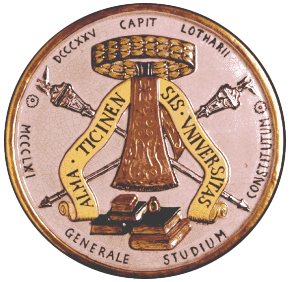
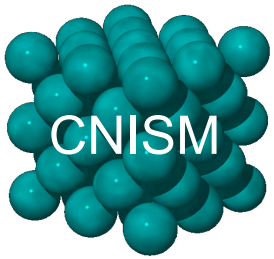




Teoria dei Solidi, Fotonica, Nanostrutture

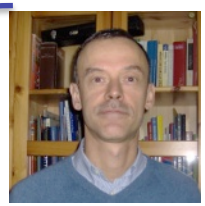
Dario Gerace

Dipartimento di Fisica, Università di Pavia
&
C.N.I.S.M. (Consorzio Nazionale Interuniversitario per le Scienze Fisiche della Materia)

Giornata di orientamento L.M. in Scienze Fisiche - 23 Maggio 2013

People involved

Photonics and Nanostructures group



Lucio C. Andreani

Dario Gerace

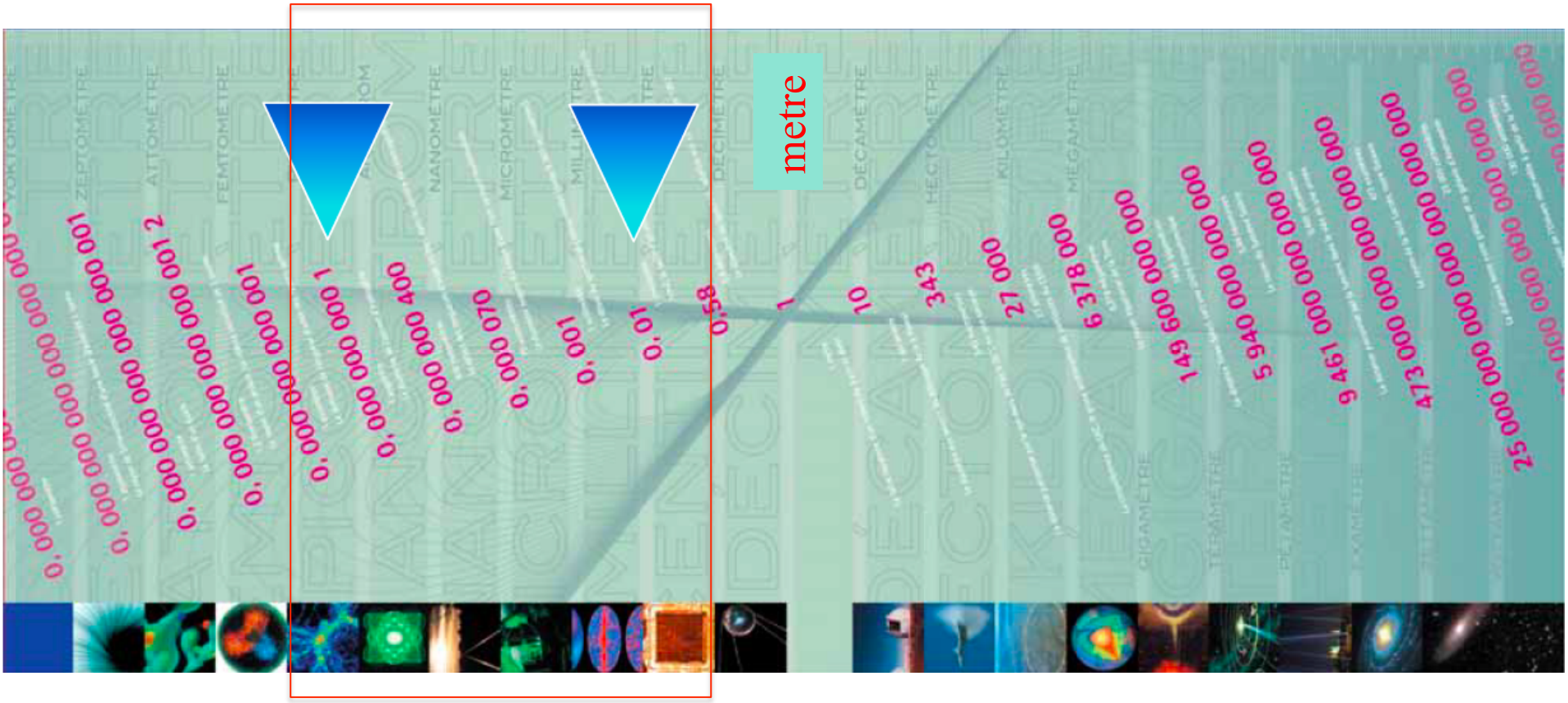
Marco Liscidini

Silvano Romano → statistical mechanics

- Post-Docs: L. Carroll, S. D'Agostino, S. Robertson
- PhD students: F. Alpeggiani, A. Bozzola, M. Bravi, S. Ferretti, S.W. Flores, P. Kowalczewski
- Several international collaborations (Canada, US, Brazil, France, Switzerland, UK …)

Condensed Matter Physics

Interested scales and ranges:

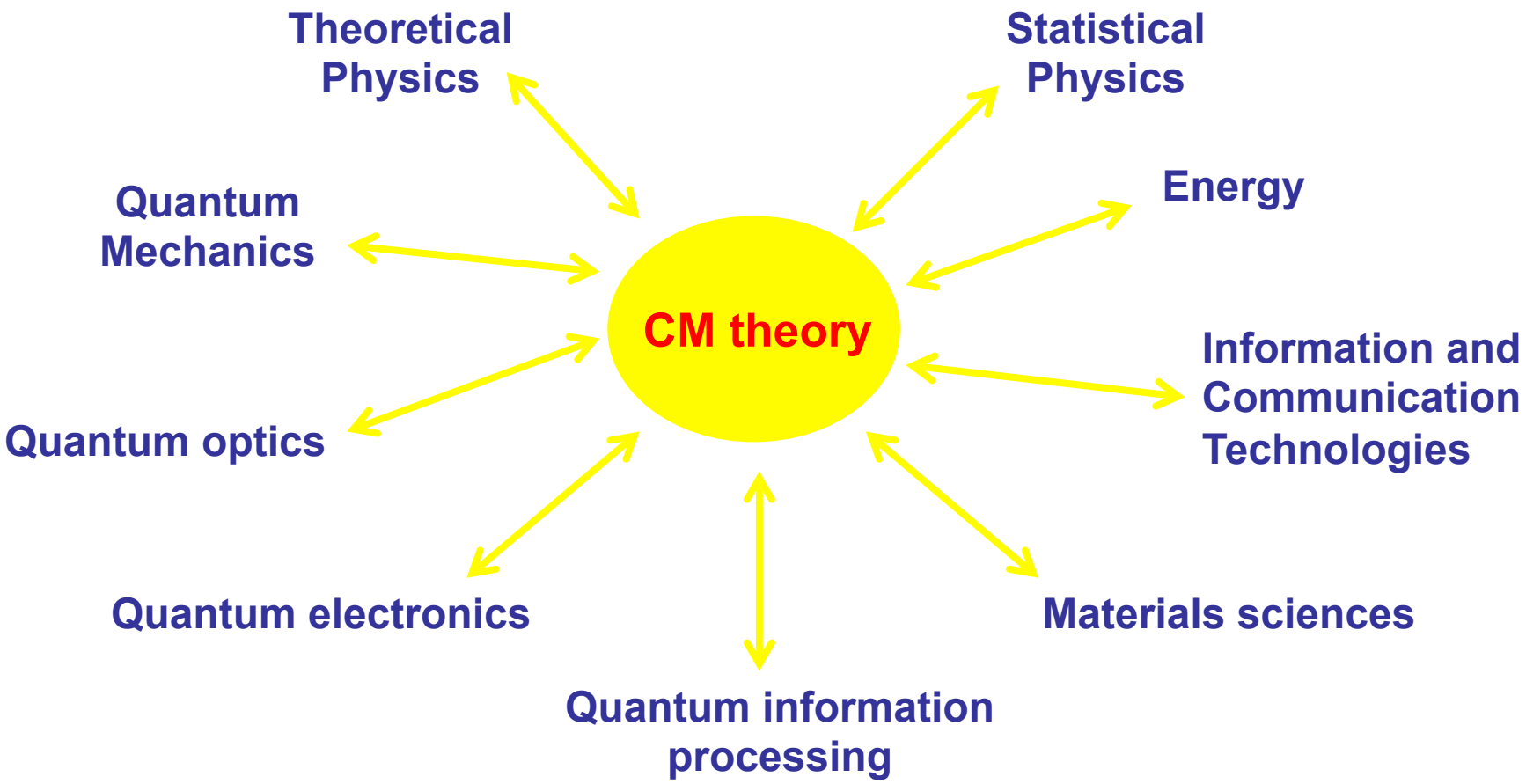


Energy scales → μeV - KeV

realm of electromagnetic interactions

Research in Condensed Matter Theory

APPLIED RESEARCH ⟷ **FUNDAMENTAL RESEARCH**



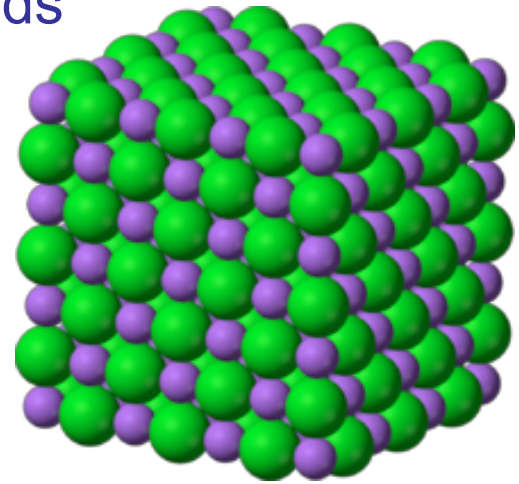
Active research lines

- Photonic Crystals: physics and applications
- Radiation-matter interaction in nanostructures
- Photovoltaics
- Nonlinear and quantum photonics
- Plasmonics and superconductors
- Statistical Mechanics of spins on lattices
- Strongly correlated systems & analog models

➢ Photonic Crystals: physics and applications

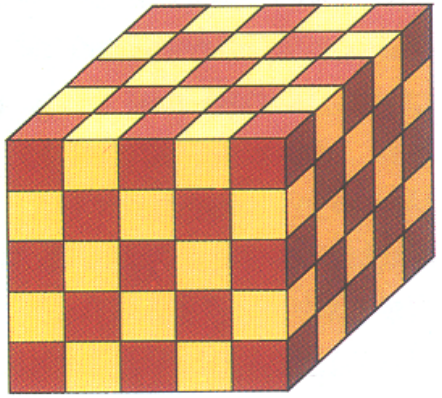
Photonic crystals

electrons in crystalline solids



Schrödinger equation

photons in periodic dielectric media

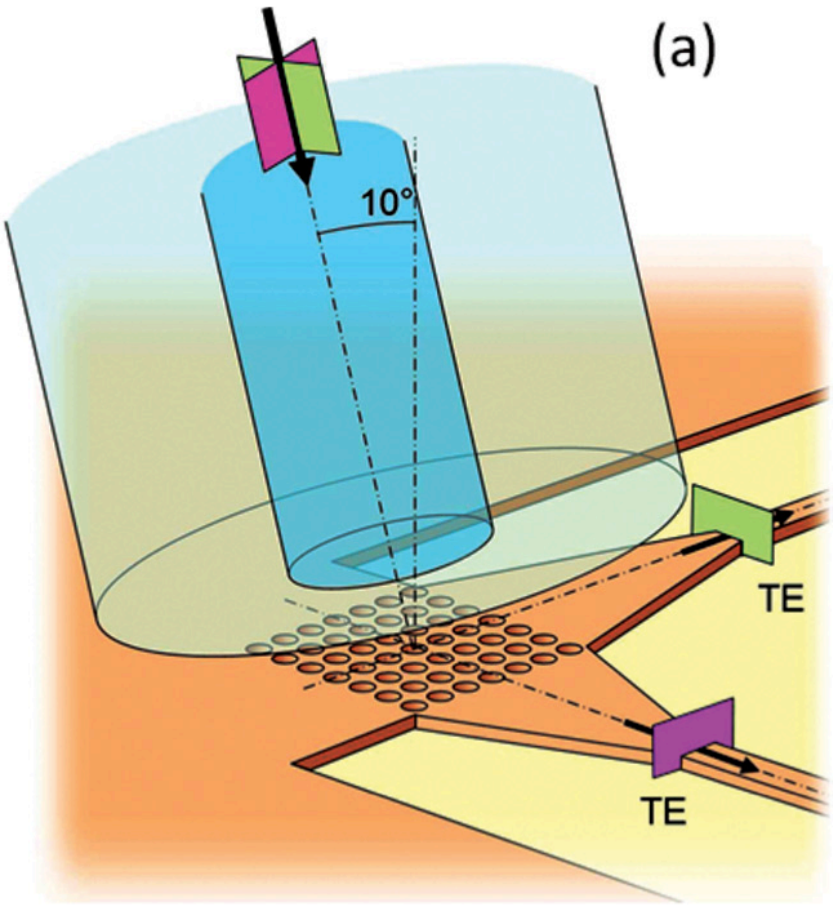


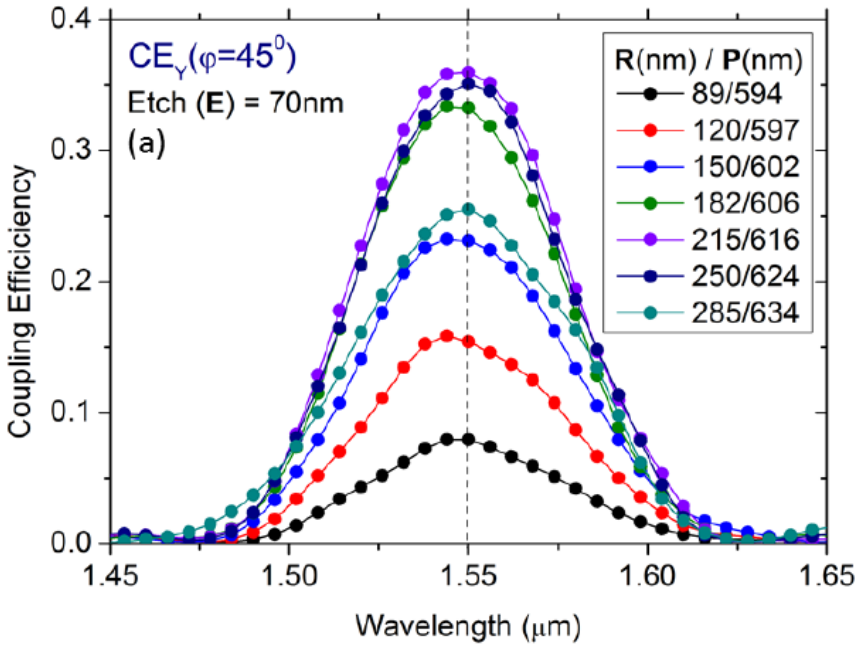
2nd-order Maxwell eqs. for harmonic fields

$$H\Psi = (-\frac{\hbar^2}{2m}\nabla^2 + U(\mathbf{r}))\Psi = E\Psi \quad \longleftrightarrow \quad \nabla \times \left(\frac{1}{\epsilon(\mathbf{r})}\nabla \times \mathbf{H}(\mathbf{r})\right) = \frac{\omega^2}{c^2}\mathbf{H}(\mathbf{r})$$

“Photonic bands” and energy gaps, as in solids!

Photonics for telecom applications (Andreani-Gerace)



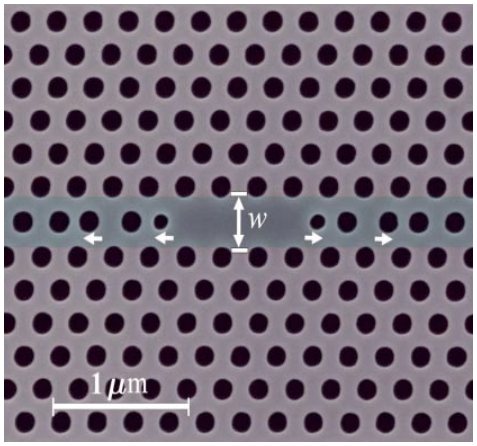


FABULOUS -FDMA Access By Using Low-cost Optical network Units in Silicon photonics , FP7-ICT-2011-8

Photonic crystal cavities (Andreani-Gerace)

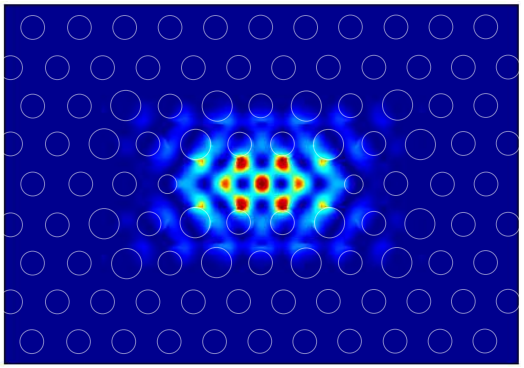
- Point-defects in PhC: high-Q, small-V nanocavities

- Control of light confinement at the nanoscale



SEM of a
fabricated device

→



$|E|^2 \sim 1/V$

$Q \sim 10^6$ → $\tau \sim 1$ ns

$V \sim (\lambda/n)^3$

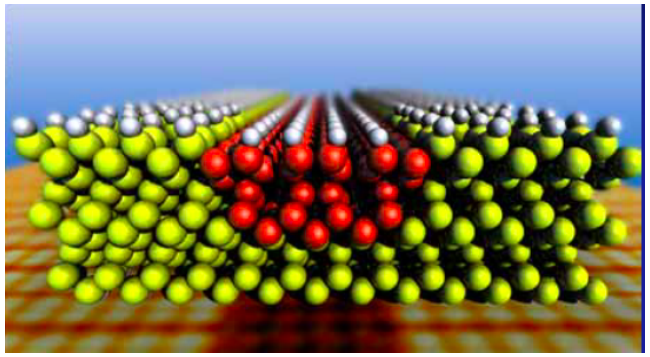
diffraction limited!

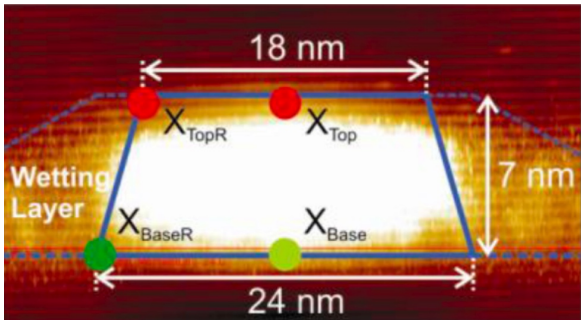
- Several applied and fundamental works in collaboration with experimental photonics group (see Marabelli)

➢ Radiation-matter interaction in nanostructures

Semiconductor Nanostructures

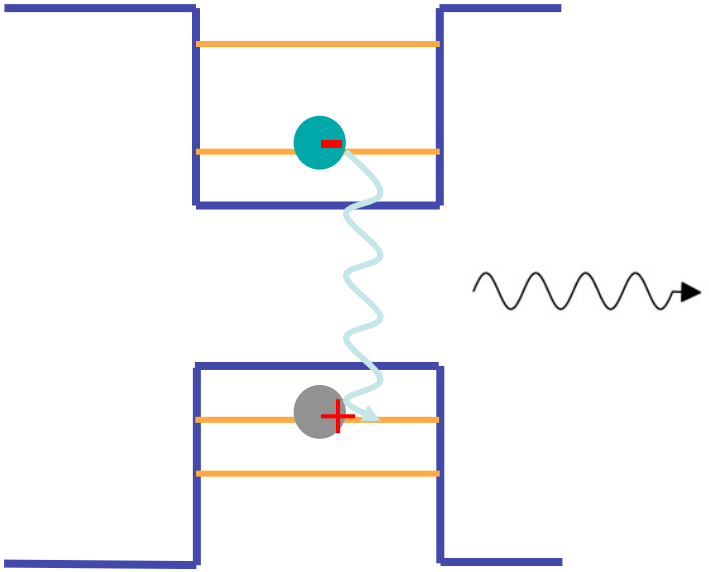
Bottom-up assembly of different semiconductors





TEM image of a quantum dot

Quantum confined electron-hole pairs in nanostructures

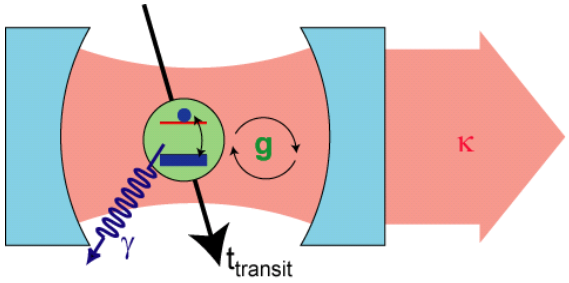


Artificial atoms

Cavity Quantum Electro-Dynamics (Gerace)

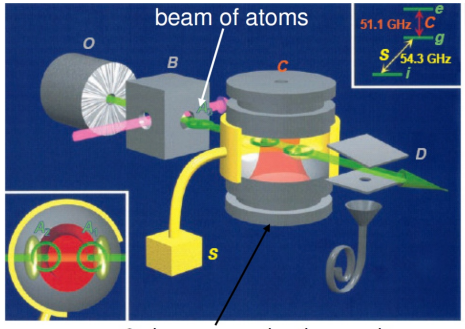
- Single (or a few) atom coupled to a high-Q/small-V resonator

model

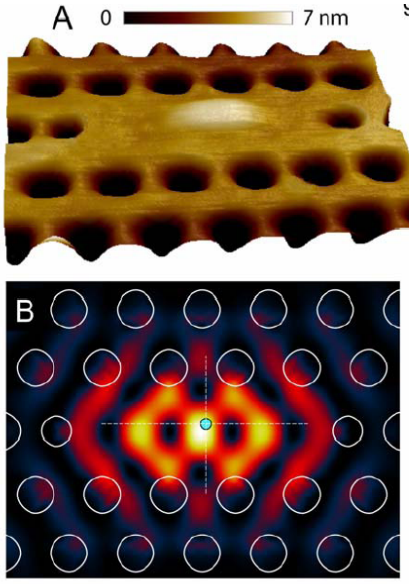


Traditionally used in atomic CQED

→ 2012 Nobel Prize for Physics!

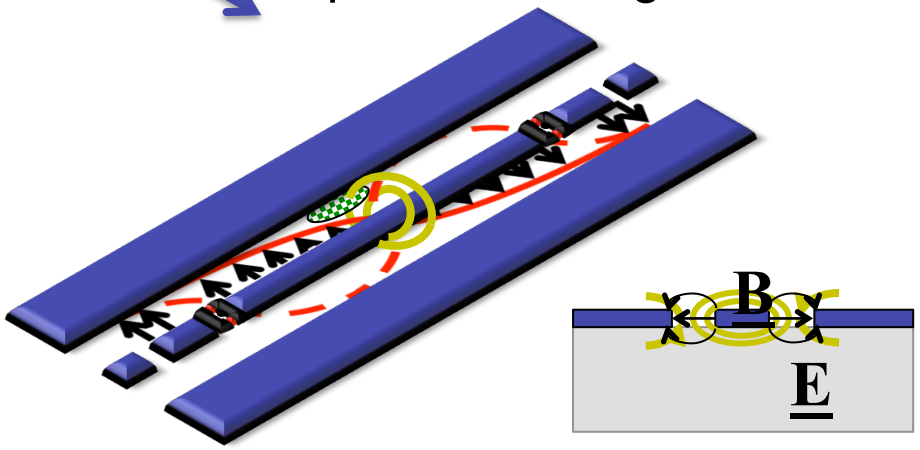


- Today applied to diverse nanostructured systems



QD in PhC cavity

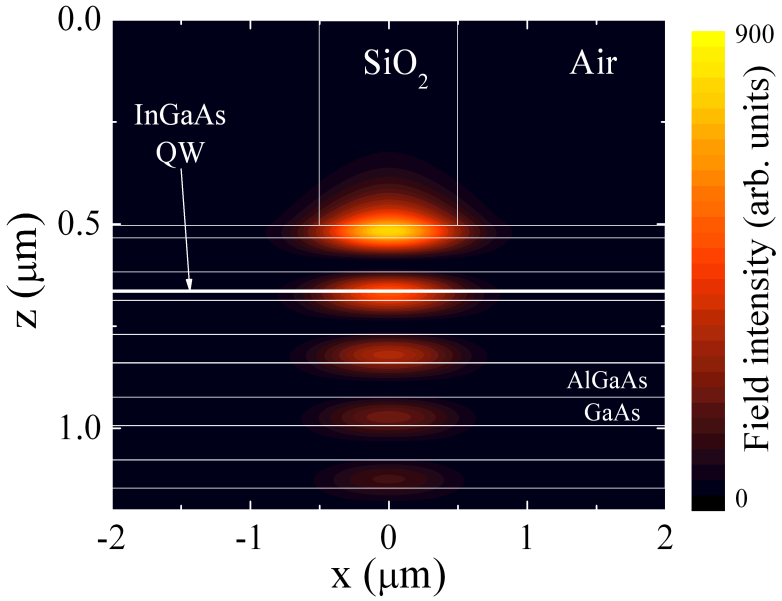
Spin ensemble in superconducting resonator

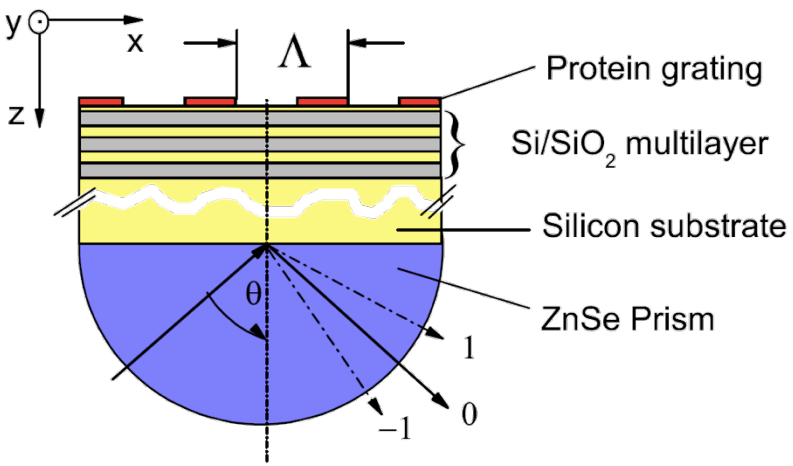


MIUR - FIRB "giovani" project with NMR group

Bloch surface waves (Liscidini)

- Theoretical study of optical surface waves in periodic media.
- Connection with fundamental research in light-matter interaction (polaritons) and optical sensing (Raman, fluorescence).





➢ Photovoltaics

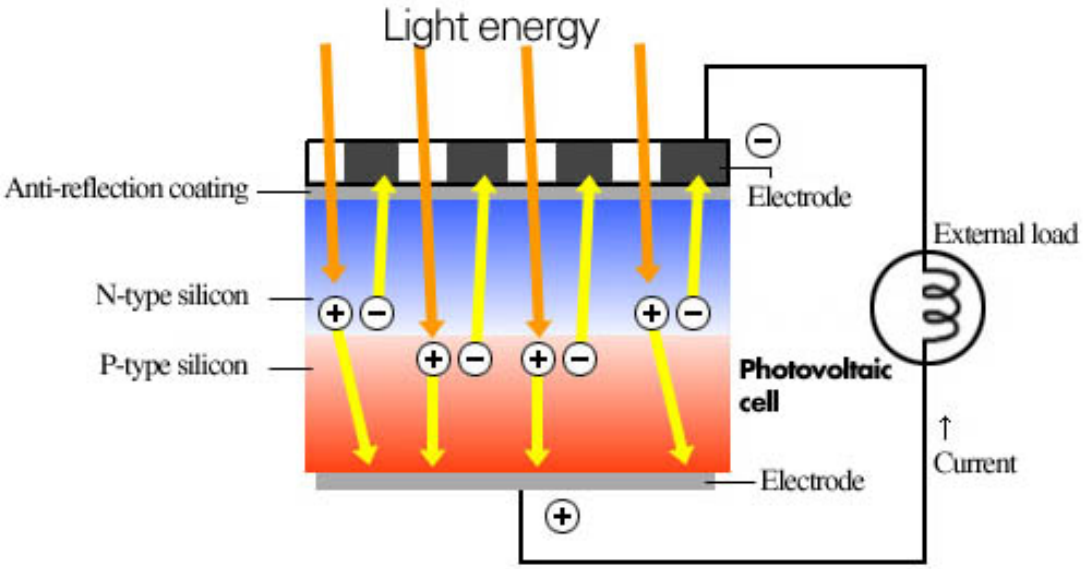
Photovoltaics: general

Photovoltaic conversion in solar cells = **optical problem** (light trapping) + **electronic problem** (carrier collection)

⇒ ideal playground for photonics + semiconductors

⇒ with both fundamental aspects (efficiency limits) and applied ones

⇒ ***cultural*** opportunities, as well as ***funding*** and ***career*** ones



Photovoltaics research (Andreani-Liscidini)

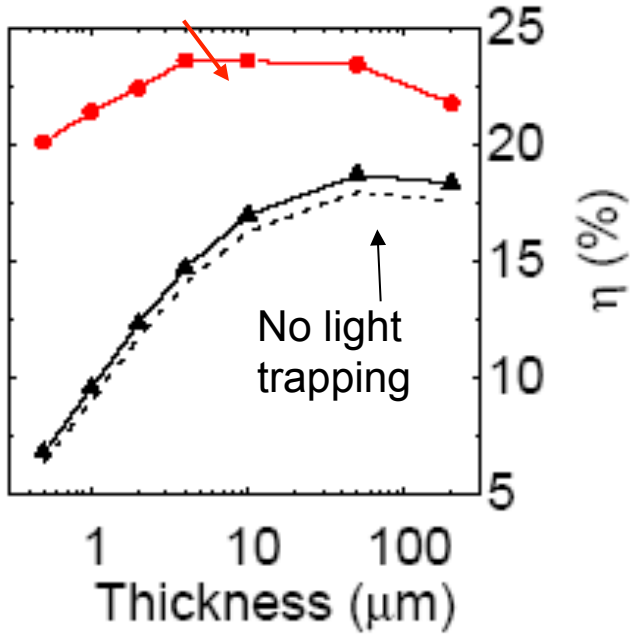
- EU FP7 Marie Curie ITN Network PROPHET – "Postgraduate Research in Photonics as an Enabling Technology"
- Fondazione Cariplo "Nanophotonics for thin-film photovoltaics"
- ENI S.p.A. research contract "Photonics for photovoltaics systems based on fluorescent concentrators"

Focus of research: towards thin-film solar cells with high conversion efficiency – crucial for large-scale photovoltaic energy production in the long term.

Highlight: thin-film silicon solar cells can be more performing than bulk ones provided optimal (Lambertian) light trapping is applied (Bozzola et al., 2013, unpublished)

→ ***Nanophotonics meets Photovoltaics***

Light trapping → optimal thickness < 10 μm



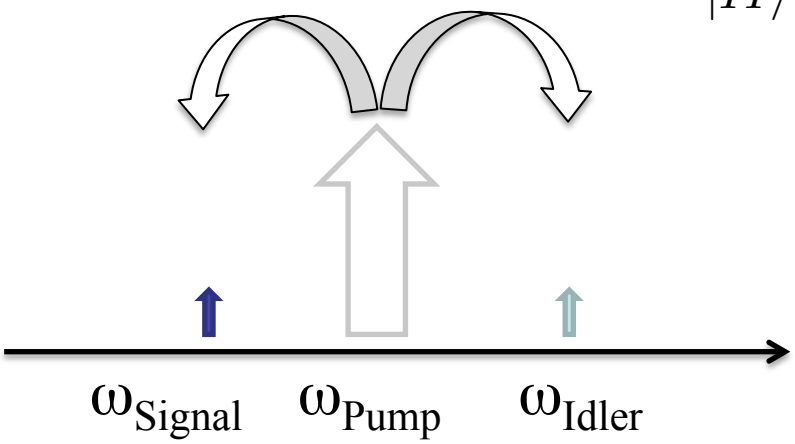
➢ Nonlinear and quantum photonics

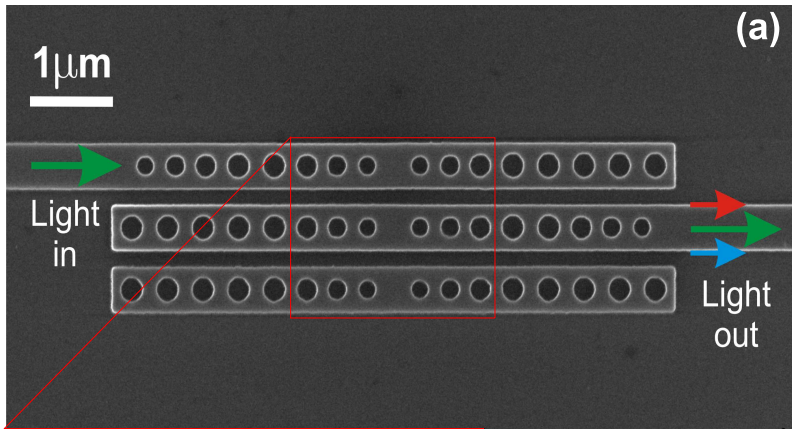
Generation of entangled-photon pairs (Liscidini)

- Theoretical study and design of possible sources of quantum correlated photon pairs in nonlinear devices

- Connections to Quantum Mechanics, Quantum Computation and Quantum Information.

$$|II\rangle = \frac{1}{\sqrt{2}} \sum_{\nu,\eta} \int d\mathbf{k_1} d\mathbf{k_2} \phi_{\nu\eta}(\mathbf{k_1}, \mathbf{k_2}) b^{\dagger}_{\nu \mathbf{k_1}} b^{\dagger}_{\eta \mathbf{k_2}} |vac\rangle$$

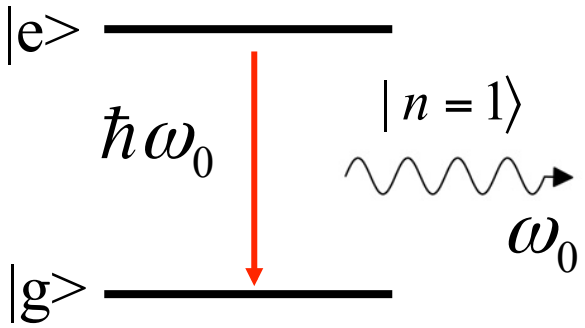




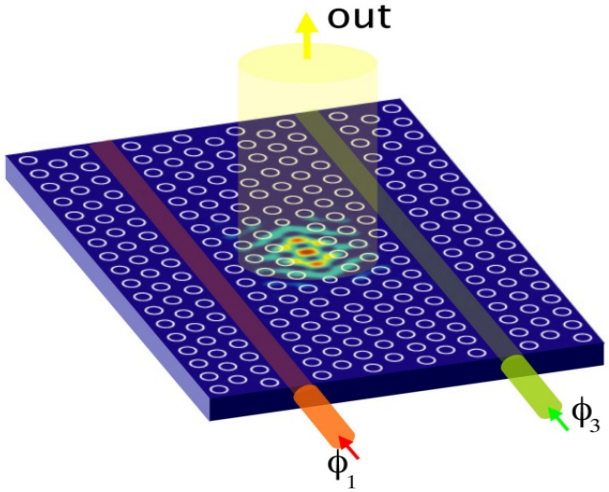
MIUR - FIRB “giovani” project (Bajoni - Liscidini)

Single-photon sources (Gerace)

- An ideal single-photon source →
- Why? → crucial for applications in integrated quantum photonics



- Our contributions: proposal for single-photon sources from passive nonlinear materials



- Ultimately: single-photon devices (transitors, diodes…)

Fundamental physics today…applications tomorrow ?

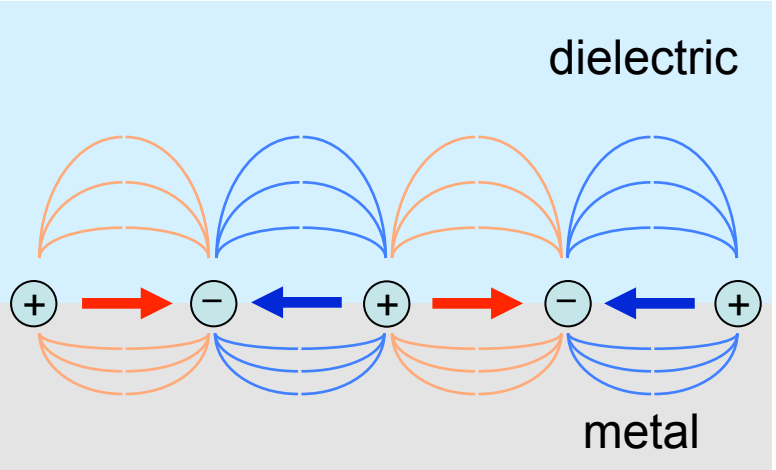
➢ Plasmonics and superconductors

Plasmonics

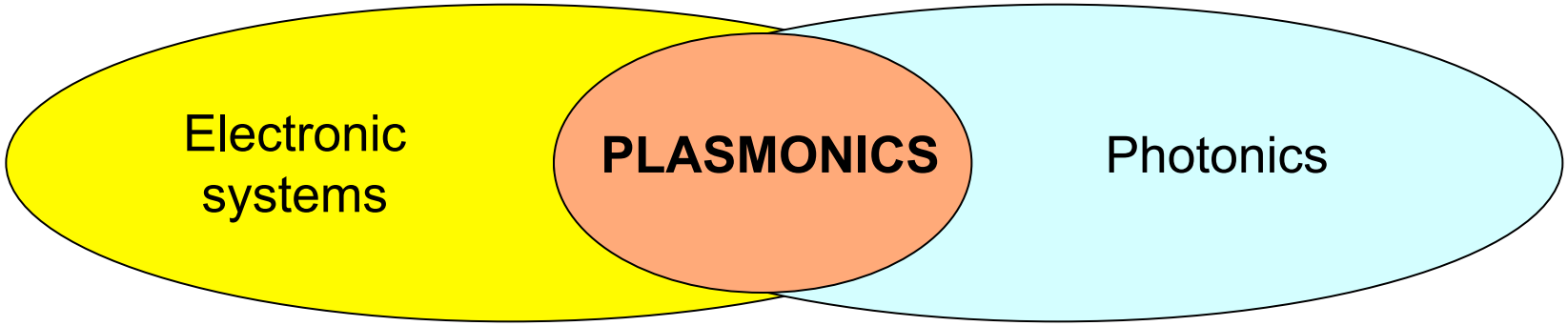
PLASMONS are collective excitations of free electrons in a metal

They can LOCALIZE → surface plasmons

They can COUPLE TO RADIATION → surface plasmon polaritons



Vibrant field of research, with many fundamental aspects (control of radiative processes, sub-wavelength optics…) and applied ones (biosensors…)

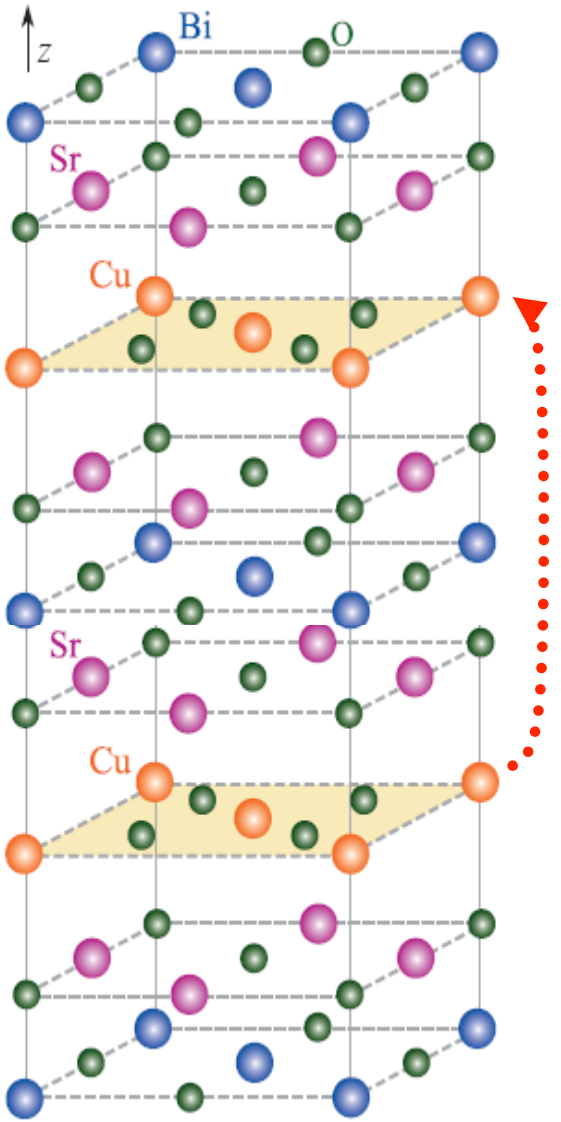


Plasmonics research (Andreani)

- Control of radiation-matter interaction, dipole-emission rates
- Surface-enhanced processes because of electric-field localization → Biosensors
- High-Tc superconductors: low-frequency plasma waves due to Josephson tunnelling along c-axis → **Terahertz plasmons**

→ Connection with Terahertz photonics

→ Possible link with mechanism of high-Tc superconductivity

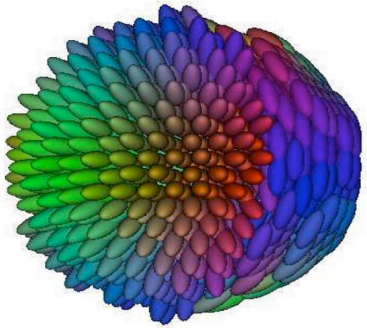


$Bi_2Sr_2CuO_{6+x}$

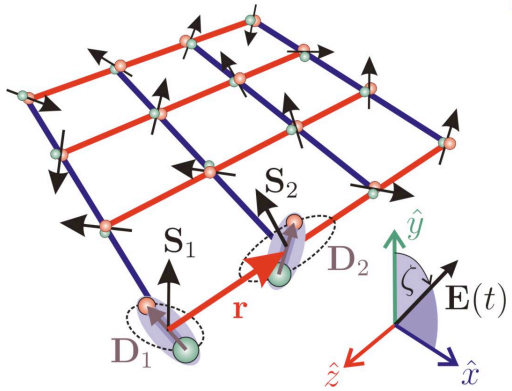
➢ Statistical Mechanics of spins on lattices

Statistical Mechanics (S. Romano)

- Computational research on liquid phases of matter



- Statistical mechanics of Spin lattices

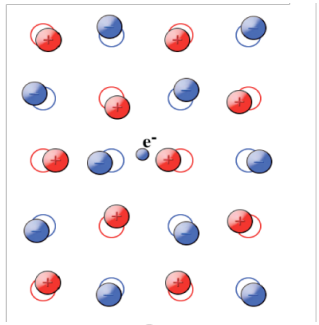


- Study of thermodynamic and structural properties of systems of interacting many particles

RELATED COURSES (L.M. Chimica):
Statistical Thermodynamics
Theoretical and Computational Chemistry

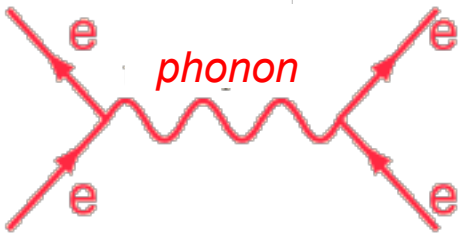
➢ Strongly correlated systems & analog models

Strongly correlated systems (Gerace-Andreani)



- The physics of interacting quasi-particles (electrons, polaritons, phonons, plasmons, magnons, …)

- Manybody theory…techniques from QFT



Analog models (Gerace)

- Studying systems with formal analogies with known models in theoretical physics

  e.g.: relativistic electrons in graphene, strongly correlated photonic lattices, analog Hawking radiation in superfluids,…

- Aim: creating a bridge between theoretical physics and CM physics of elementary excitations

Visit our website
(jointly with experimental photonics group)

http://fisica.unipv.it/nanophotonics