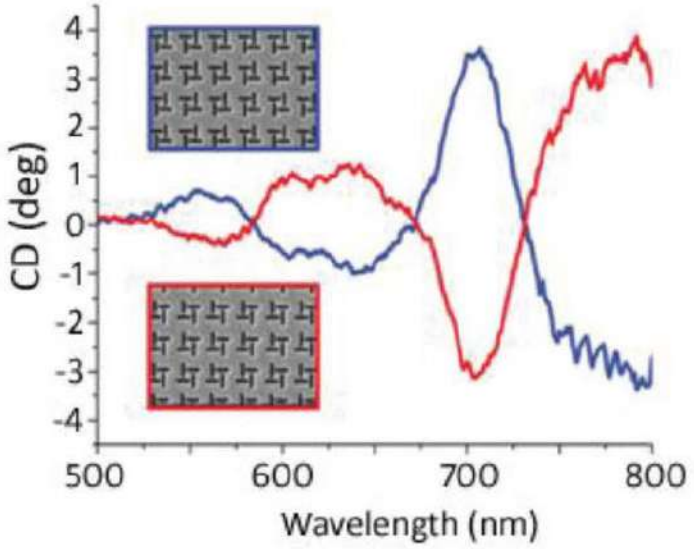


- 2D quasi-chirality; inverted CD spectra for light incident from both sides (3D chiral objects are not like this):

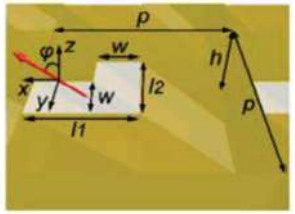


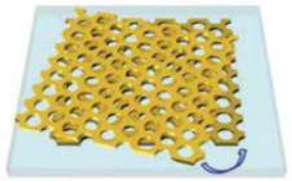
Also nanoslits!



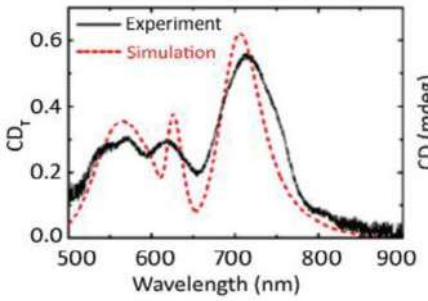


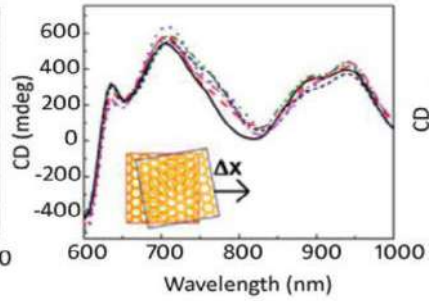
- 3D chiral hole structures in a metal film and chiral ensembles of achiral holes in metal films: filling with functional materials:



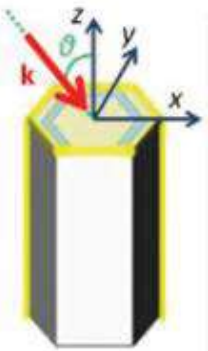


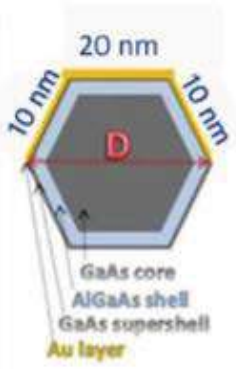
Moiré patterns generate strong plasmonic CD response

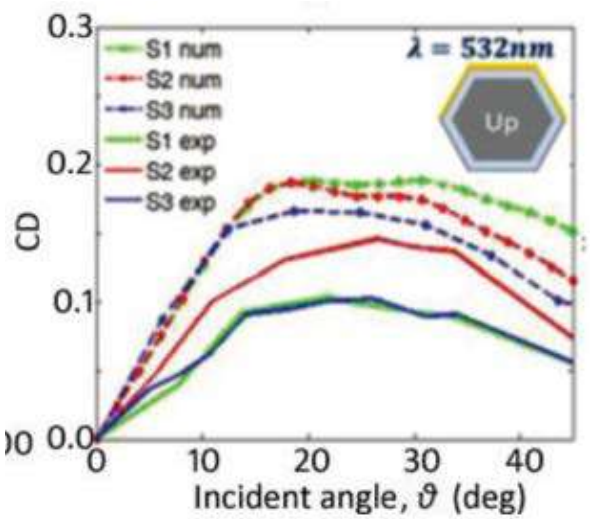




- Extrinsic (pseudo) chirality: an obliquely incident CPL beam gives achiral surfaces a sense of chirality:





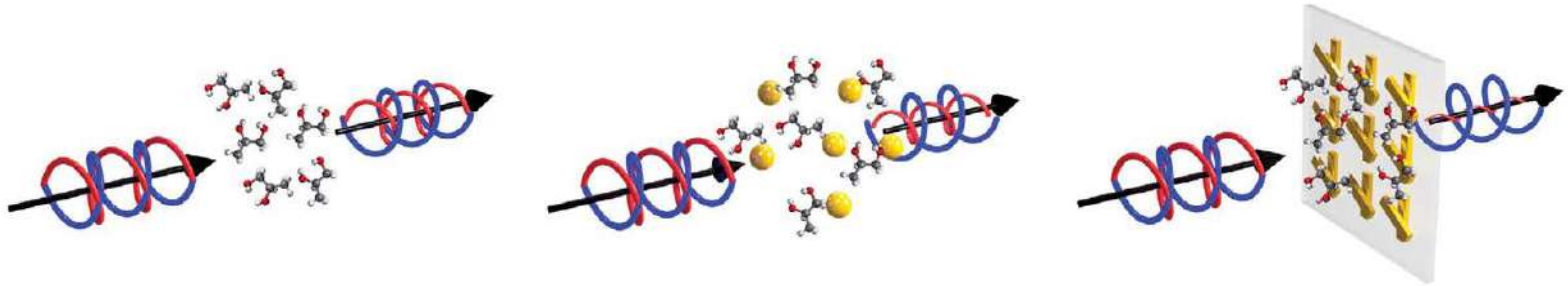


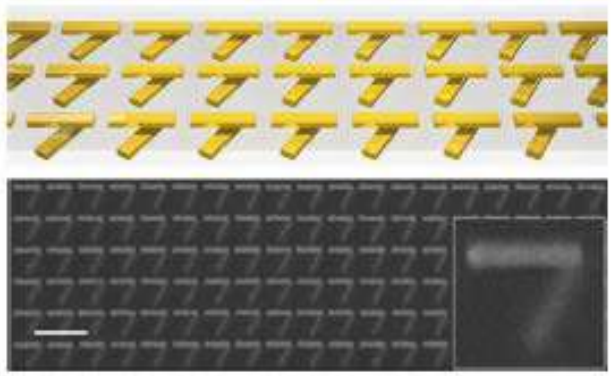
Chirality detection of enantiomers using twisted optical metamaterials

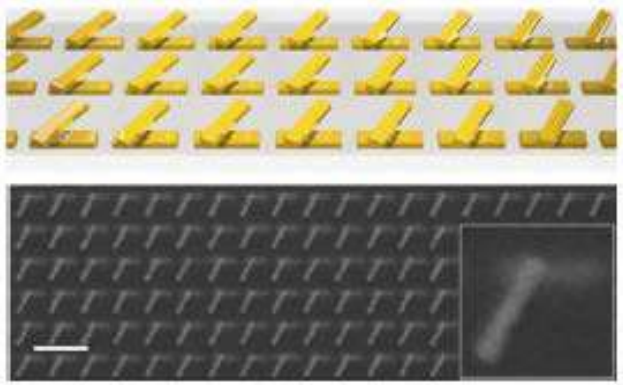
Yang Zhao Andrea Alù[1]

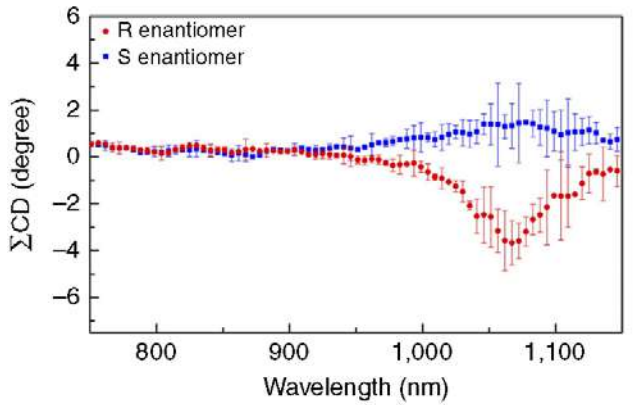
nature COMMUNICATIONS

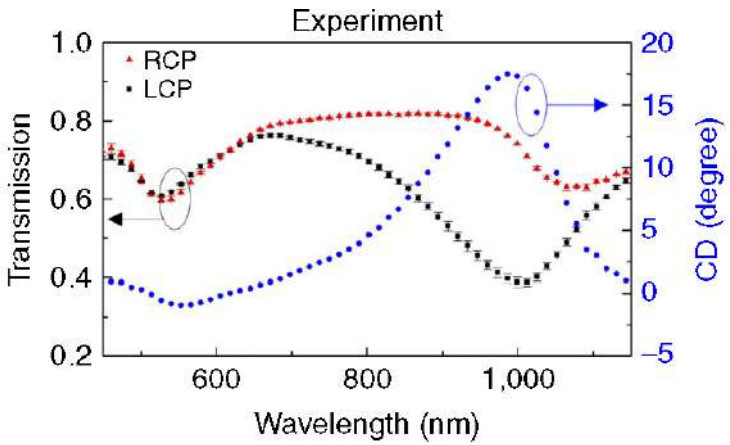
- Ultrathin, planarized nano-photonic interface to sense chiral molecules with weak CD at VIS and NIR

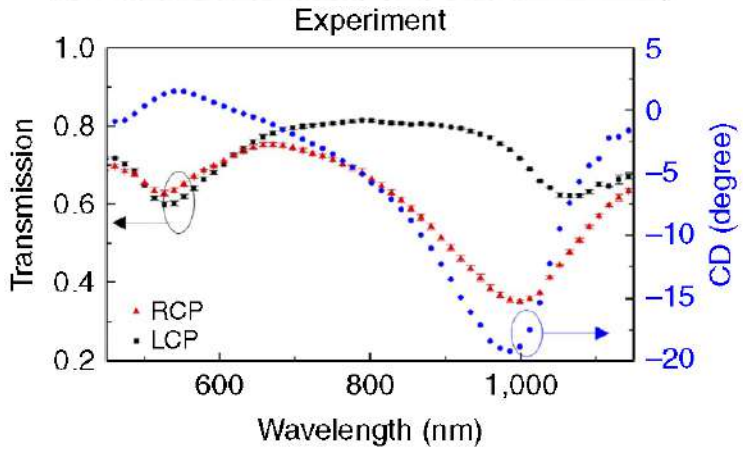


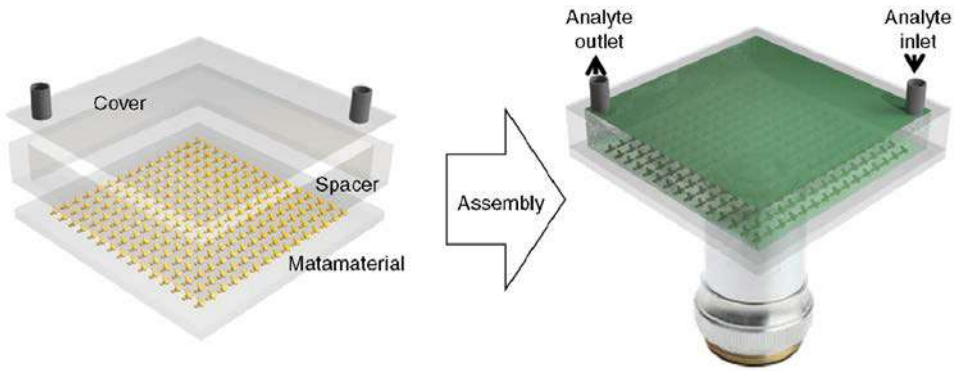




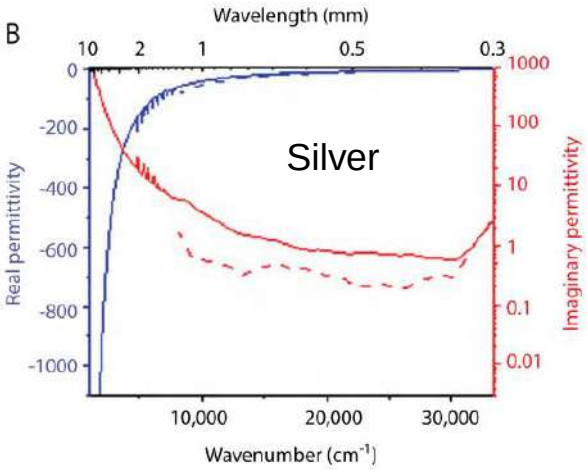


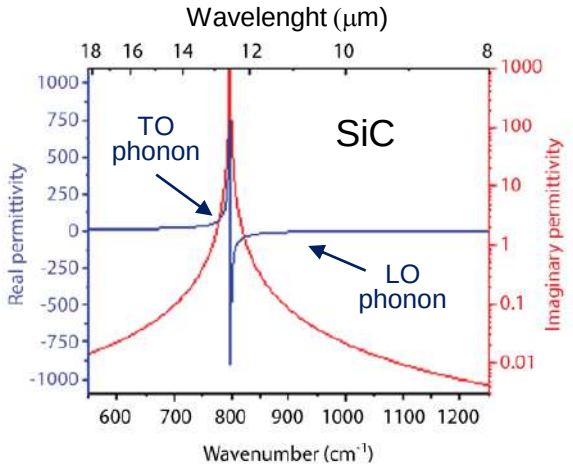






Phonon Polaritons

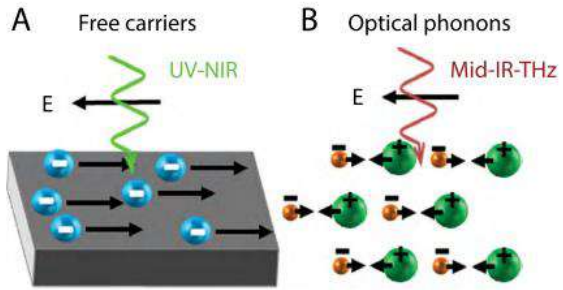




Caldwell, Joshua D., et al. *Nanophotonics* (2015)

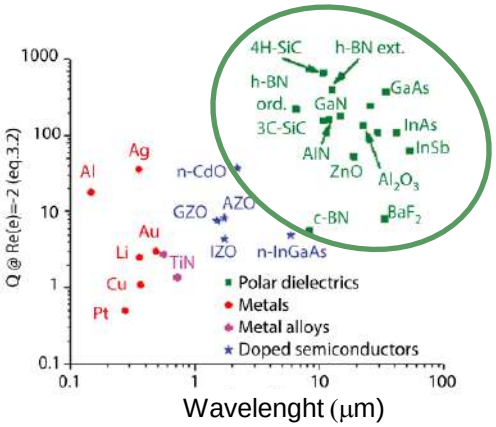
- To have subwavelength confinement $\epsilon_1(\omega) < 0$.
- Noble metals limited to visible range.
- High Losses at optical frequencies.

- Polar dielectrics can have $\epsilon_1(\omega) < 0$ due to optical phonons in the *Reststrahlen* band.
- Lower losses (phonon scattering vs electron scattering for metals).
- Resonances with higher quality factors.

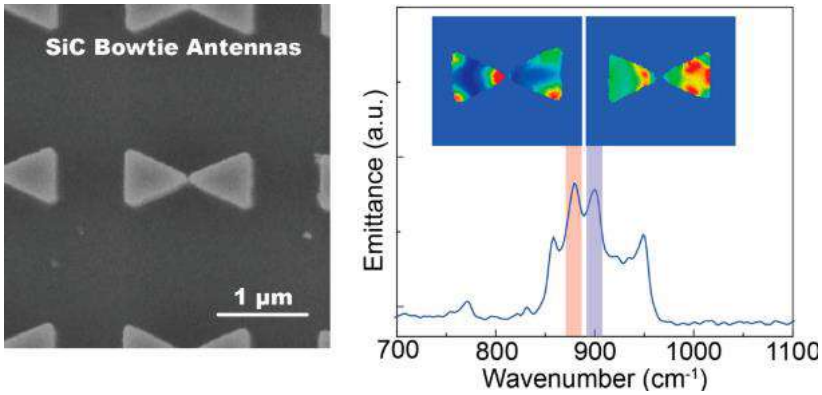


Plasmon

Phonon Polariton

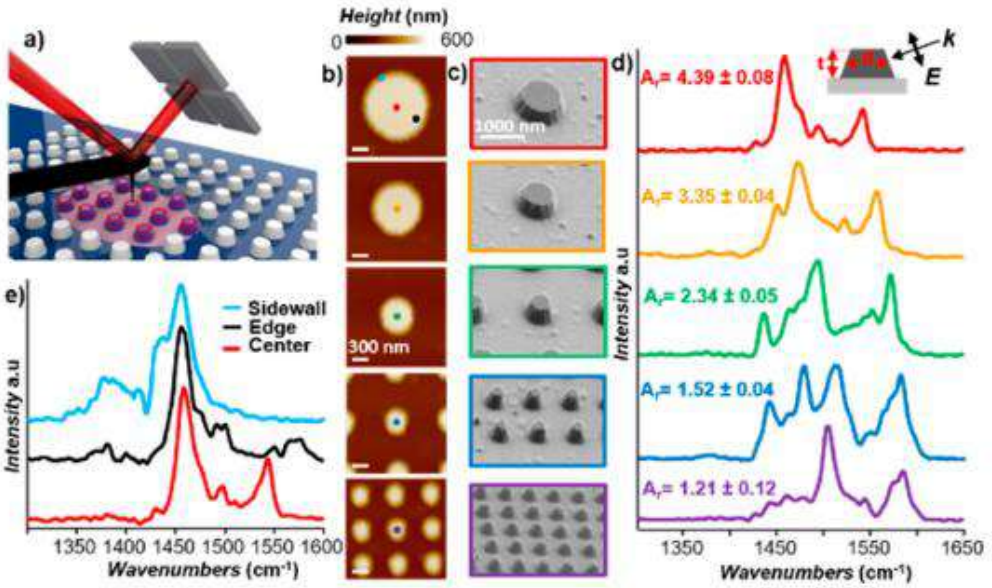


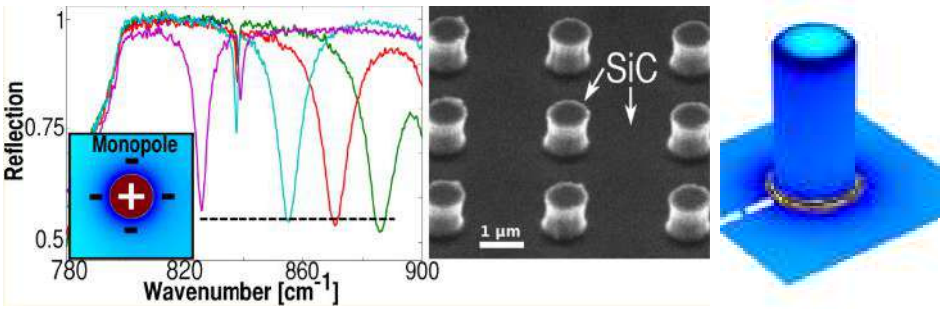
Phonon Polaritons antennas



Wang, Tao, et al. *ACS Photonics* 4.7 (2017).

Hyperbolic materials





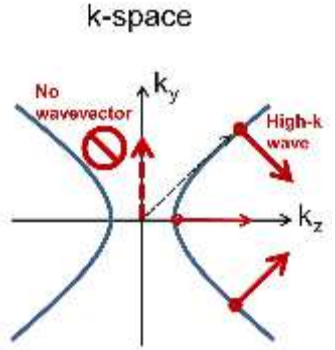
Chen, Yiguo, et al. *ACS Photonics* 1.8 (2014).

$$[\varepsilon] = \begin{pmatrix} \varepsilon_o & 0 & 0 \\ 0 & \varepsilon_o & 0 \\ 0 & 0 & \varepsilon_e \end{pmatrix}.$$

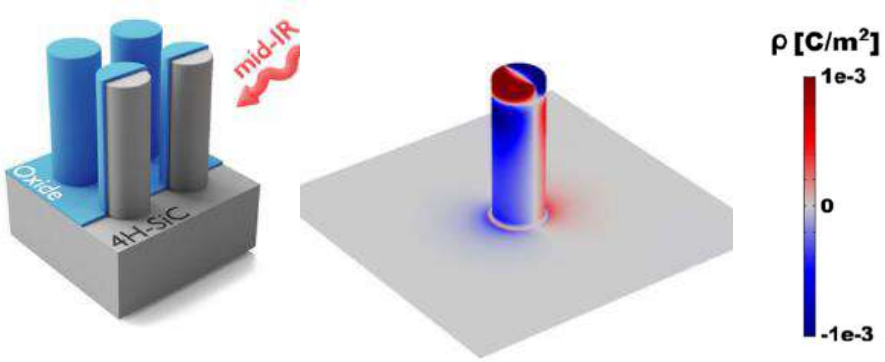
$$\frac{k_x^2 + k_y^2}{\varepsilon_o} + \frac{k_z^2}{\varepsilon_e} = \frac{\omega^2}{c^2}$$

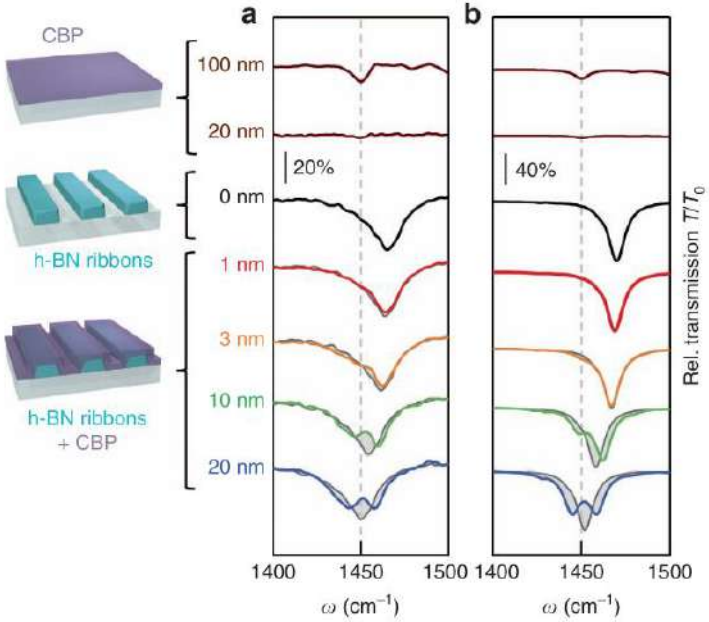
Brown, Lisa V., et al. *Nano letters* 18.3 (2018).

$\varepsilon_0 > 0$ and $\varepsilon_e < 0$

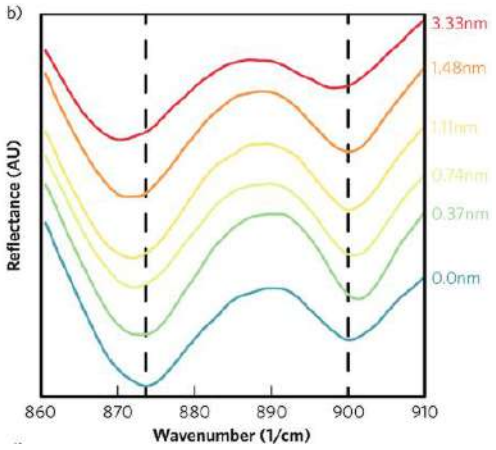


Sensing with Phonon Polaritons

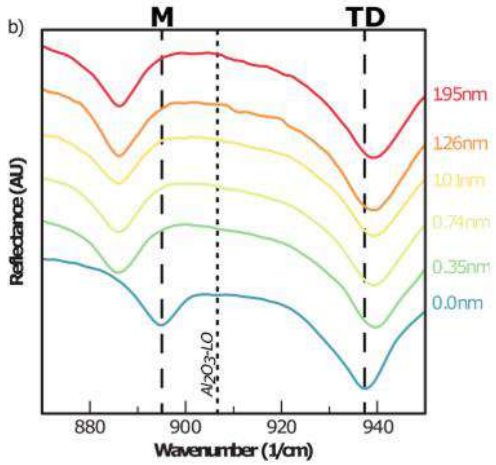




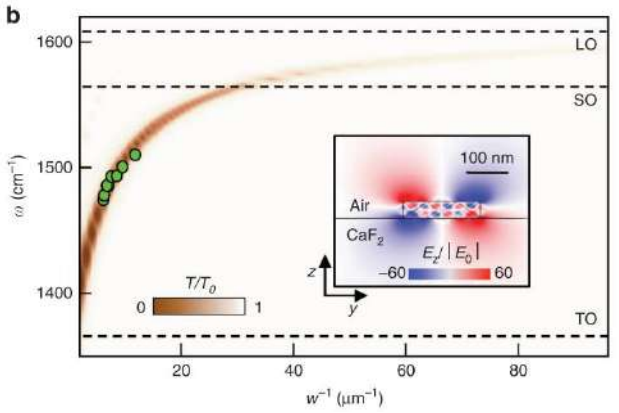
ZrO_2 coating



Al_2O_3 coating



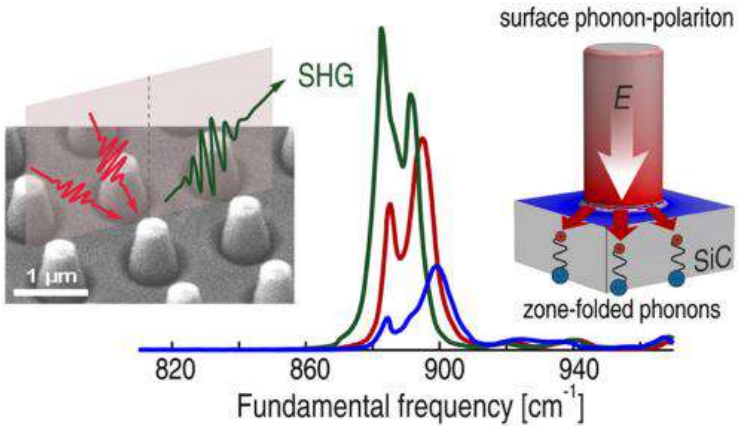
Berte, Rodrigo, et al. *ACS* Photonics 5.7 (2018).



Autore, Marta, et al. *Light: Science & Applications* 7.4 (2018).

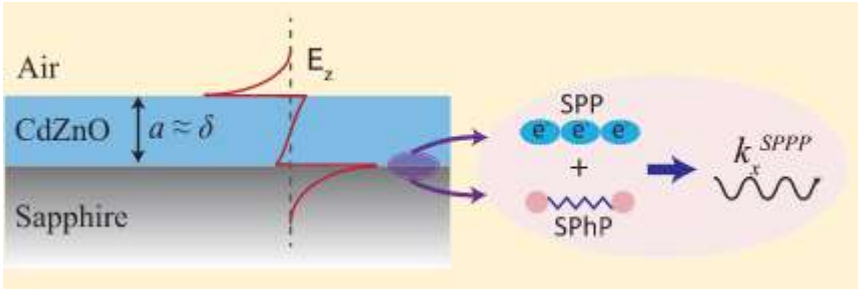
Phonon Polaritons Applications

Nonlinear optics



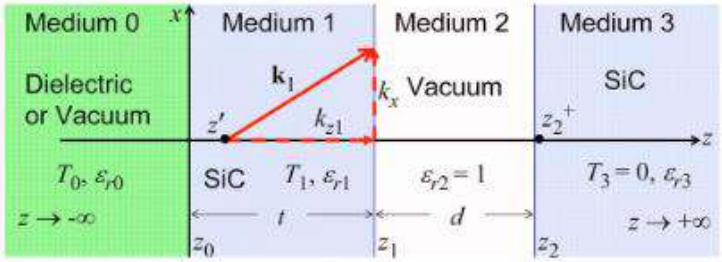
Razdolski, Ilya, et al. *Nano Letters* 16.11 (2016).

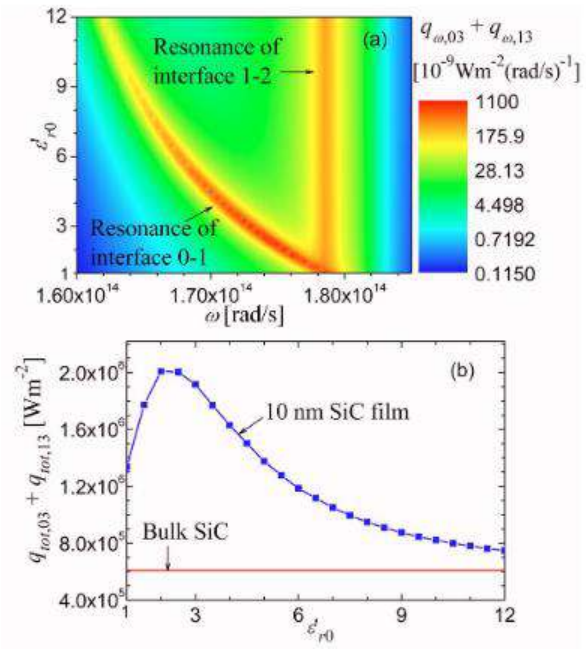
Hybrid Phonon-Plasmon Polaritons



Tamayo-Arriola, Julen, et al. *ACS Photonics* 6.11 (2019).

Radiative nanoscale heat transfer





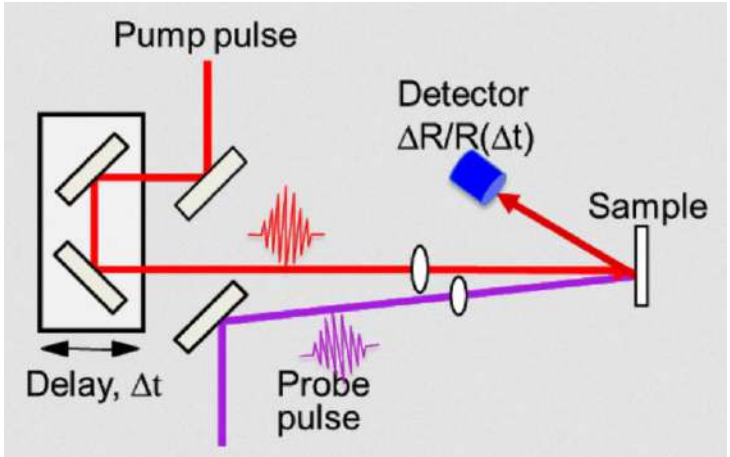
Francoeur, Mathieu, M. Pinar Mengüç, and Rodolphe Vaillon. *Applied Physics Letters* 93.4 (2008).

Ultrafast dynamics in nanomaterials

- Time scale of electronic events

- Phosphorescence (up to hours)

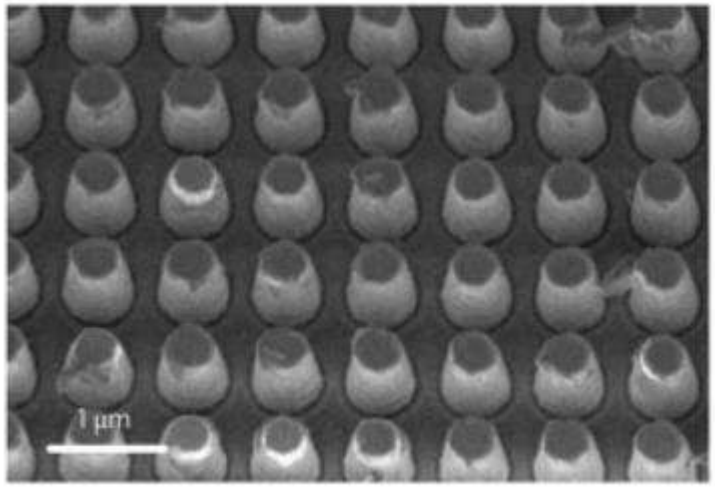
- Fluorescence (ns)

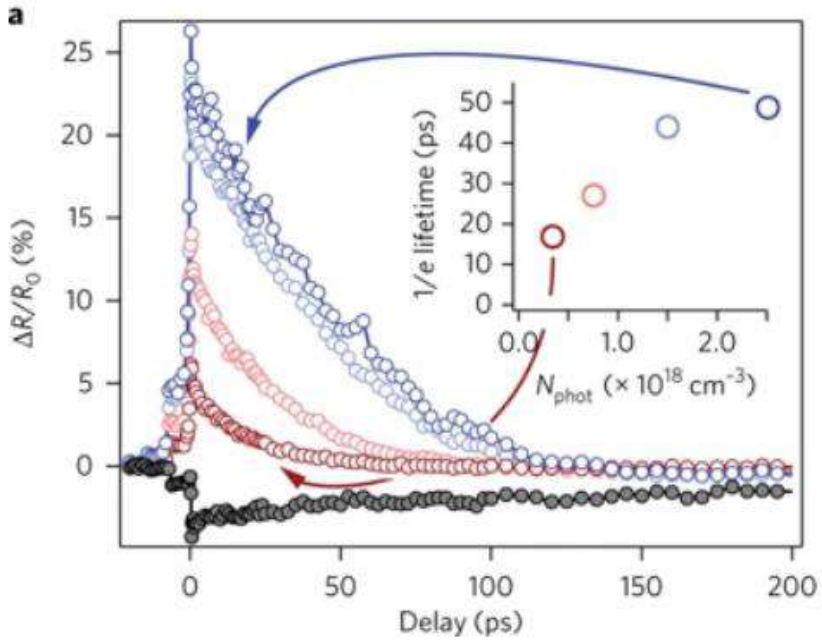


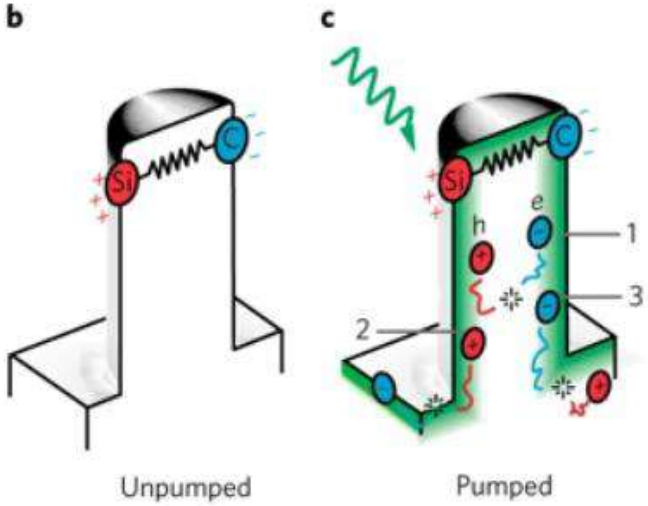
- Non-linear dynamics
  (fs – "instantaneous")

Ultrafast dynamics in nanomaterials

- Surface Phonon Polaritons + free carriers



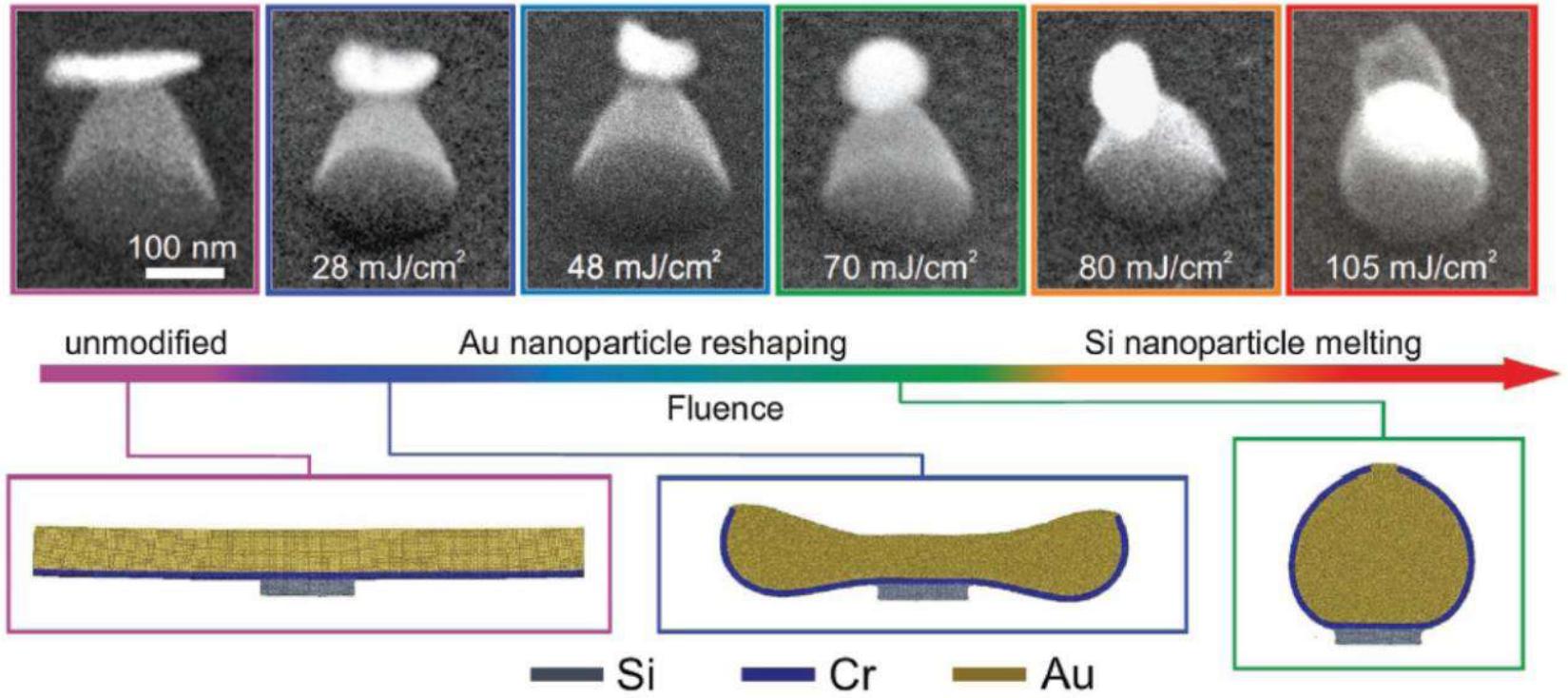




Dunkelberger, *et al*, Nat Photonics **2018**

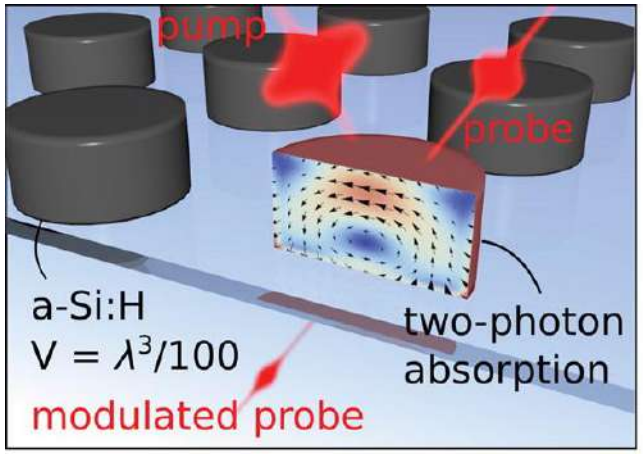
Ultrafast dynamics in nanomaterials

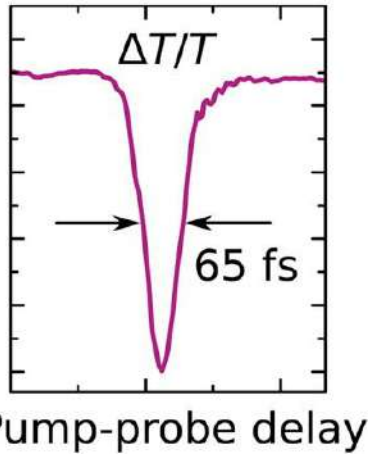
- Non-reversible processes



Zuev, *et al*, Adv Mat **2016**

Ultrafast dynamics in nanomaterials

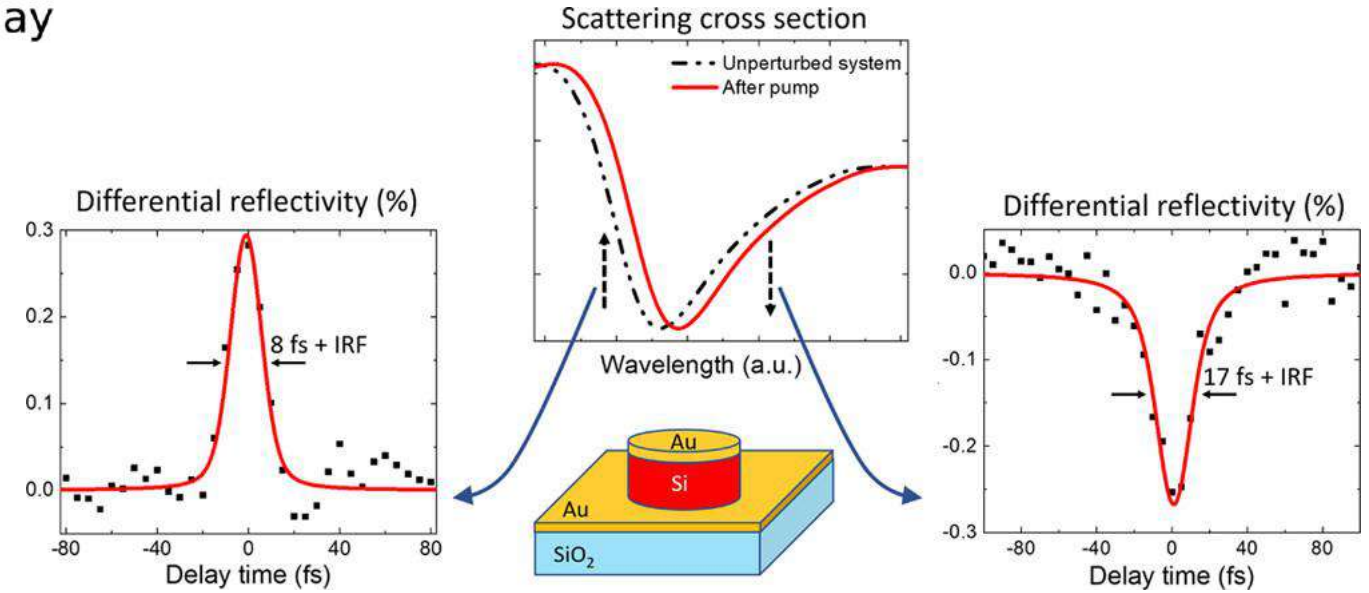




Shcherbakov, *et al*, Nano Letters **2018**

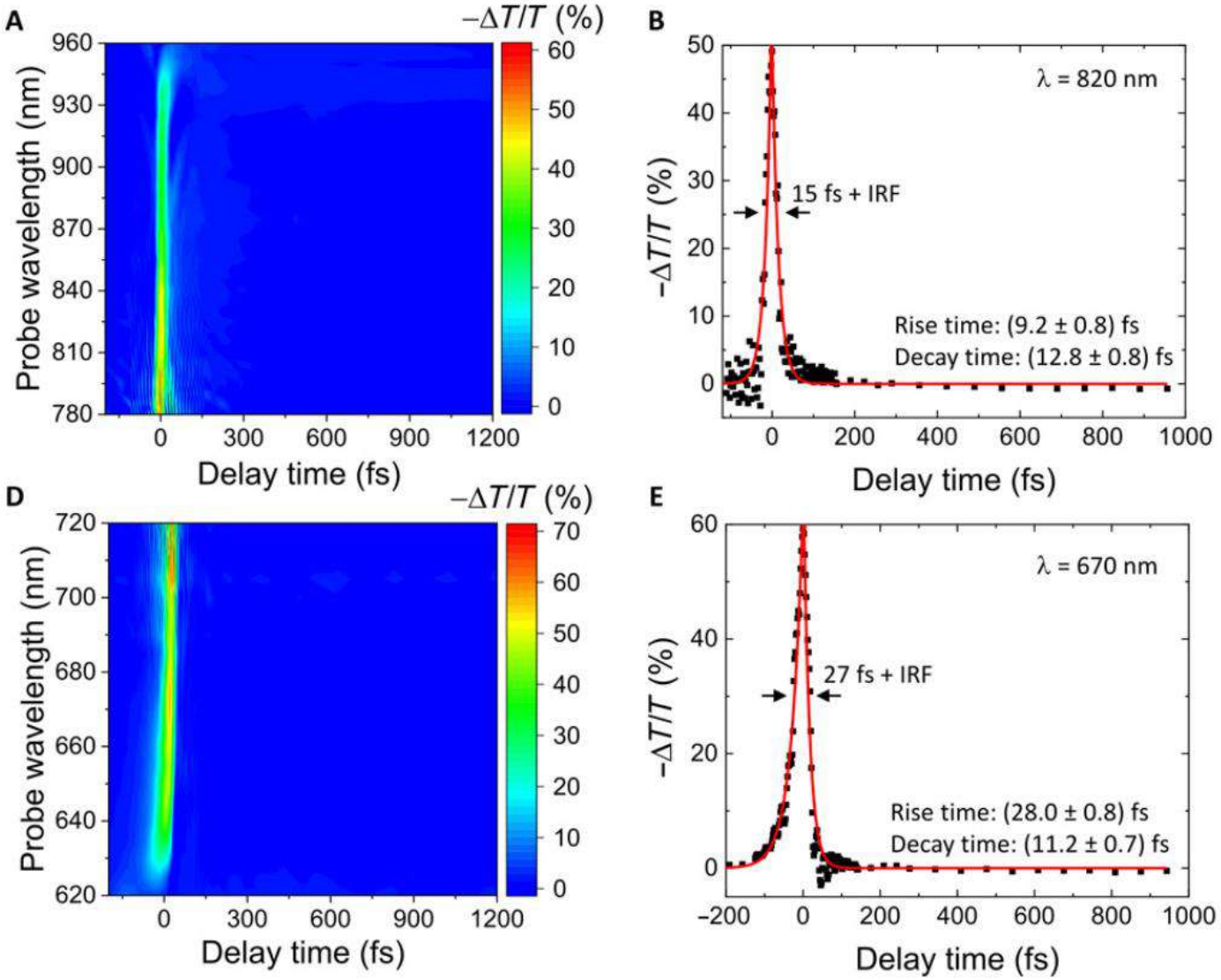
- Metasurfaces

- Single antennas



Grinblat, Berte, *et al*, Nano Letters **2018**

Ultrafast dynamics in nanomaterials



Grinblat, *et al*, Sci Adv **2019**

Ultrafast dynamics in nanomaterials