Beyond metals and semiconductors: nano-oxides for integrated nonlinear photonic devices

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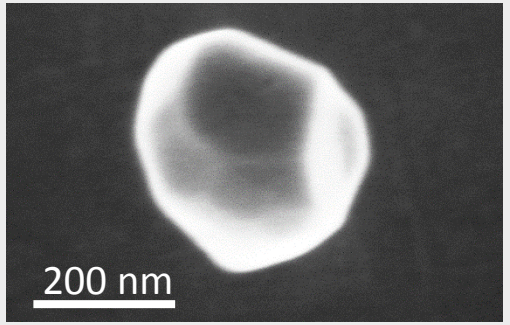

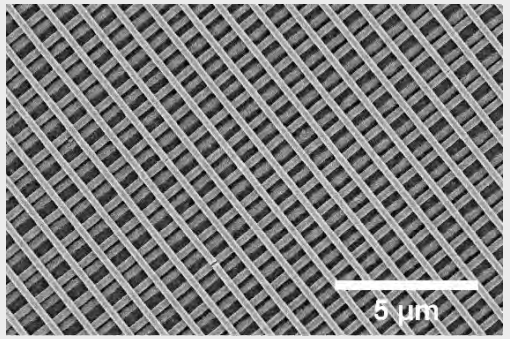

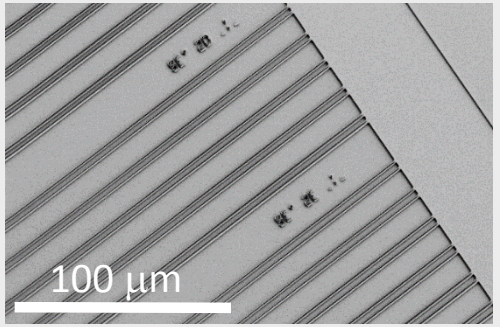

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Size

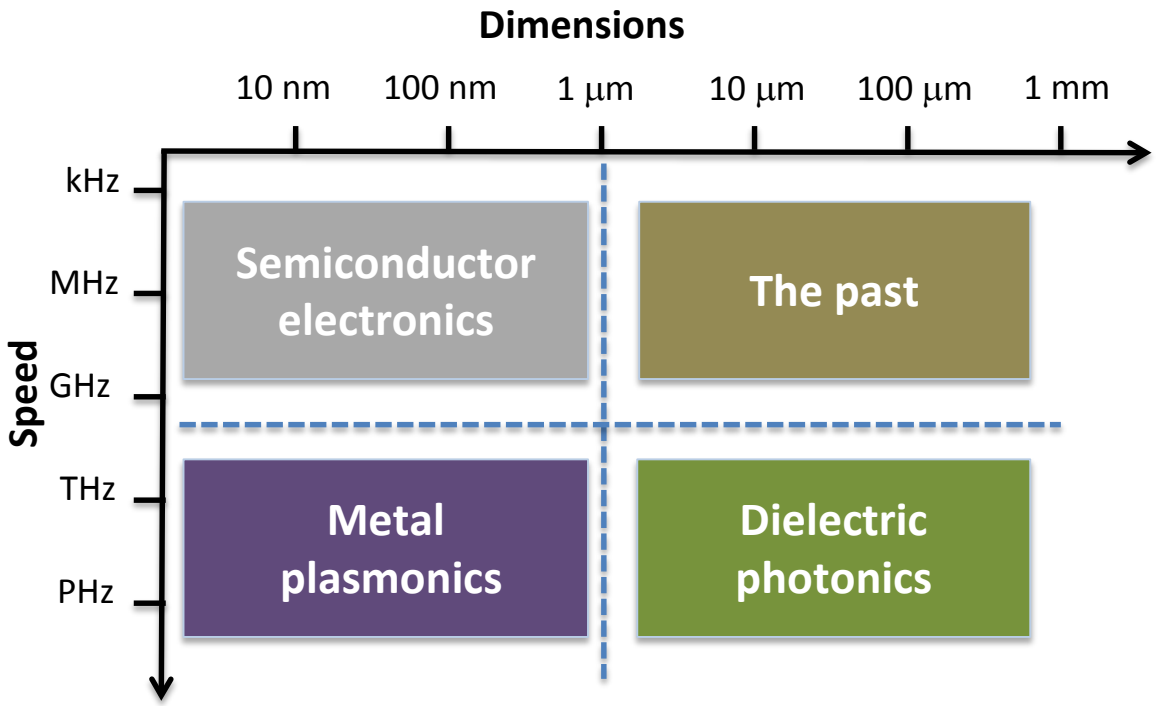
Power

Heat

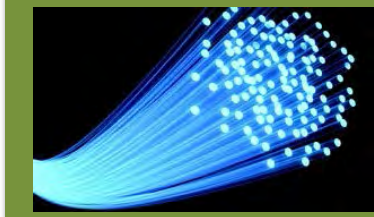
Size : limited by the laws of diffraction

Limited speed due to interconnect delay times

Small size
High speed
High losses



Limited in size by laws of diffraction

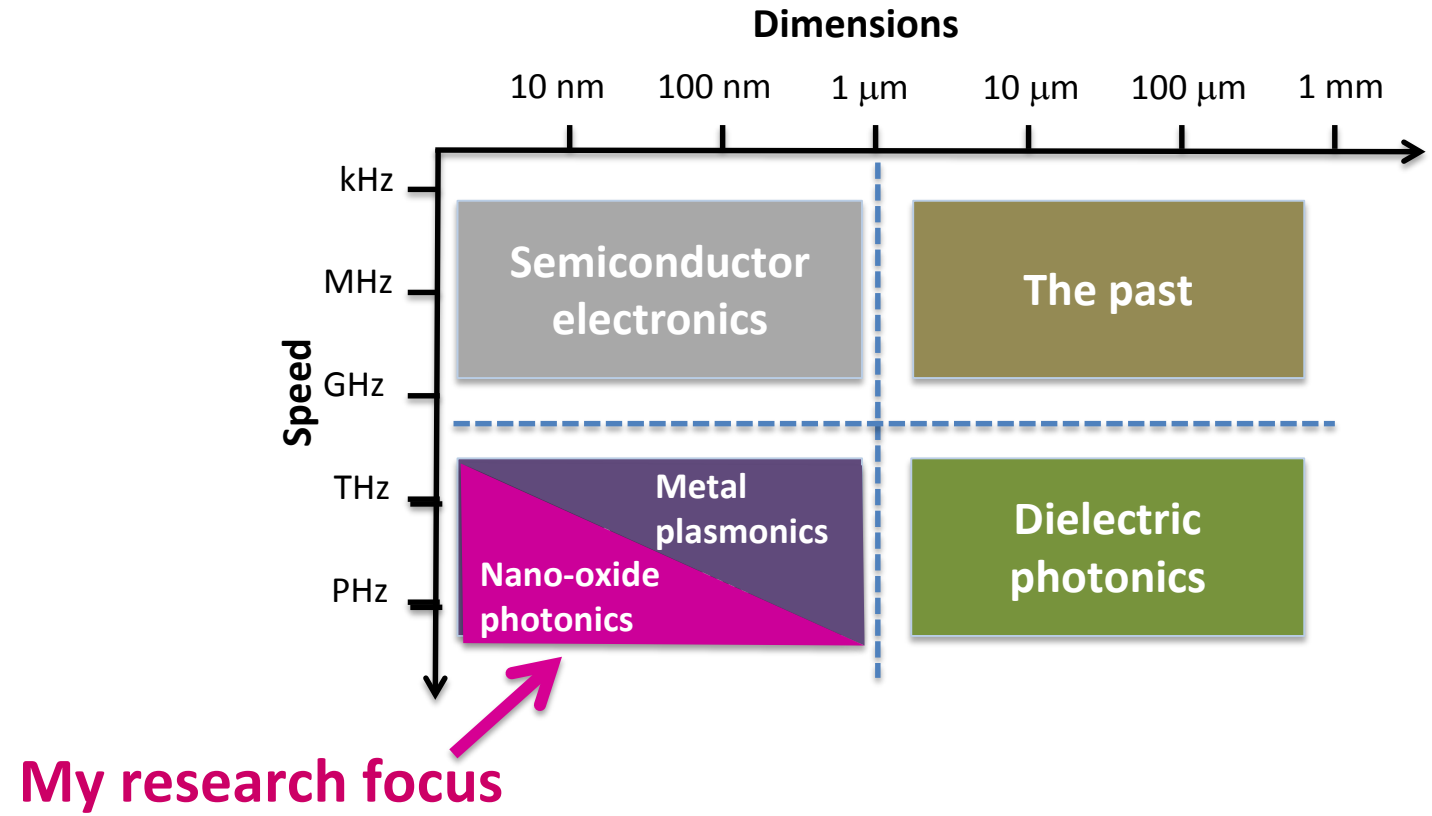


Adapted from Brongersma,& Shalaev *Science* 328 (2010)

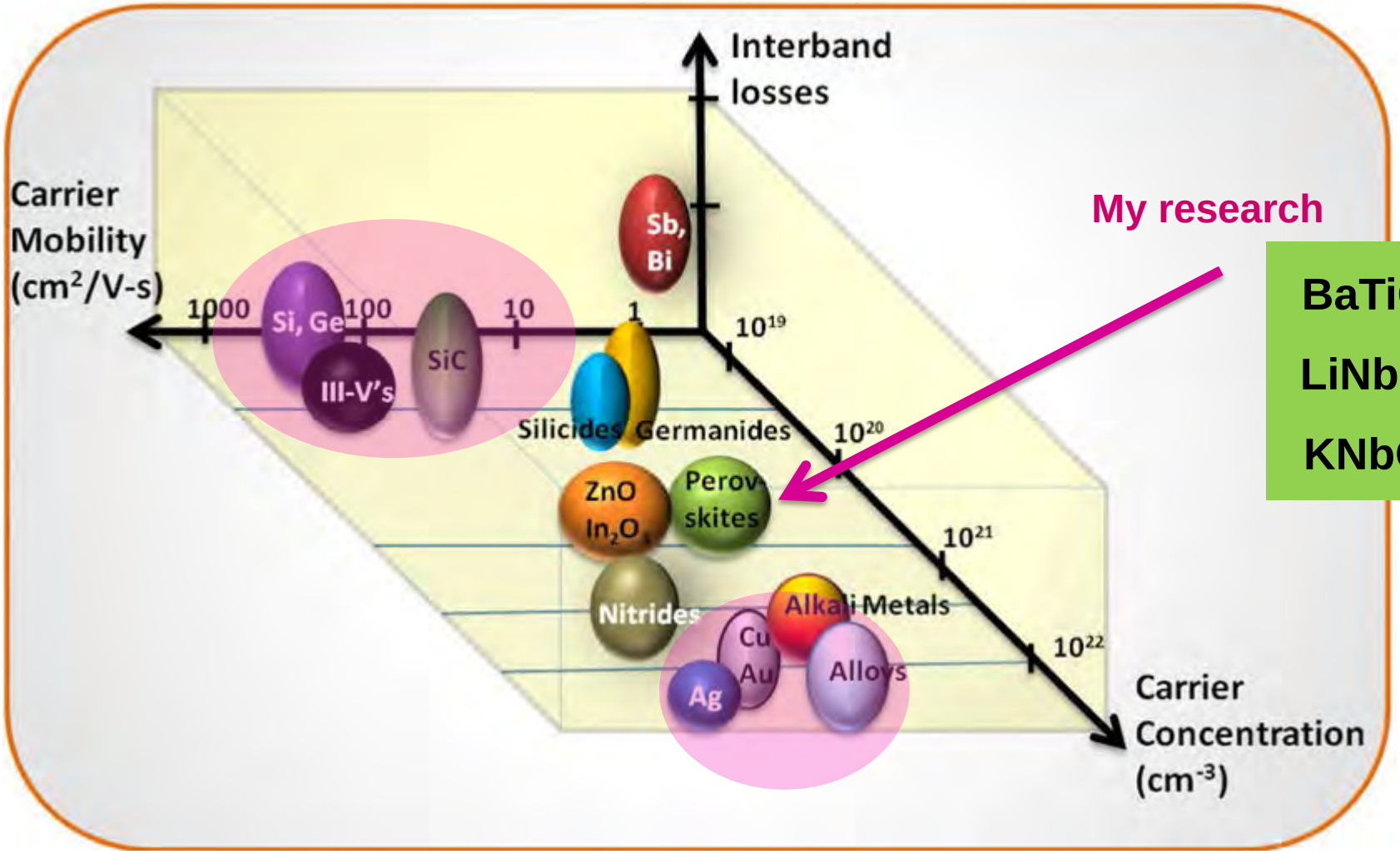
HEAT : thermal losses in metals

J. B. Khurgin, How to deal with loss in plasmonics and metamaterials, Nature Nanotechnology, 10, 2015.

Evolution of materials : what is next ?

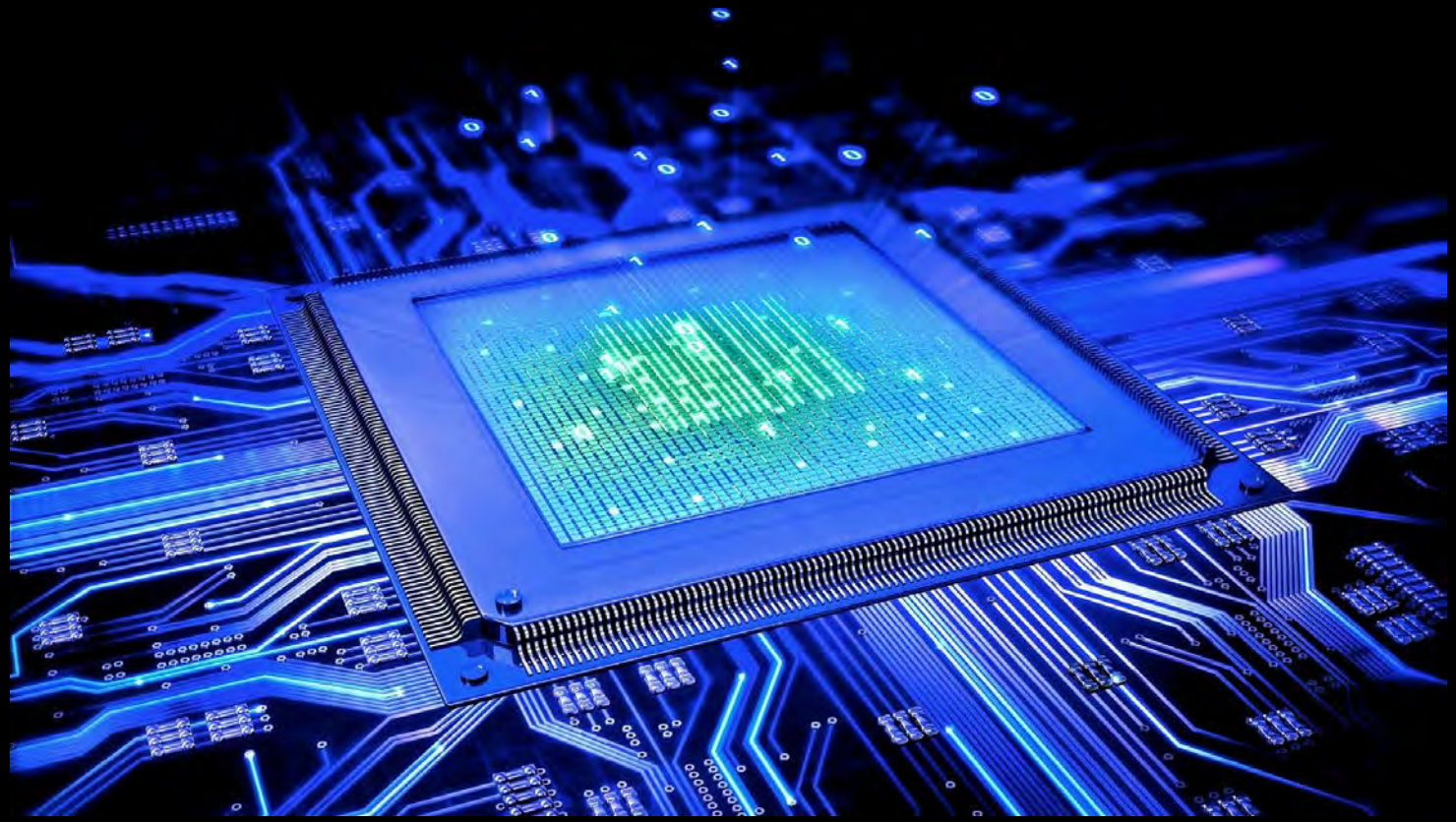


Nano-oxides as bridge



Plasmonics and metamaterials: looking beyond gold and silver, SPIE 2012, Alexandra Boltasseva

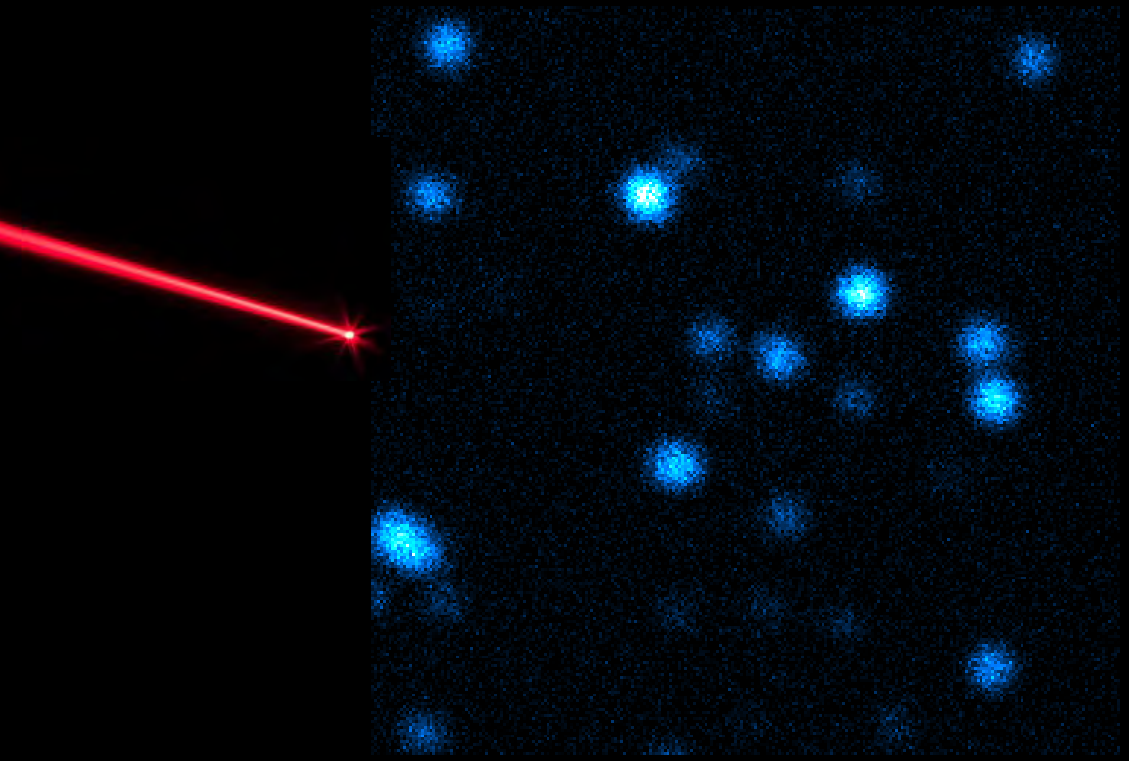
HEAT : lossless integrated plateform



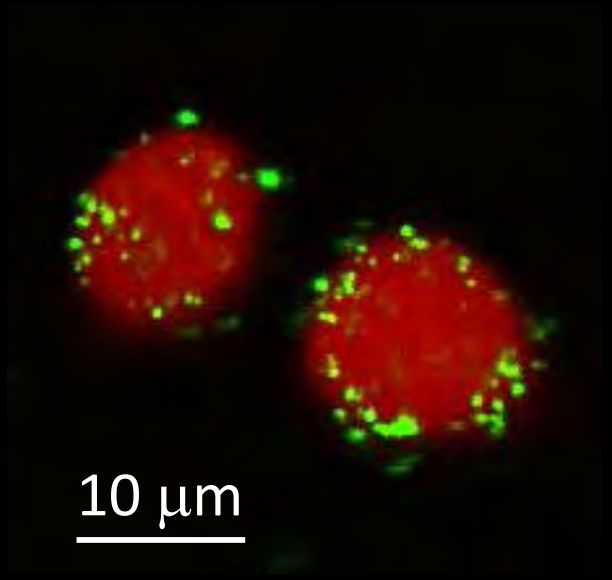
300 nm to 5 µm

SIZE: Small and still bright

Safe markers for bioimaging



Down to 15 nm in diameter



Hsieh, C.-L.; Grange, R.; Pu, Y.; Psaltis, D..
Biomaterials 31, 2272, **2010**

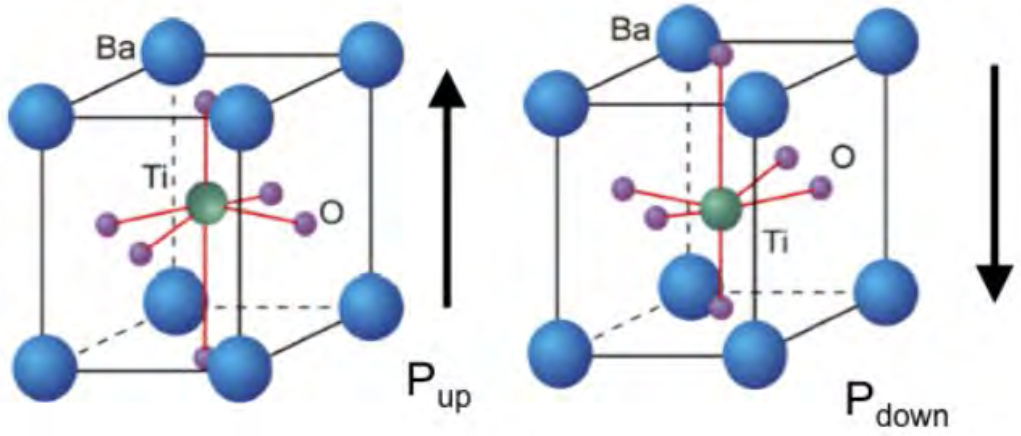
POWER : low power comsumption & robust

1.4 billions € telescope
Lifetime of 4 years

Robust compact devices

Physical properties

- **Non centrosymmetric bulk crystals:** $BaTiO_3$, $LiNbO_3$, $KNbO_3$, ZnO, GaAs
- **Notable bulk properties**: ferroelectric, second order nonlinearity, n > 2, electro-optic



Physical properties of *Chi2* materials

- **Non centrosymmetric bulk crystals:** $BaTiO_3$, $LiNbO_3$, $KNbO_3$, ZnO, GaAs
- **Notable bulk properties:** ferroelectric, second order nonlinearity, n > 2, electro-optic

Polarization

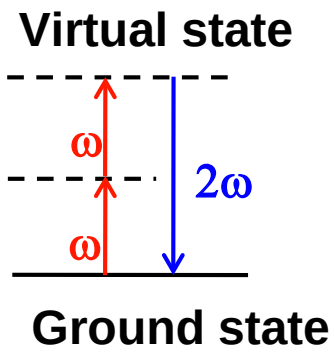
$$\vec{P} = \varepsilon_0 \chi_1 \vec{E} + \varepsilon_0 \chi_2 \vec{E}^2 + \varepsilon_0 \chi_3 \vec{E}^3 + \ldots$$

χ electric susceptibility

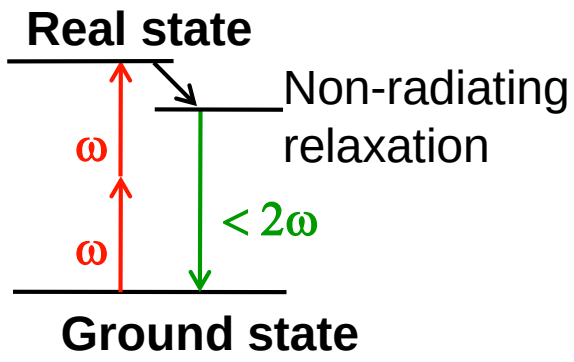
$\chi_2 \neq 0$

$$\begin{bmatrix} d_{11} & d_{12} & d_{13} & d_{14} & d_{15} & d_{16} \\ d_{21} & d_{22} & d_{23} & d_{24} & d_{25} & d_{26} \\ d_{31} & d_{32} & d_{33} & d_{34} & d_{35} & d_{36} \end{bmatrix}$$

Second-Harmonic Generation (SHG)



2-photon fluorescence



pm/V

$LiNbO_3$	$BaTiO_3$	GaAs
$d_{32} = -30$	$d_{33} = 6.8$	$d_{36} = 370$
$d_{31} = -5.9$	$d_{31} = 15.7$	
	$d_{15} = 17.0$	

Challenge at the nanoscale

Quadratic effect

SHG signal ≈ $\chi^{(2)}$ $(E_{field})^2$

≈

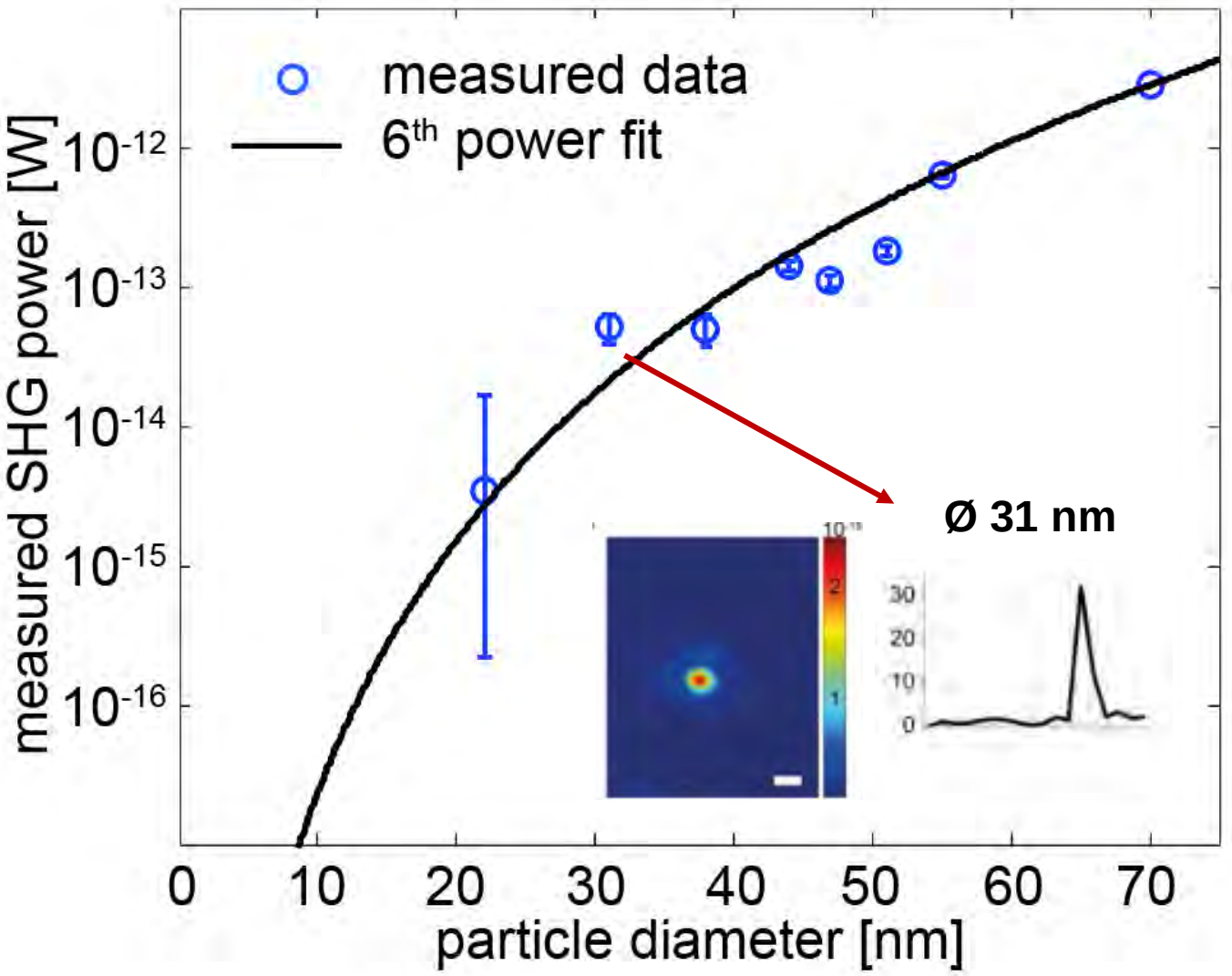
(volume)²

≈

(radius)⁶

The challenge

How to boost nonlinear optical signal ?



E. Kim, A. Steinbrück, V. Buscaglia, T. Pertsch, and R. Grange, ACS Nano 7 (2013).

Optical Nanomaterial Group

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To scale down materials for nonlinear optics while still having strong signal, easy fabrication and marketable devices




Anton Sergeyev
Marc Reig Escalé
Flavia Timpu
Maria Timofeeva
Claude Renaut
Viola Vogler
Fabian Kaufmann
Romolo Savo




Funding

FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation

State Secretariat for Education, Research and Innovation SERI
Swiss Space Office

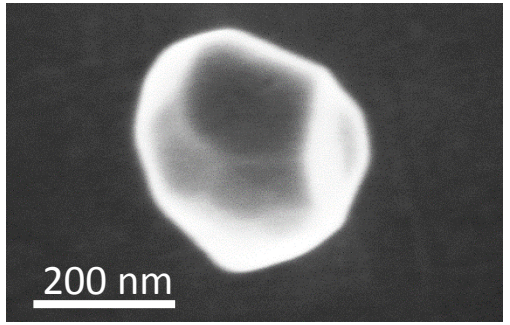
BRIDGE

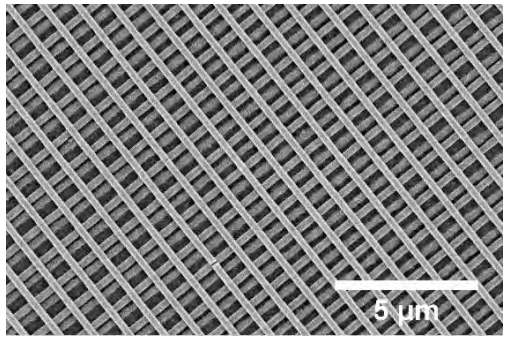
erc
European Research Council
Established by the European Commission

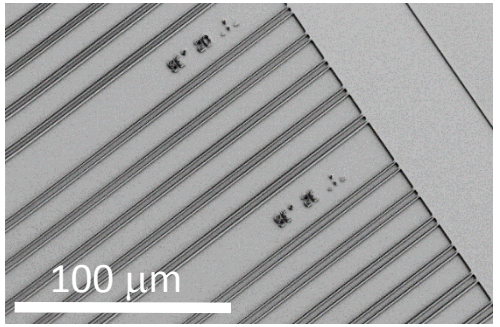
Outline

Strategies to enhance nonlinear optical signals

1. **with plasmonics**
2. **with Mie resonances**
3. **with cavity effects**
4. **with phase matching**

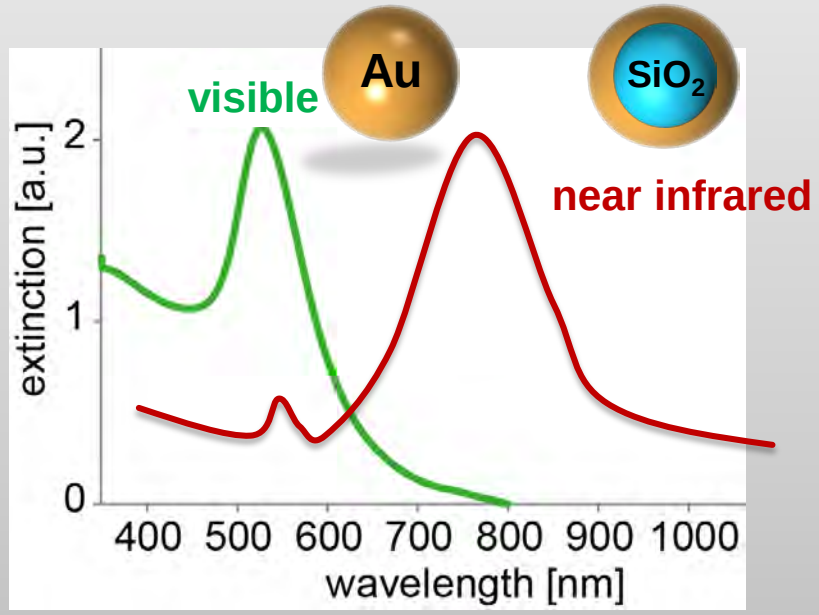




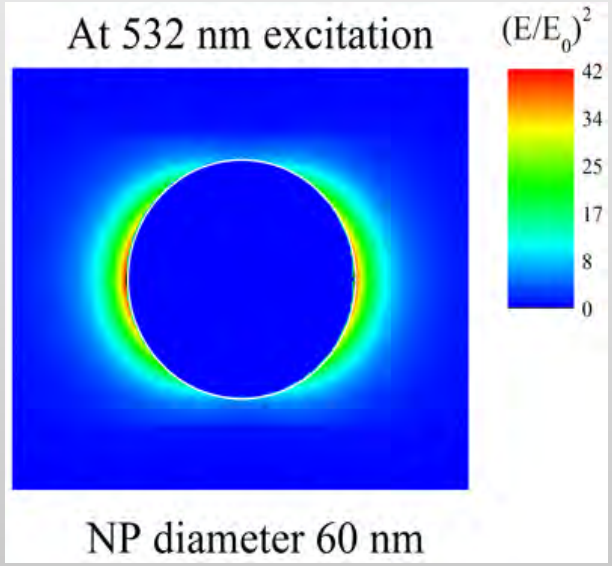


Combination of Plasmonics …

Calculated electric dipole resonance



Strong localized field at the surface



http://nanoplasmon.com/what-is-lspr/

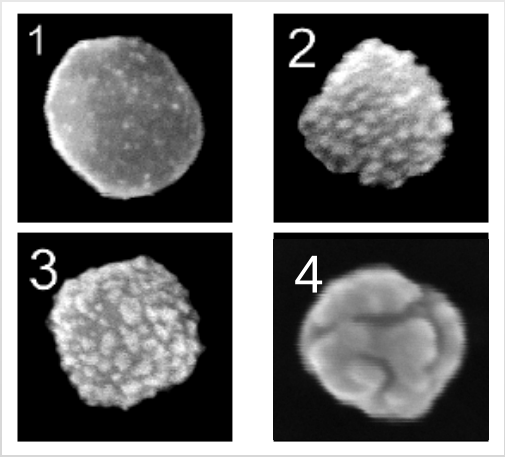
El-Sayed, Atwater, Polman, Halas, Novotny, Fritsche, Aizpurua, ...

ZnS nanoparticles in gold nanoantenna
Linnenbank et al, Light Sci. Appl. 5(1), e16013 (2016).

Kauranen, M.; Zayats, A. V. Nonlinear Plasmonics. Nature Photonics 2012, 6, 737–748.

Combination of Plasmonics with *Chi2* materials

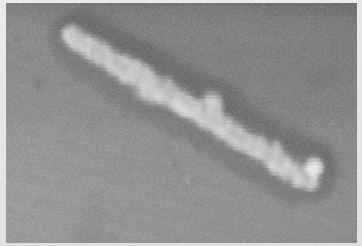
Core-shell $BaTiO_3$- Au

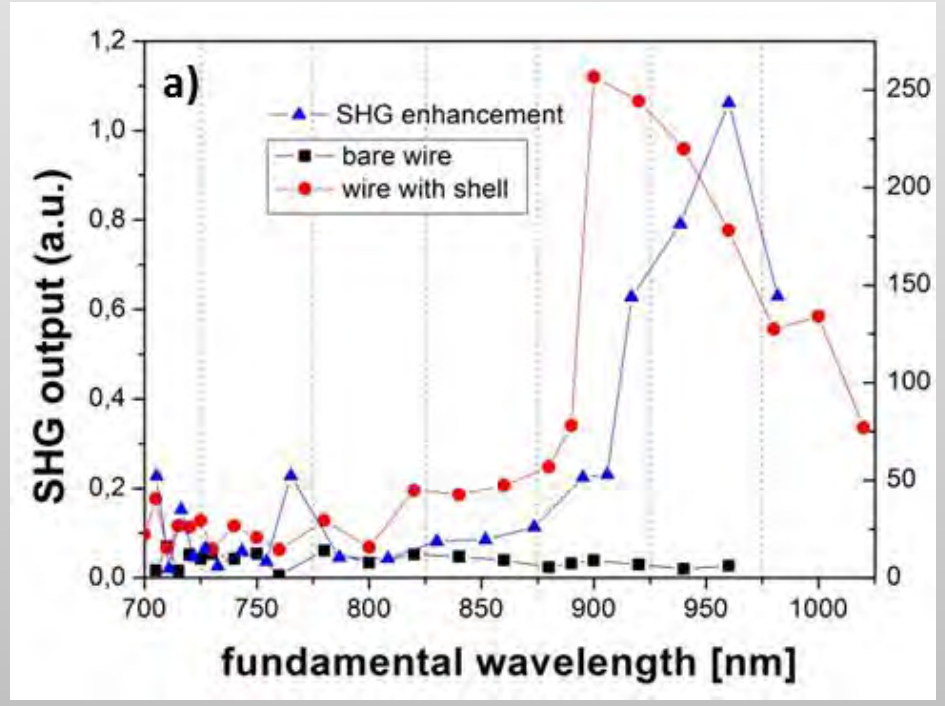


SHG Enhancement Factor = 500

Y. Pu, R. Grange, Ch.-L. Hsieh, and D. Psaltis, Phys. Rev. Lett., 104, 2010.

Core-shell $KNbO_3$ nanowires



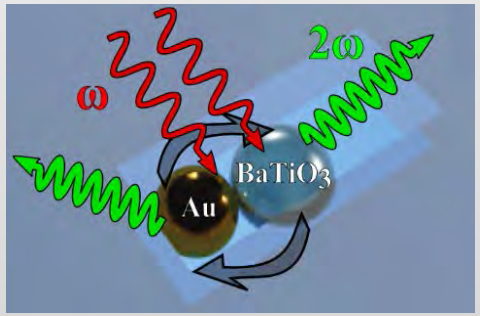


SHG Enhancement Factor = 250

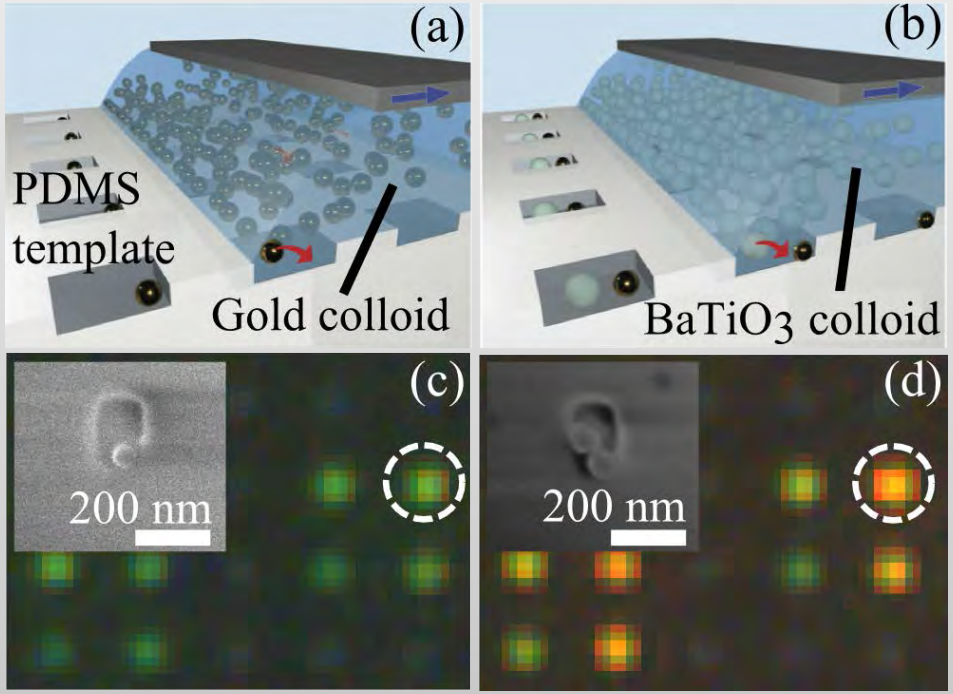
J. Richter, et al. Nanoscale, 6, 5200, 2014.

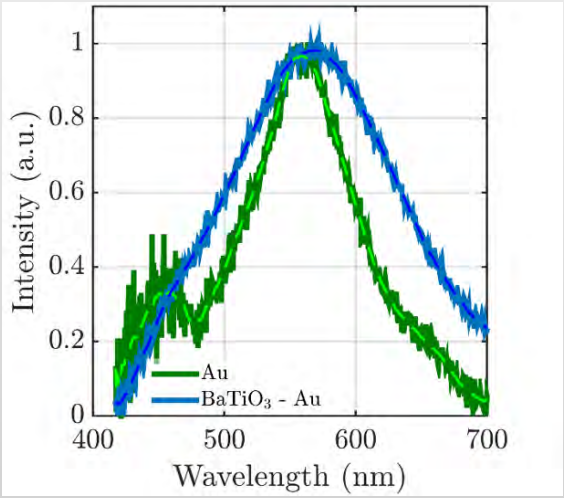
Combination of Plasmonics with *Chi2* materials

Enhanced SHG from Sequential Capillarity-Assisted Particle Assembly of Hybrid Nanodimers



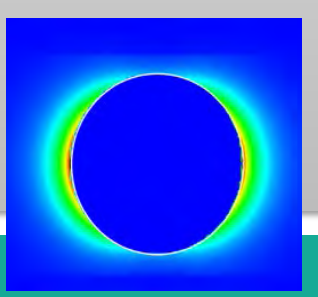
Collaboration with Lucio Isa (ETH) and Heiko Wolf (IBM)





5-15 times Enhanced SHG

Timpu, F.; Hendricks, N. R.; Petrov, M.; Ni, S.; Renaut, C.; Wolf, H.; Isa, L.; Kivshar, Y.; Grange, R. **Nano Letters**, 17, 5381, 2017.

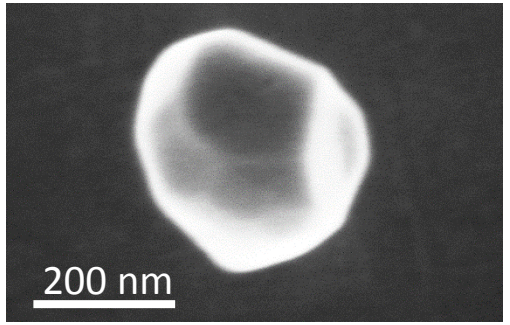


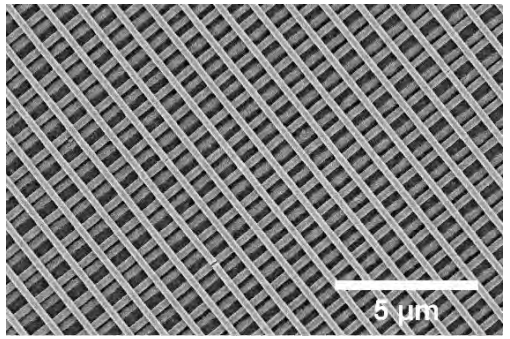
Enhancement with plasmonics: using the field in the vicinity of the particle

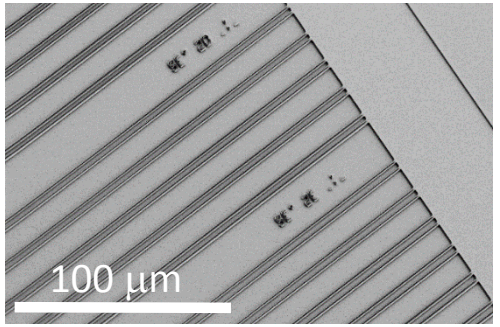
Outline

Strategies to enhance nonlinear optical signals

1. with plasmonics
2. **with Mie resonances**
3. with cavity effects
4. with phase matching

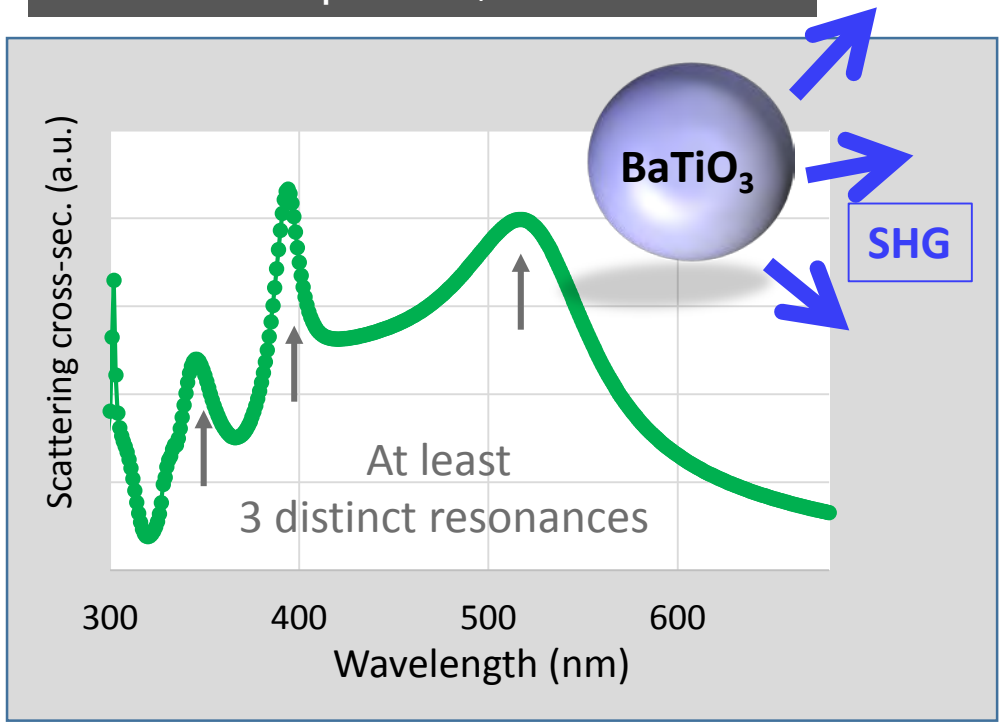


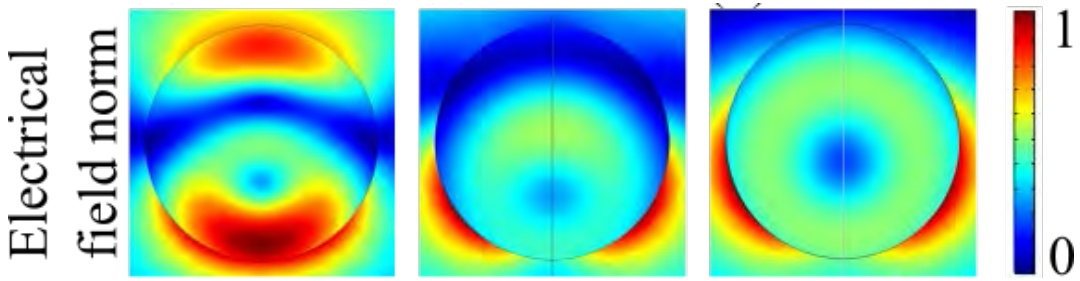




Mie resonances of the material istelf

$BaTiO_3$ nanoparticle, d = 200 nm



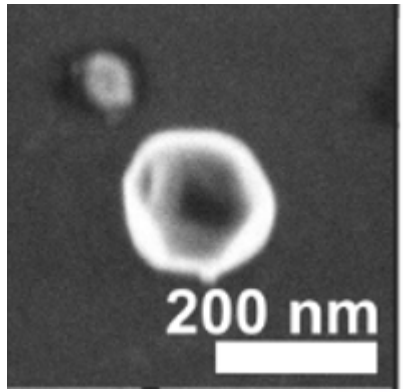


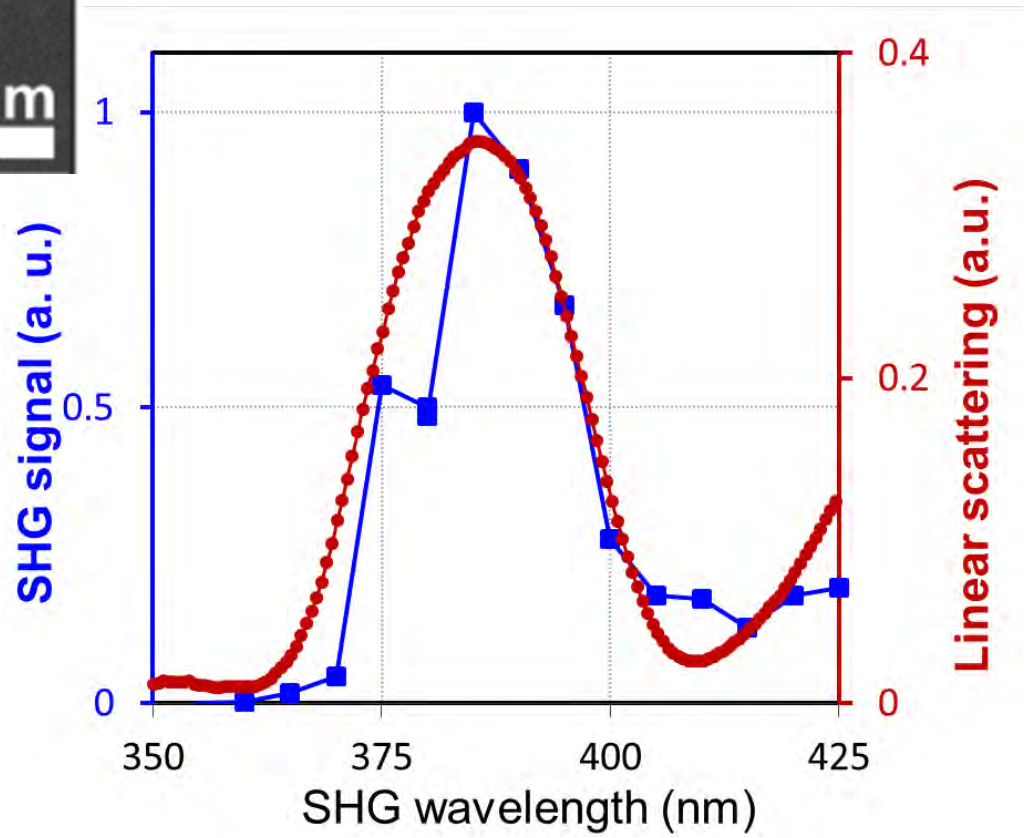
$$\vec{P} = \varepsilon_0 \chi_1 \vec{E} + \varepsilon_0 \chi_2 \vec{E}^2 + \varepsilon_0 \chi_3 \vec{E}^3 + \ldots$$

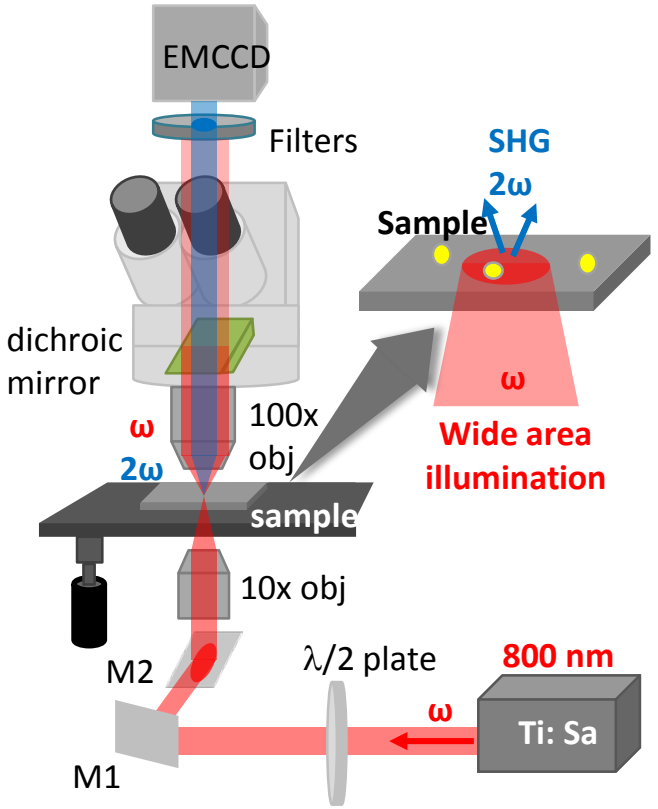
Material	$\chi(2)$ coeff. (pm/V)
Silicon	0
SiO_2 (Quartz)	0.335
$BaTiO_3$	6.8 to 17
$LiNbO_3$	6 to 34
GaAs	134 to 256

'Dielectric' material: electromagnetic field amplified in the volume of the nanoparticle

Mie resonances enhance SHG from single nanoparticle

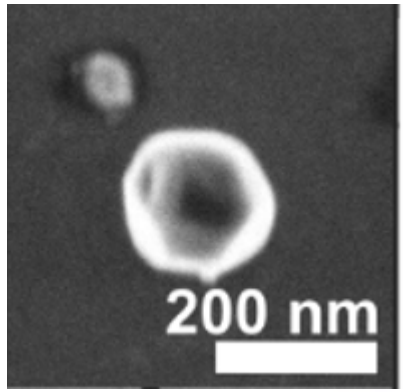


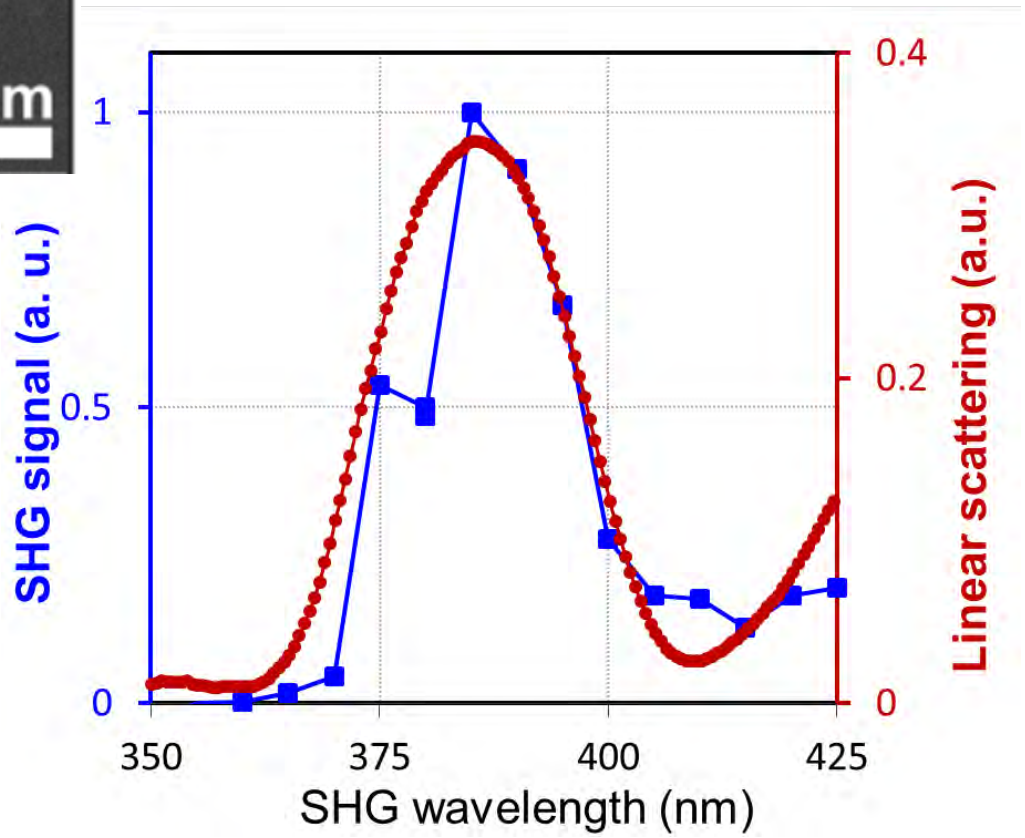


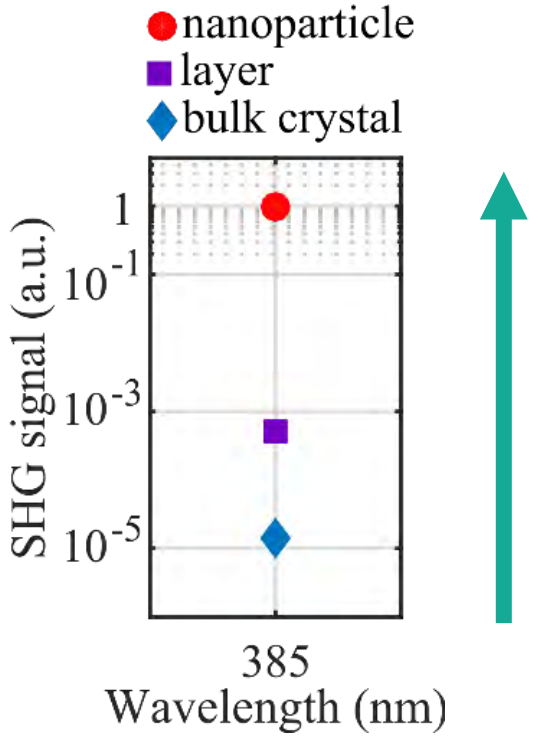


F. Timpu, A. Sergeyev, N. Hendricks, and R. Grange, ACS Photonics, 4, 2017.

Mie resonances enhance SHG from single nanoparticle







10^4 enhancement with a single resonance !

F. Timpu, A. Sergeyev, N. Hendricks, and R. Grange, ACS Photonics, 4, 2017.

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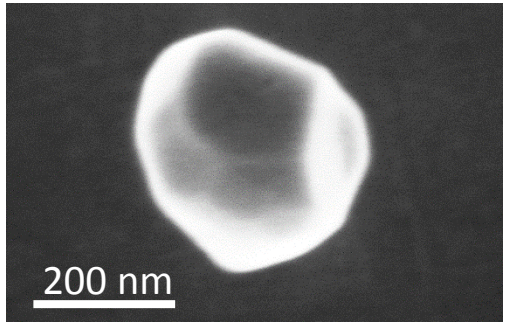
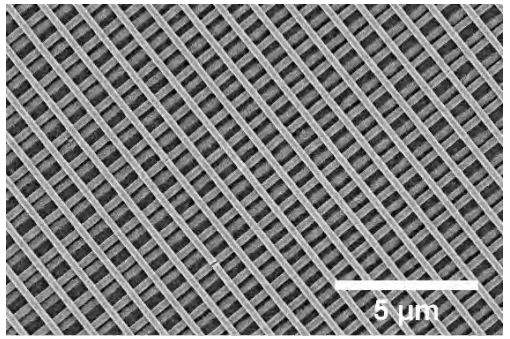
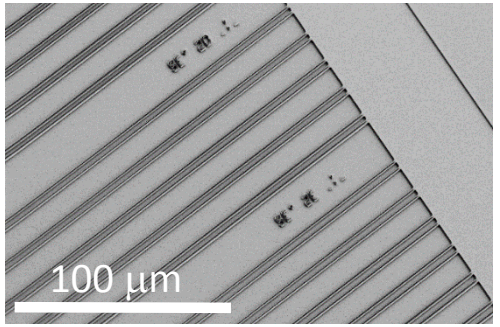
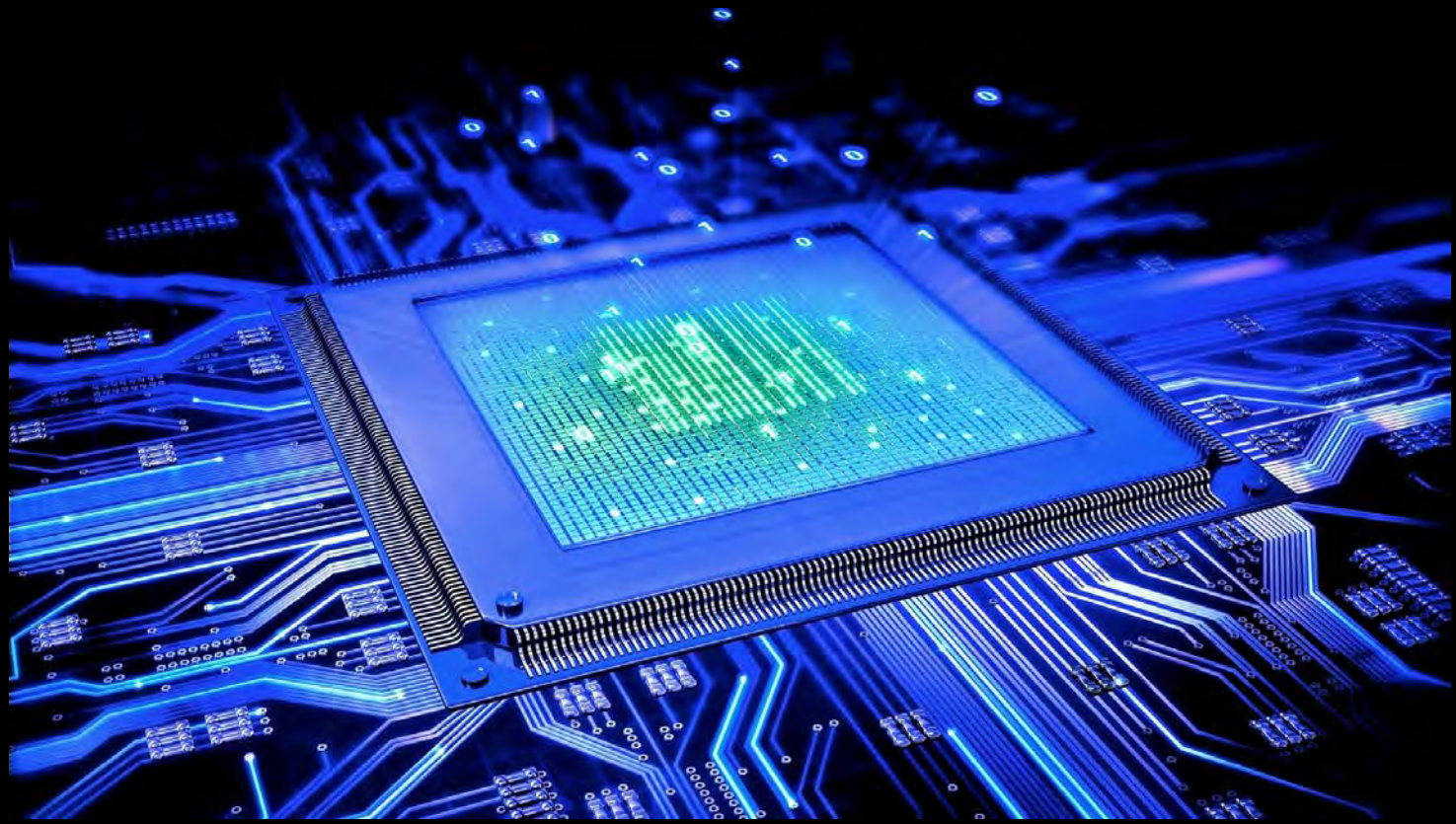




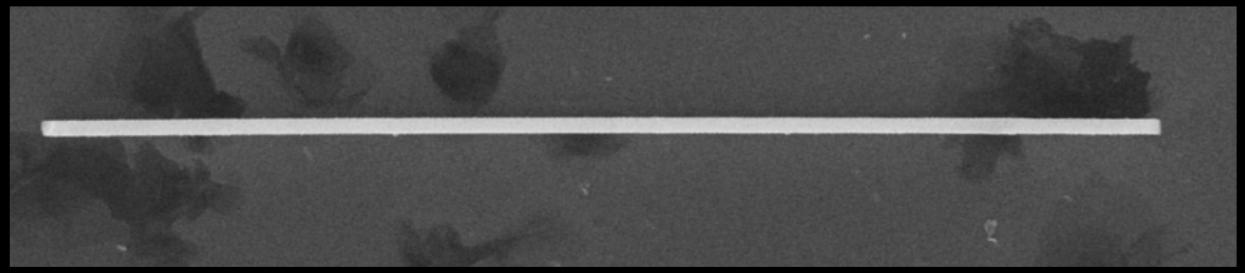


HEAT : lossless integrated plateform

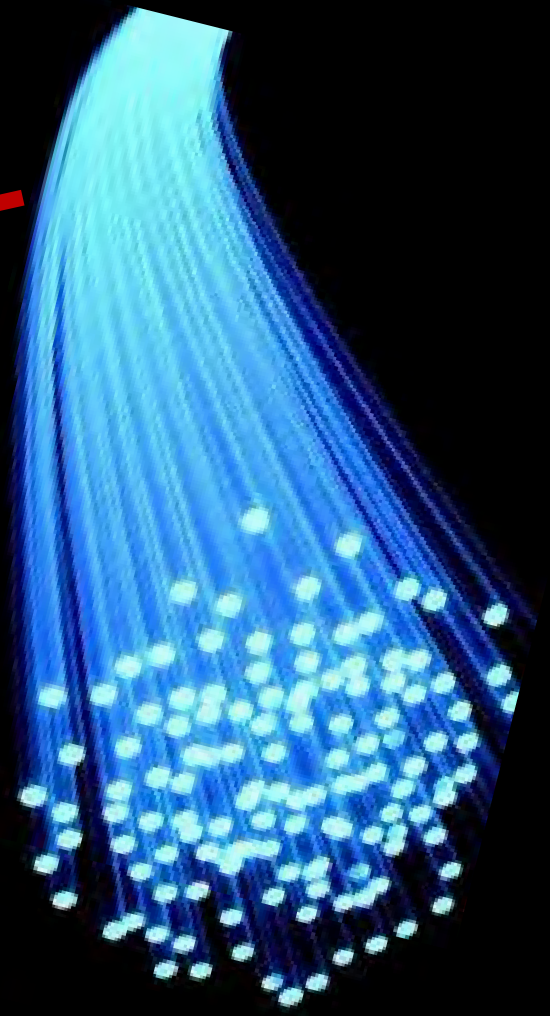


$LiNbO_3$ nanowaveguides

400 nm core diameter



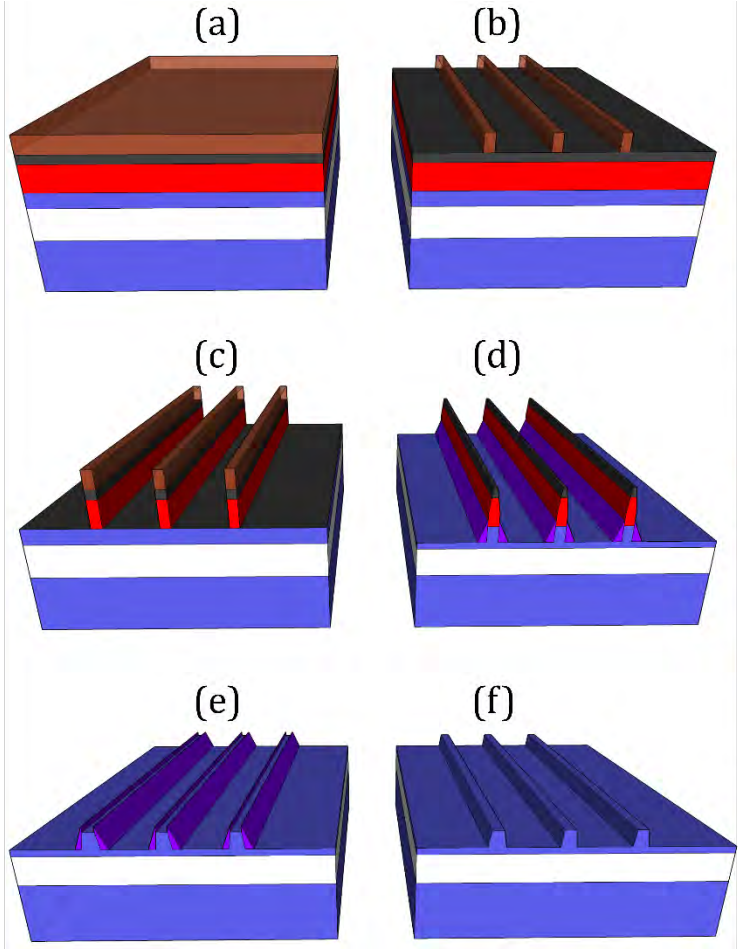
100 x

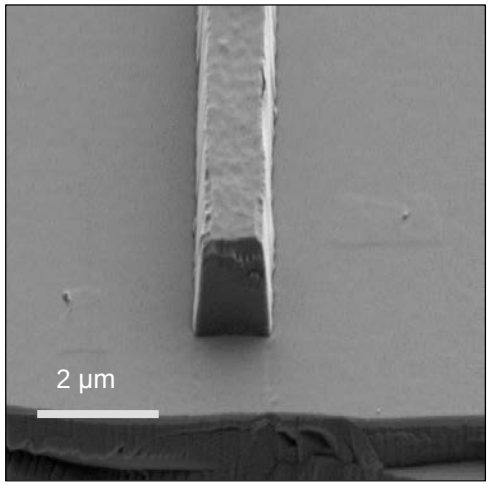


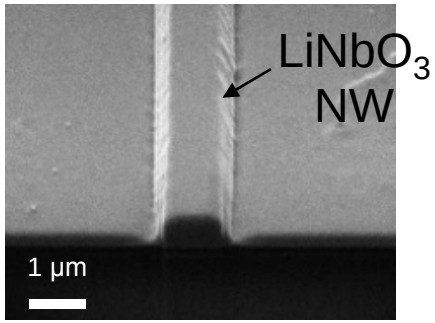
A. Sergeyev et al, Opt. Exp. **21**, 19012, 2013.

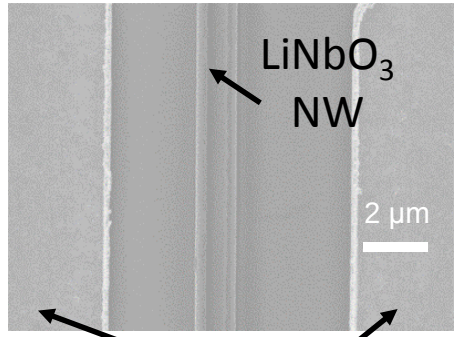
Fabrication of $LiNbO_3$ nanowaveguides

Process flow: Plasma etching (BRNC & First clean rooms)

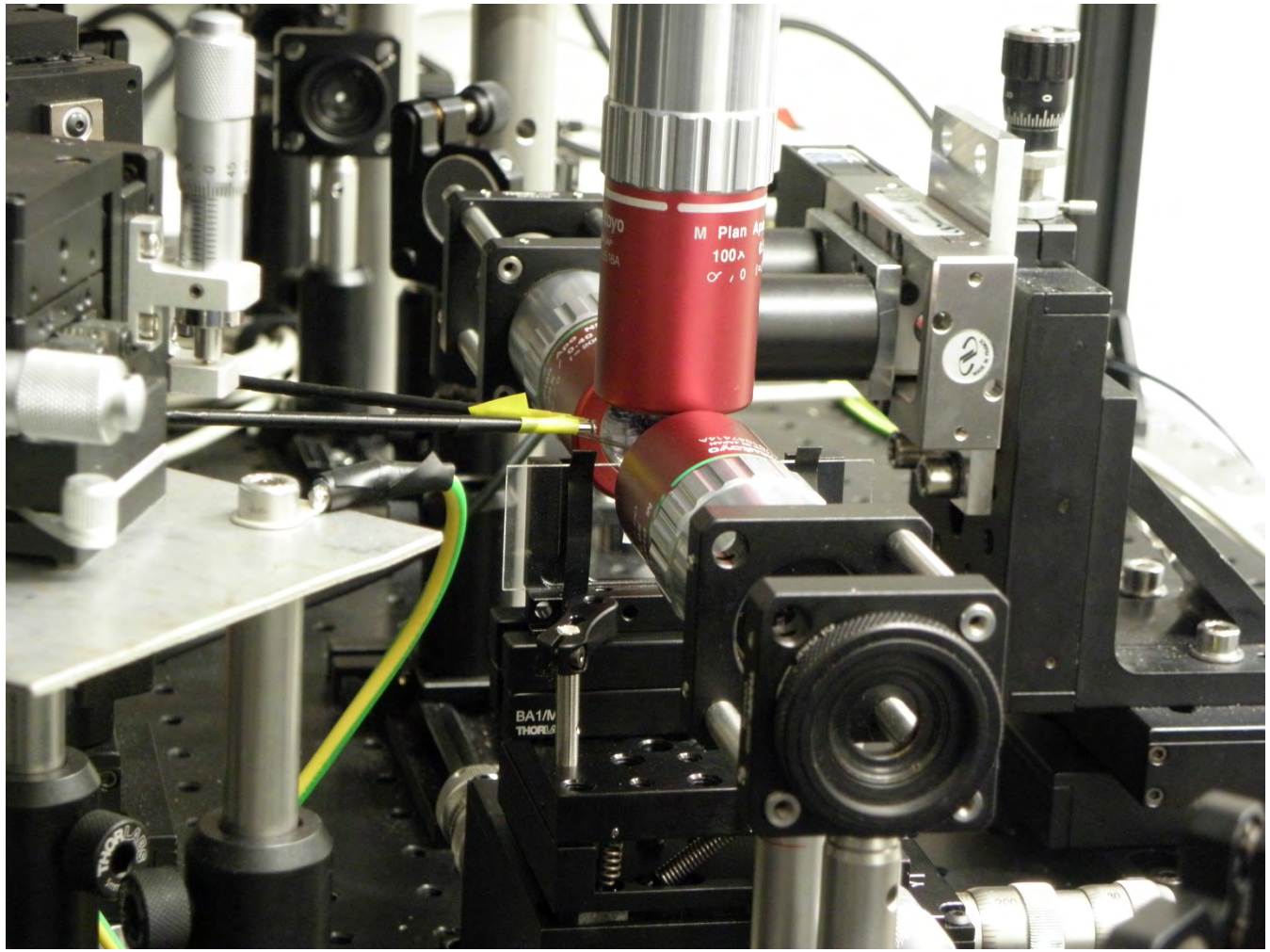








Extreme electro-optic tuning



M. Reig Escalé et al., *submitted December 15 2017*

Decision-making processes

When	Where	Position	Turning points	Failures
2002-2006	ETH Zurich	**PhD student**	• Topic not applied enough • My creativity was limited • Stuck in CH (career of my husband)	• No external mentor • industry, diplomacy, patent attorney
2006-2007	Swiss Government	**Scientific Advisor**	• Missing to be actor of research • Stuck in CH • Who is THE optics prof at EPFL	• Colleagues saying it will be impossible to go back to research
2007-2010	EPF Lausanne	**Post-doc (+2 sons)**	• Time to be more independant • Family ready to go abroad • Meeting with APTT	• Netherlands (1) • UK(3) • Germany (4)
2011-2014	Friedrich Schiller Uni Jena, DE	**Junior Group Leader (+1 daughter)**	• End of the 4 years • Time to go back for my husband career	• My 1st PhD student quit • My husband hated his job (dual career!) • Research grant: Humboldt, ERC St... • Prof position in Jena, HES
2015-2019	ETH Zurich	**Assist prof (non tenure track)**	• Grants: SNF, ERC Start, SSO • Collaborations • 4 PhD students, 4 post docs	• No permanent position • Workplace far from my family • Publish in Nature something

Action

Relationships matter(even in sciences or research)

Look for people who are generous :

Meaning they want that something good happen to you.

1. **In caring/listening/loving (parents, friends, husband, day care for your kids)**
2. **In ideas, advice, time for feed back (teachers, professors, young and old professors, from your gender and not only, from your team at work)**

Avoid the other kind of people (toxic ones)

But do not expect them to act, just to advice you. YOU have to act / find the right position / write your projects / insist to get feed back from those people.