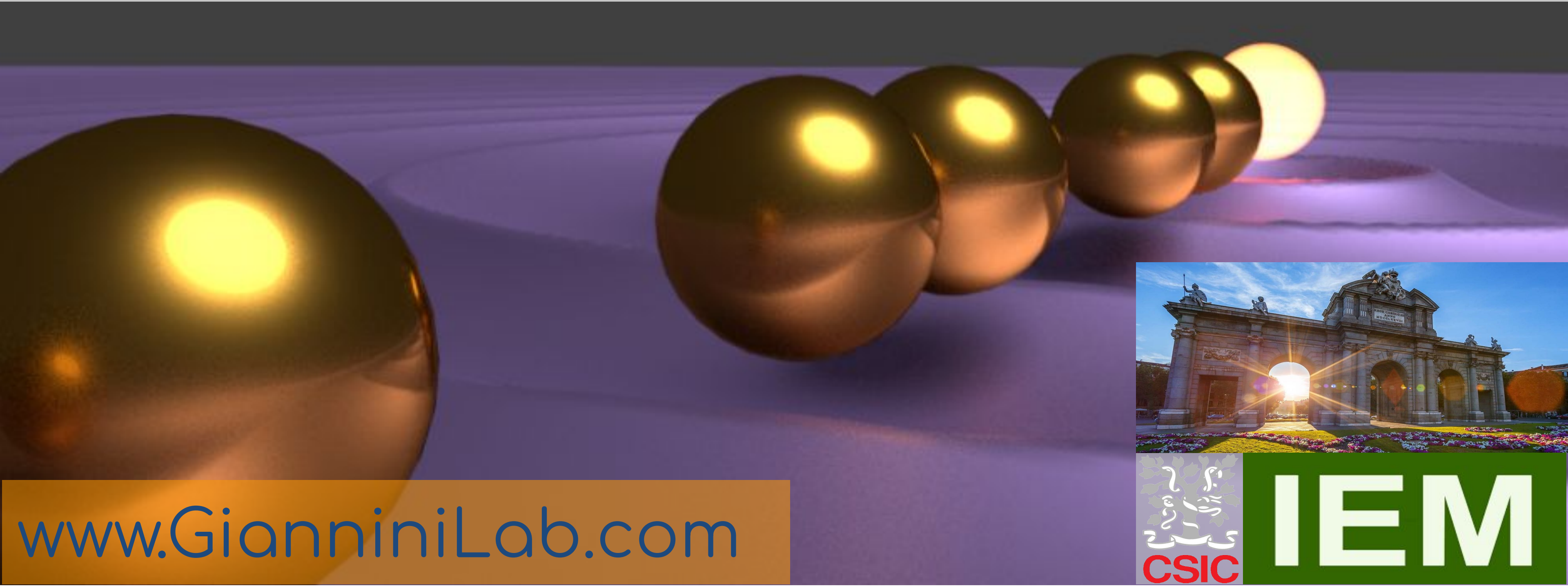
Topological quantum dots:

a novel platform for THz lasing and quantum optics

Vincenzo Giannini



www.GianniniLab.com

CSIC IEM

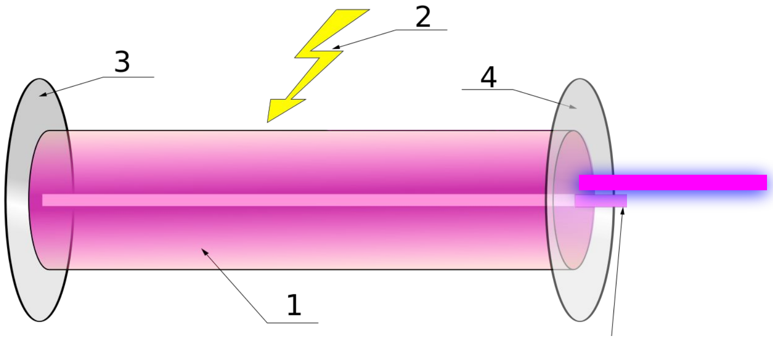
Acknowledgments

Marie Rider

Derek Lee

Peter Haynes

Incipit: The Laser



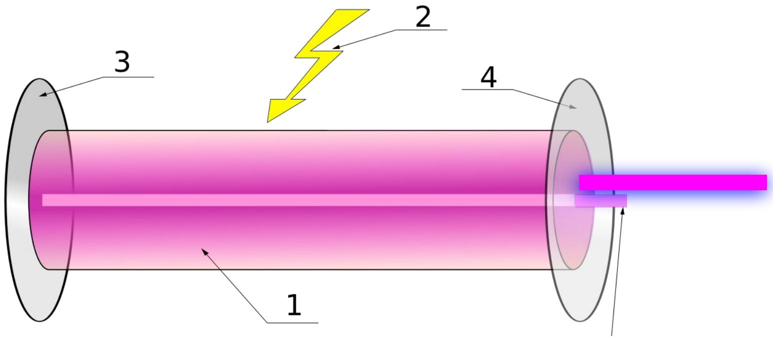
Components of a typical laser:

1. Gain medium
2. Laser pumping energy
3. High reflector

Pump:

1. Flashlamp
2. Another Laser
3. Electric Current
4. Chemical Reaction
5. ...

Incipit: The Laser



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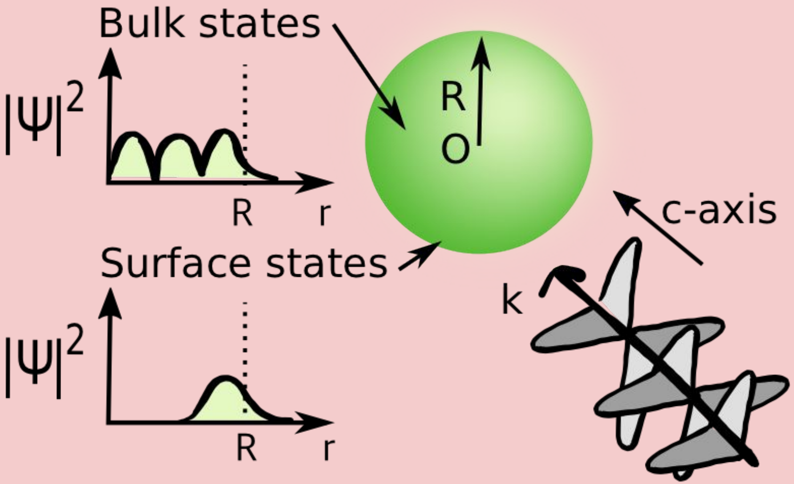
5. ...

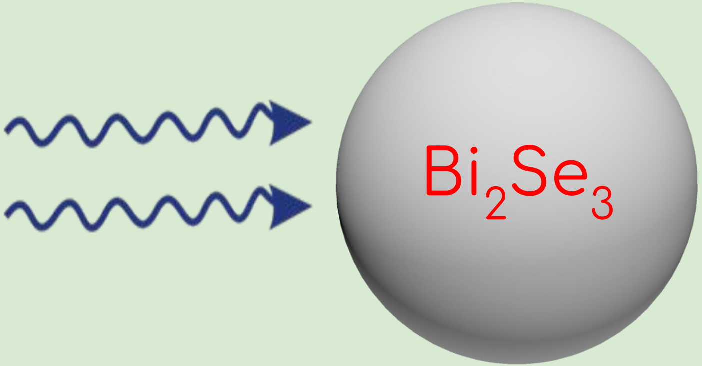
Thermal pumping → **Entropy Paradox**

OUTLINES

Topological Quantum Dots

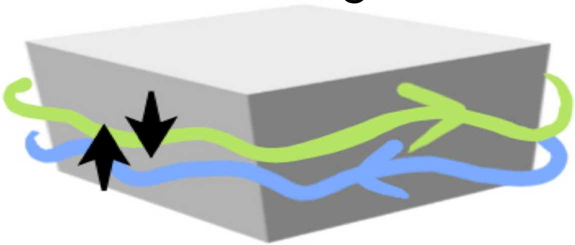


THz Lasing



Topological NanoPhotonics

Insulating bulk



Conducting edge states

Robustness of subwavelength modes against:

1. Unidirectional light propagation
2. No scattering from sharp bending
3. Robust to disordered and perturbation
4. Single nanoparticle THz lasing

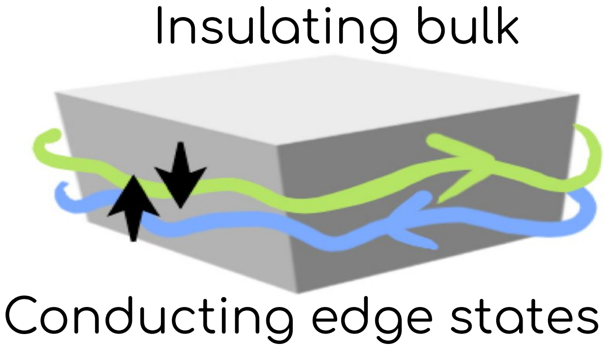
Journal of Applied Physics

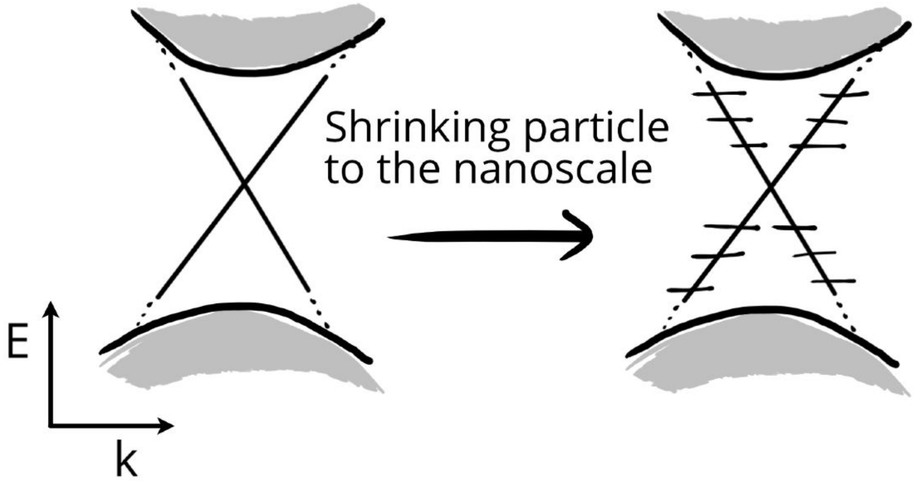
A perspective on topological nanophotonics: Current status and future challenges

Cite as: J. Appl. Phys. **125**, 120901 (2019); https://doi.org/10.1063/1.5086433
Submitted: 20 December 2018 . Accepted: 02 March 2019 . Published Online: 22 March 2019

Marie S. Rider, Samuel J. Palmer, Simon R. Pocock, Xiaofei Xiao, Paloma Arroyo Huidobro, and Vincenzo Giannini

Shrinking TI to the Nanoscale





nature COMMUNICATIONS

ARTICLE

Received 10 Feb 2016 | Accepted 27 Jun 2016 | Published 5 Aug 2016

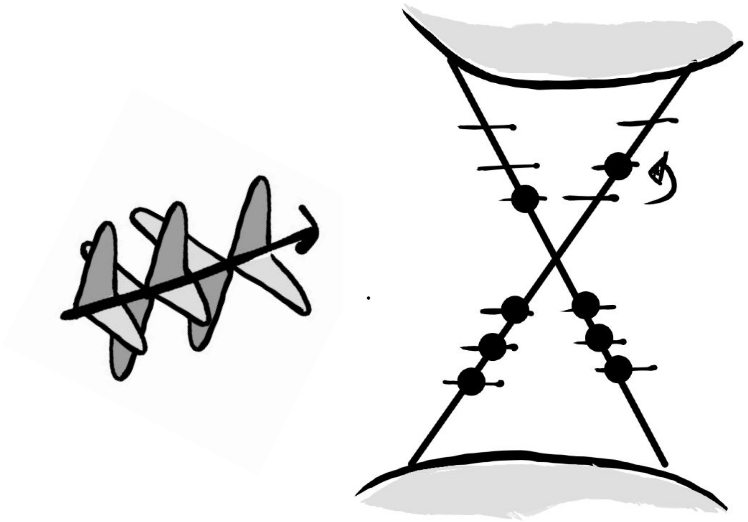
DOI: 10.1038/ncomms12375 OPEN

Single-electron induced surface plasmons on a topological nanoparticle

G. Siroki[1], D.K.K. Lee[1], P.D. Haynes[1,2] & V. Giannini[1]

TINPs as Quantum Dots

- Energy levels ~0.1-10 THz for 50-100 nm nanoparticles
- ∝1/R and defined by quantum numbers *s,n,m*



$$E_{snm} = \frac{sA}{R}\left(n + |m| + \frac{1}{2}\right)$$

$$s = \pm 1$$

$$n = 0, 1, \ldots$$

$$|m| = \frac{1}{2}, \frac{3}{2}, \ldots$$

Siroki et al., Nature Comms., 12375, (2016)

Topological-QDs Transitions

$$E_{snm} = \frac{sA}{R}\left(n + |m| + \frac{1}{2}\right)$$

$$s = \pm 1$$
$$n = 0, 1, ...$$
$$|m| = \frac{1}{2}, \frac{3}{2}, \cdots$$

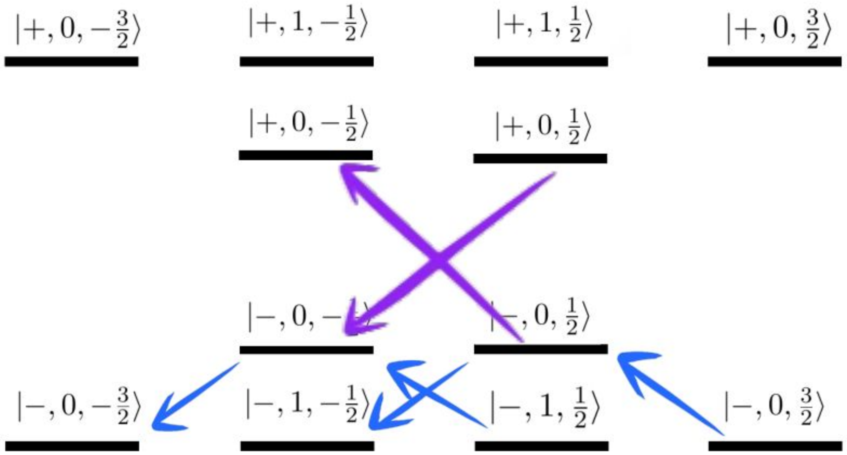
50 nm Bi2Se3 nanoparticle
LH-polarized

Type 1

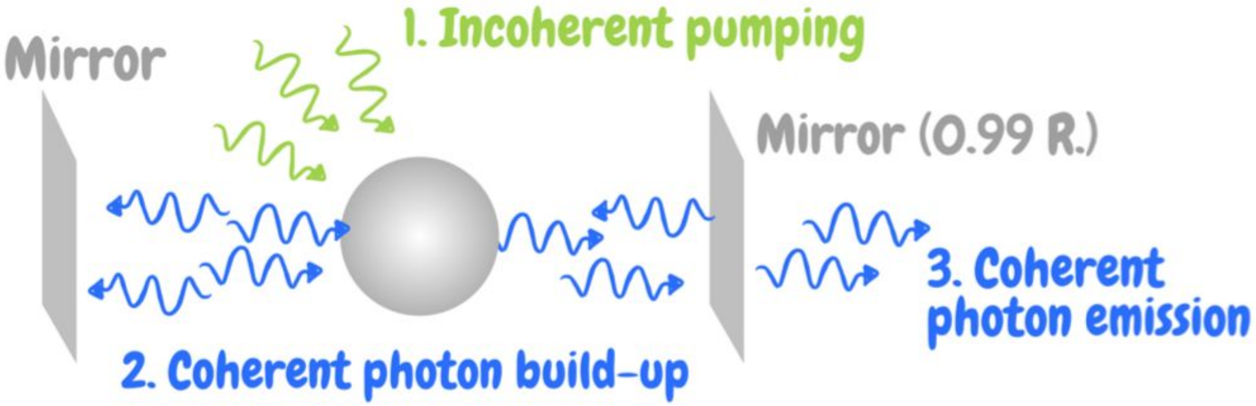
$$\Delta s = 0,\ \Delta(n + |m|) = \pm 1,\ \Delta m = -1$$

Type 2

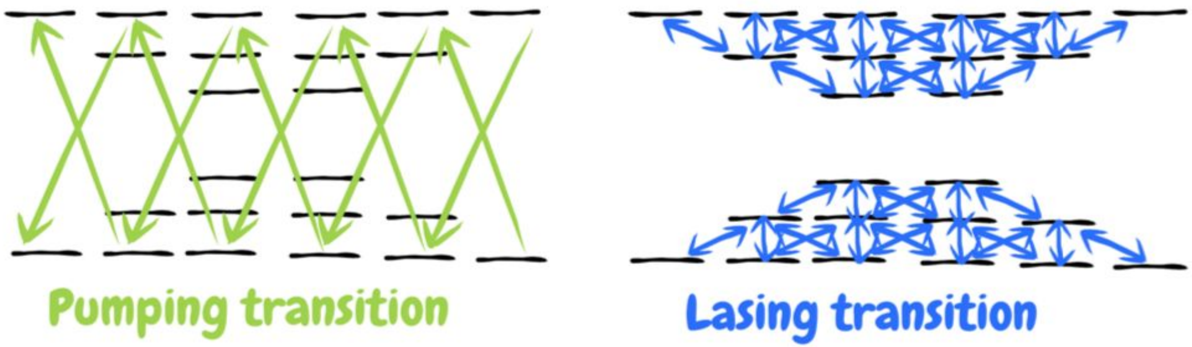
$$\Delta s \neq 0,\ \Delta(n + |m|) = 0,\ \Delta m = -1$$



Topological-QDs Lasing

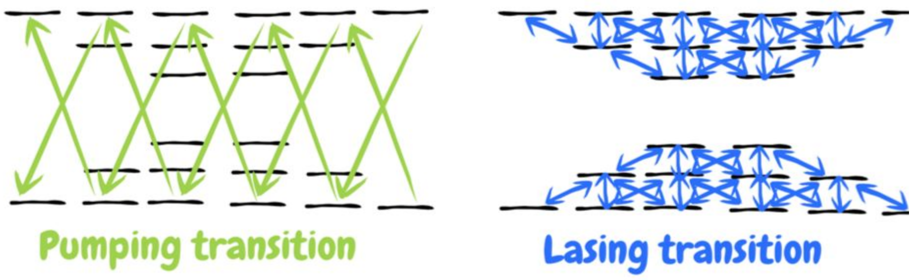


T=0 K

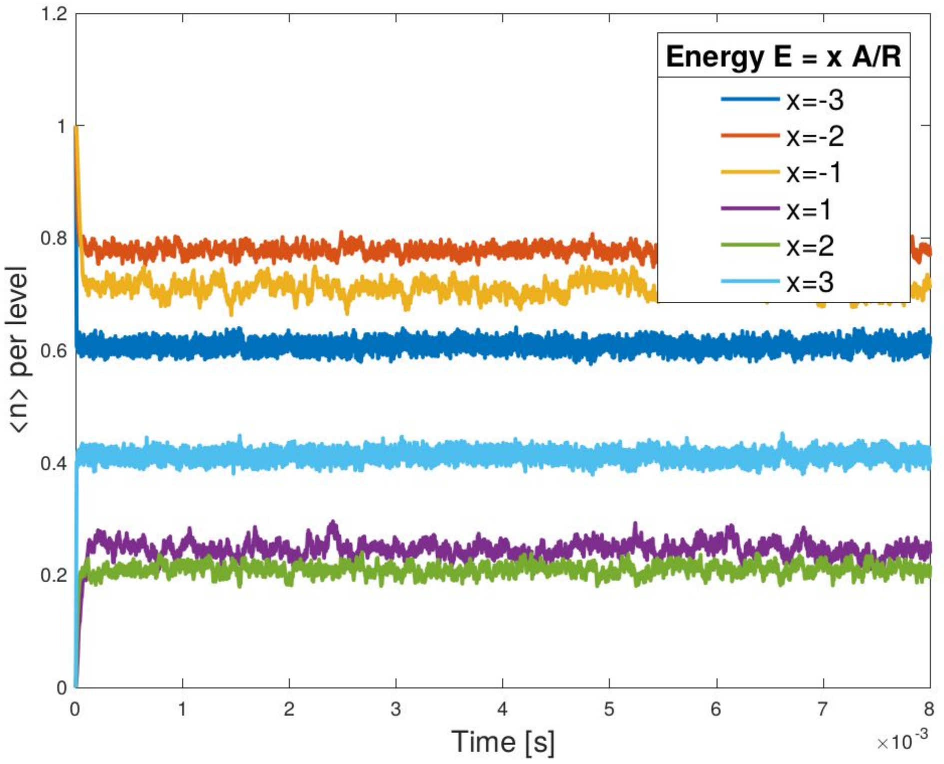


Monte Carlo Simulations

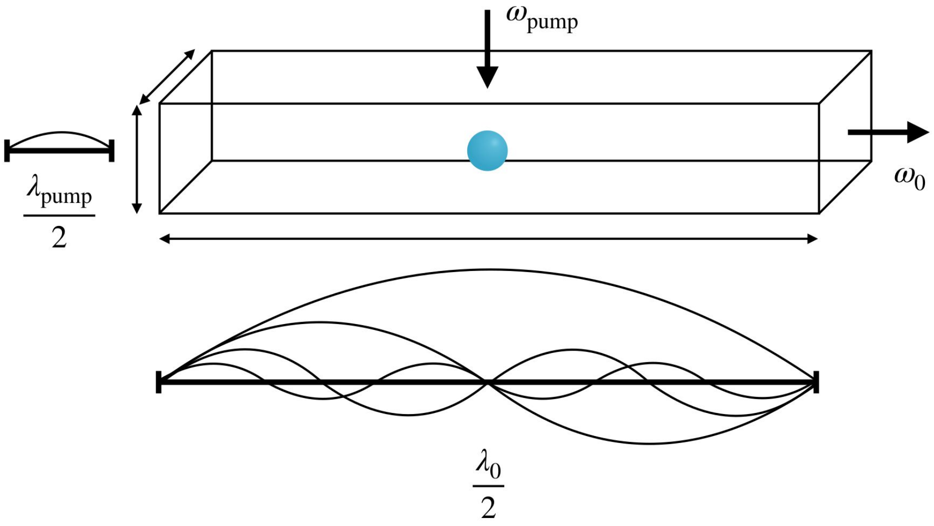
R = 50 nm, Laser frequency ~ 6 THz



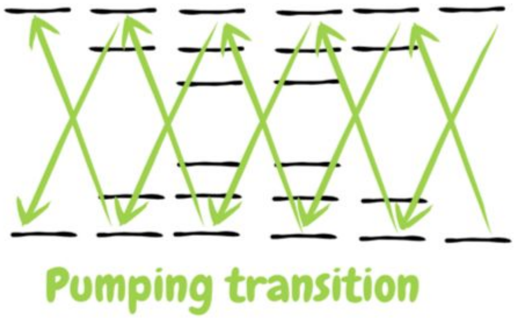
T=0 K, can we do better?

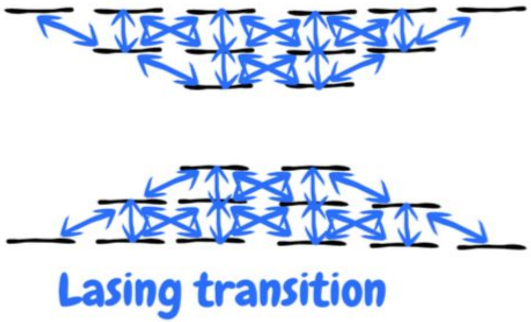


Thermal Pump



2ω problem!





Topological-QDs Lasing

Volume 85, Number 7 PHYSICAL REVIEW LETTERS 14 August 2000

Near-Field Spectral Effects due to Electromagnetic Surface Excitations

Andrei V. Shchegrov*
Rochester Theory Center for Optical Science and Engineering
and Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627-0171

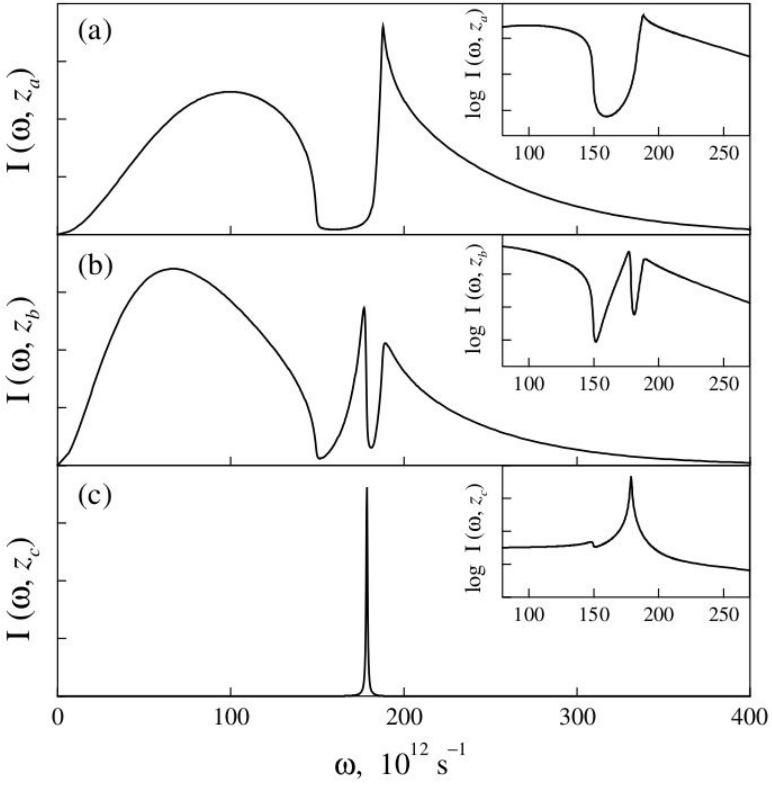
Karl Joulain, Rémi Carminati, and Jean-Jacques Greffet

PHYSICAL REVIEW B **76**, 165415 (2007)

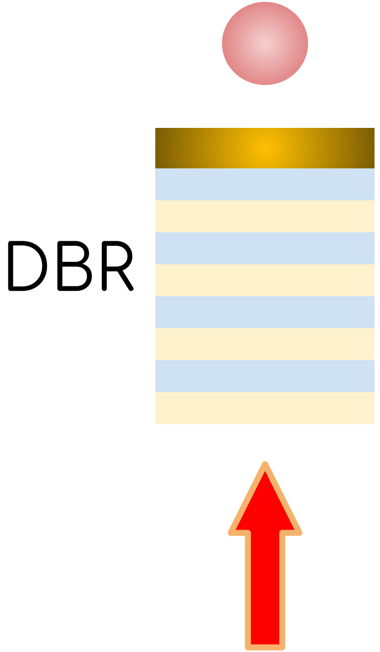
Tamm plasmon-polaritons: Possible electromagnetic states at the interface of a metal and a dielectric Bragg mirror

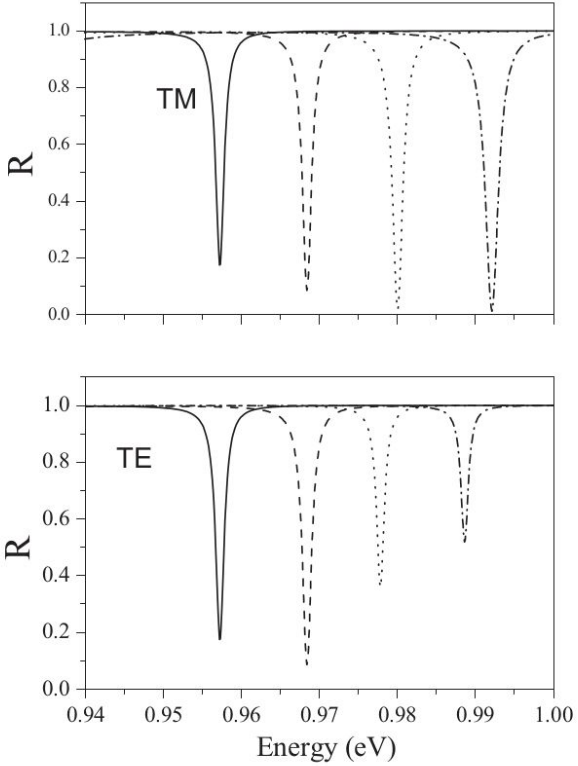
M. Kaliteevski,[1] I. Iorsh,[2] S. Brand,[1] R. A. Abram,[1] J. M. Chamberlain,[1] A. V. Kavokin,[3] and I. A. Shelykh[4,5]

Thermal Near-Field and Tamm Plasmons



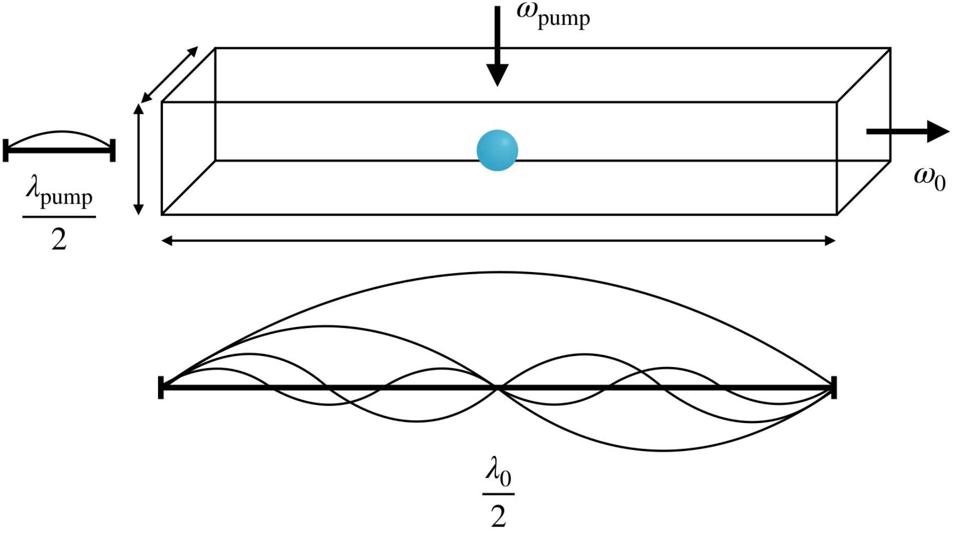
A.V. Shchegrov et al., PRL, 85, 7, 2000

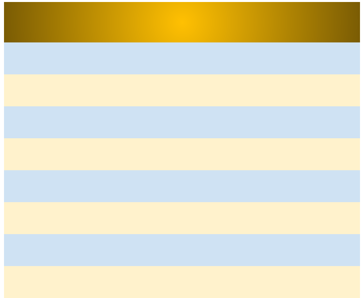


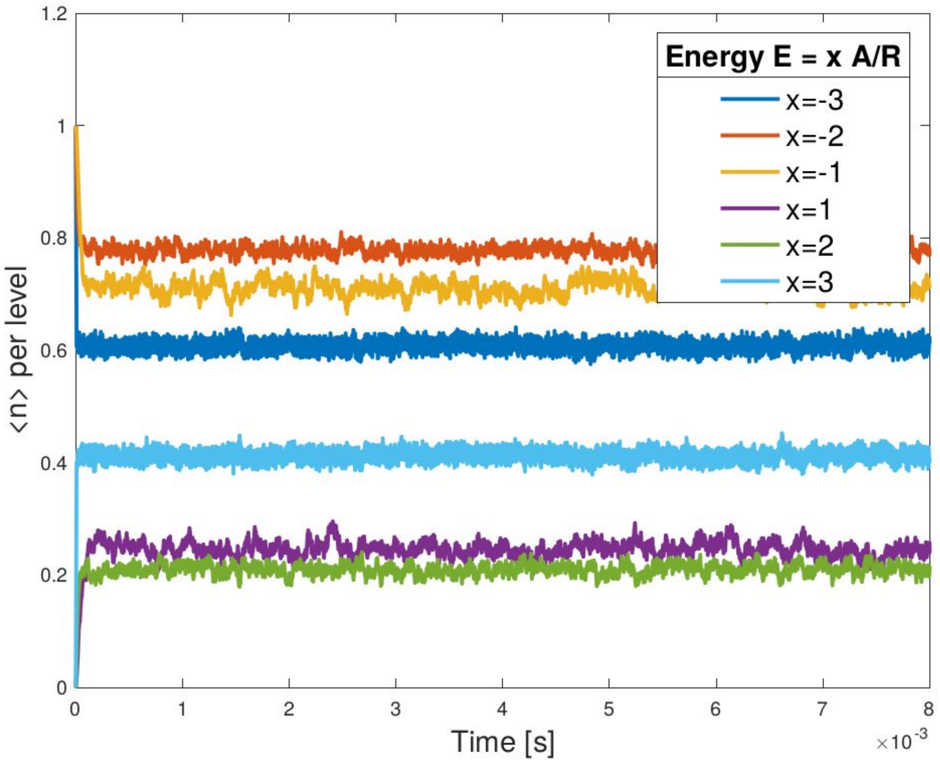


M. Kaliteevski et al. PRB, 76, 165415, 2007

Topological-QDs Lasing







Conclusions

- Energy Discretization of TINPs
- Lasing Scheme is Possible
- Thermally Induced Lasing

PLASMONICA 2020

International school on Plasmonics and Nano-Optics

Info: www.Plasmonica.it/2020school

Place:
Madrid, Serrano 121

Date:
22^{nd}- 25^{th} of June 2020

Organizers:
Pablo Albella
Antonio Fernández Domínguez
Vincenzo Giannini
José Antonio Sánchez Gil

Technical committee
Ambra Giannetti
Andrea Chiappini

Info:
school@plasmonica.it

Web-pages:
www.Plasmonica.it/2020school
www.GianniniLab.com/Plasmonica.html

www.GianniniLab.com

Topological Nanoparticles

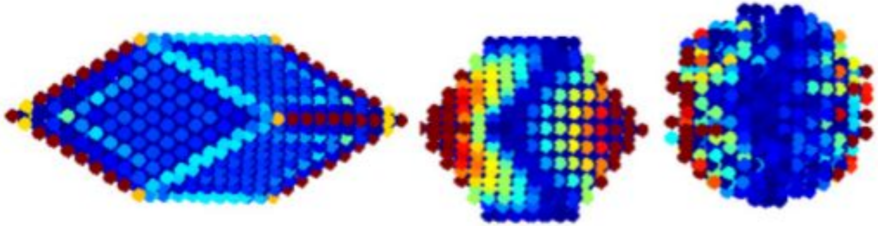
- Topological surfaces states are a bulk property!

Do we have enough bulk in a nanoparticle?

PHYSICAL REVIEW MATERIALS 1, 024201 (2017)

Protection of surface states in topological nanoparticles

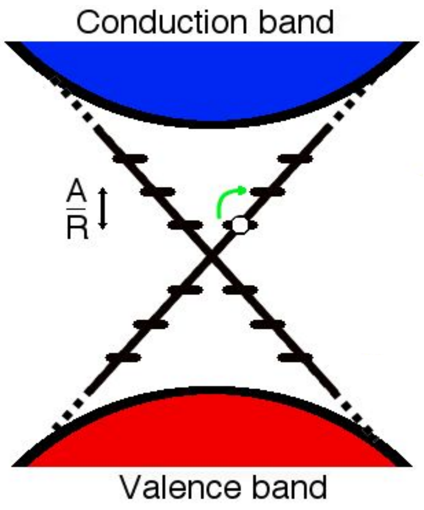
Gleb Siroki,[1,*] Peter D. Haynes,[1,2] Derek K. K. Lee,[1] and Vincenzo Giannini[1,3]



Topological Insulator Nanoparticle

Quantized Bands

A is a constant entering surface Dirac equation that determines the energy spacing of surface states



PHYSICAL REVIEW B **86**, 081303(R) (2012)

Surface states of topological insulators

Fan Zhang,* C. L. Kane, and E. J. Mele

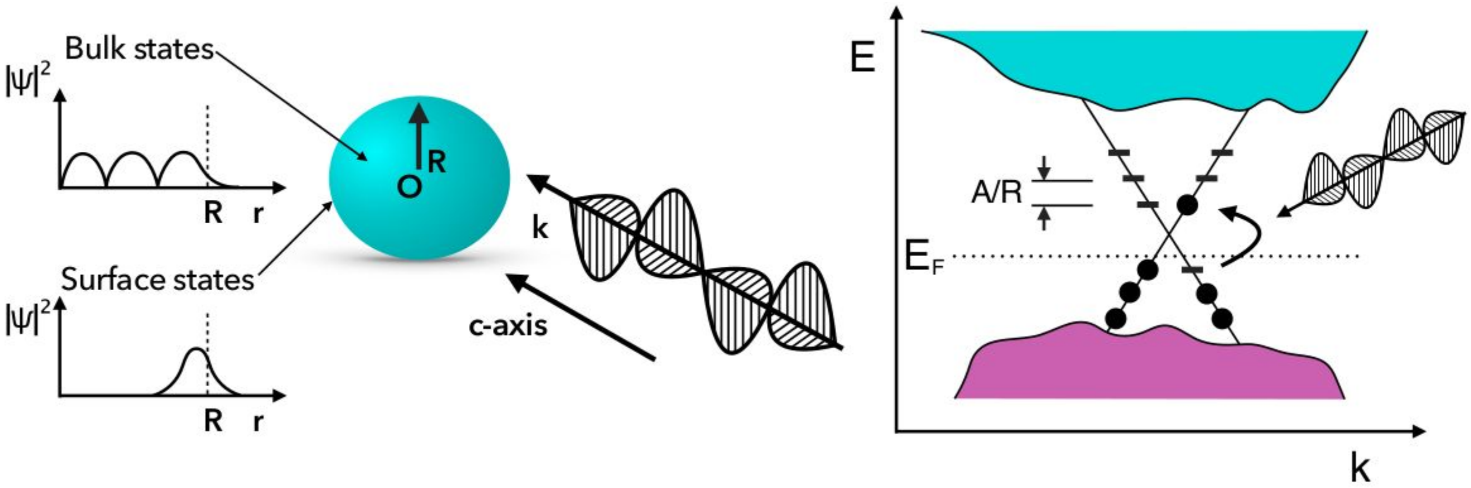
PHYSICAL REVIEW B **86**, 235119 (2012)

Spherical topological insulator

Ken-Ichiro Imura,[1] Yukinori Yoshimura,[1] Yositake Takane,[1] and Takahiro Fukui[2]

...+Light

- A simple system (Sphere, Bi_2Se_3)
- A simple perturbation (circularly polarized light)
- Time dependent Perturbation Theory to the Imura simplified four-band Hamiltonian of Bi_2Se_3

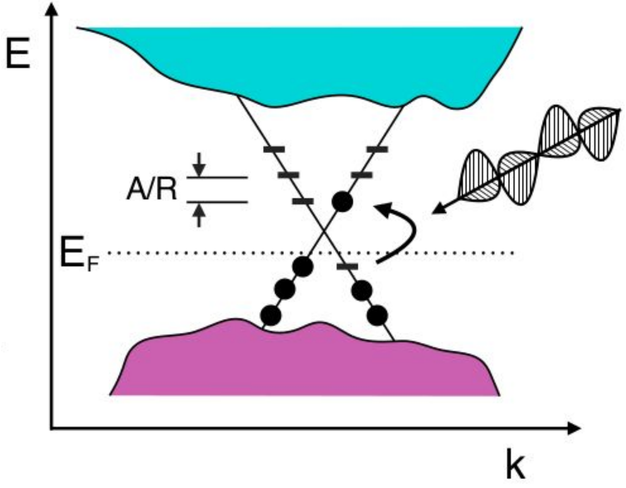


Light + Topological Insulator Nanoparticle

...the perturbation (light) **induces a time dependent surface charge density!**

$$\sigma_{abs} = 4\pi R^3 \frac{2\pi}{\lambda} Im\left(\frac{\varepsilon_{in} + \delta_R - 1}{\varepsilon_{in} + \delta_R + 2}\right)$$

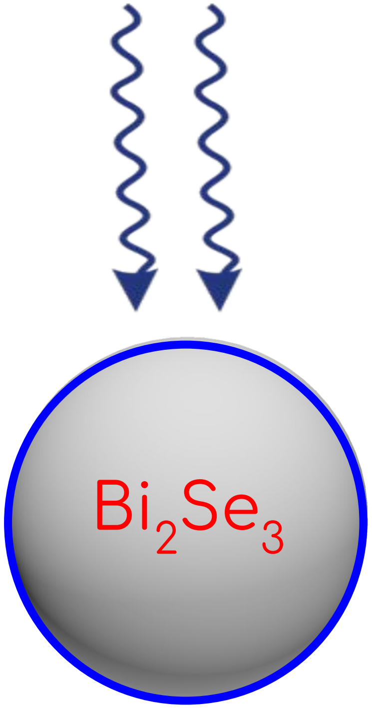
$$\delta_R = \frac{e^2}{6\pi\epsilon_0}\left(\frac{1}{A - \hbar\omega R} + \frac{1}{A + \hbar\omega R}\right)$$

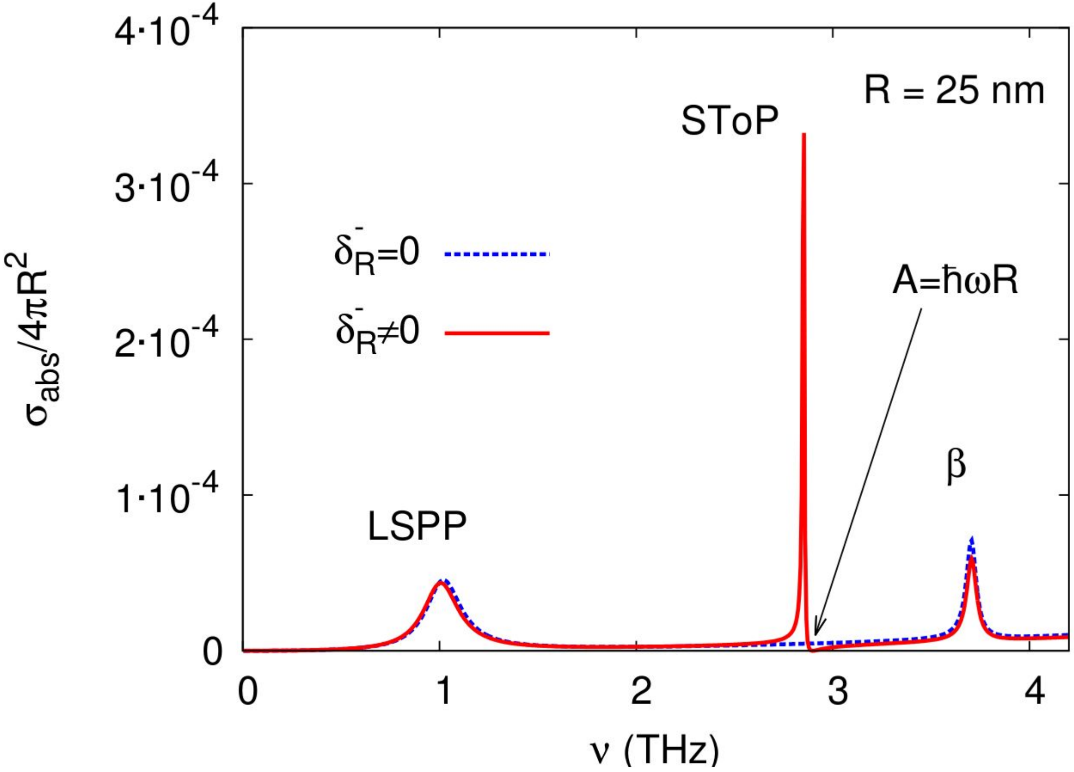


Fermi Energy and Radius dependence

Siroki et al., Nature Comms., 12375, (2016)

Surface Topological Polariton





Siroki et al., Nature Comms., 12375, (2016)

Topological Quantum Dots (SToP Mode)