CENTRO DE INVESTIGACIONES EN OPTICA, A.C.

# *Proposals of research projects for graduate thesis*

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# *Contents*

## *Title: Optical properties of atomic monolayers (MLs)*

***Specialization Area*** : Photonics.

***Postgrade Program*** : Master and Doctorade in Sciences.

***General Objective*** : To perform a theoretical study of the linear and non linear (NL) optical properties of atomic MLs.

***Particular Objectives*** :

- To calculate the dielectric function.
- To calculate the second order nonlinear susceptibility.

***Group*** : Optical Properties of Nano systems, surfaces and interfaces.

***Colaboration with*** : Dr. Bernardo Mendoza Santoyo.

## *Title: Spin injection in atomic MLs*

***Specialization Area*** : Photonics.

***Postgrade Program*** : Master and Doctorade in Sciences.

***General Objective*** : To perform a theoretical and numerical study of the spin injection in atomic MLs.

***Particular Objectives*** :

- To calculate the degree of spin polarization.
- To calculate the spin injection current.

***Group*** : Optical Properties of Nano systems, surfaces and interfaces.

***Colaboration with*** : Dr. Bernardo Mendoza Santoyo.

# *Atomic monolayers (MLs)*

- Layered crystals form in an array of atomic MLs and are called two dimensional (2D) materials.
- Since the discovery of graphene, 2D materials have been a subject of study due to their potential applications.
- Examples of layered crystals are graphene, molybdenum disulfide, boron nitride, etc.
- Atomic structures of one and few MLs present different physical properties than those of the respective bulk crystals.

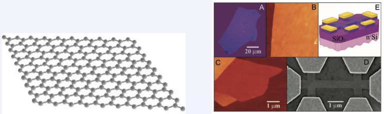



Figure: Atomic scheme (left) and films (right) of graphene. Novoselov, Geim et al. prepared graphitic sheets of thickness down to a few atomic layers, including a single layer graphene, to fabricate devices and to study their electronic properties. [Novoselov et al., Science, **306**, 666 (2004)]

# *Example: Quintulayer (QL)* $\alpha$-$In_2Se_3$ structures

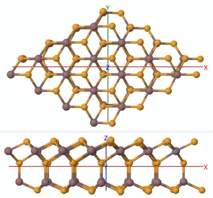



Figure: Top and side views of 1QL of $\alpha$-$In_2Se_3$ structure with wurtzite type configuration.

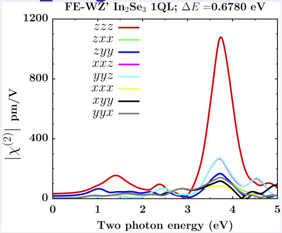



Figure: Spectra of the second order NL susceptibility.

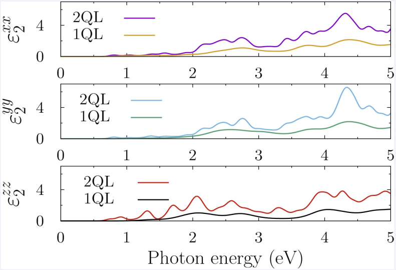


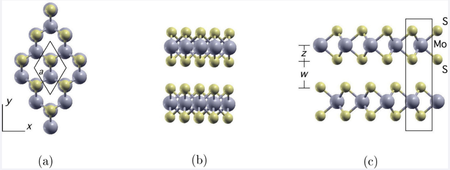

Figure: Spectra of components of the imaginary part of dielectric function.

***Conclusions:***

- The linear response is sensitive to the number of QLs.
- The NL response is more sensitive to atomic-structure changes.

# *Example: spin injection on $MoS_2$ MLs*

Figure: Top and side views of a $MoS_2$ bilayer.



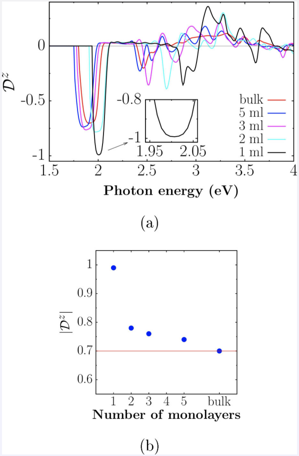




Figure: a) Spectra of the degree of spin polarization $\mathcal{D}^z$ for bulk and $n$-monolayer ($n$ ml) $MoS_2$ structures, under incidence of circularly polarized light. (b) Maximum $|\mathcal{D}^z|$ values.

Conclusion: Incidence of circularly polarized light on 1ml $MoS_2$ structure will inject 100% of spin-polarized electrons on the conduction bands in direction -$z$, having a degree of spin polarization value of -1.

[Arzate et al., PRB **93**, 115433 (2016)]

## *Title:* *Non linear (NL) effects in PCFs*

***Specialization Area*** : Fiber Optics and Lasers

***Postgrade Program*** : Master and Doctorade in Sciences.

***General Objective*** : To perform a theoretical study of the non linear effects that takes place during the propagation of optical pulses in PCFs

***Particular Objectives*** :

- To calculate the modal optical properties of PCFs.
- To obtain the evolution of pulses along its propagation in PCFs such as:
  - Pulse compression.
  - Self-frequency shift.
  - Raman shift.
  - Four wave mixing.
  - Soliton dynamics.
  - Supercontinuum.

***Colaboration with*** : Dr. Ismael Torres Gómez

## *Title: PCF sensors based on NL effects*

***Specialization Area*** : Fiber Optics and Lasers

***Postgrade Program*** : Master and Doctorade in Sciences.

***General Objective*** : To propose sensing schemes based on NL effects in PCFs

***Particular Objectives*** :

- To obtain the evolution of pulses along its propagation in the proposed PCF sensing scheme.
- To obtain dispersion and NL parameters for sensing physical properties such as refractive index, temperature, pressure, strain, salinity, magnetic field, etc.

***Colaboration with*** : Dr. Ismael Torres Gómez

# *Photonic Crystal Fibers (PCFs)*

- PCFs are optical fibers that have a periodic refractive index in its transversal section, while it is constant along its axial axis.
- PCFs favor the generation of NL effects.
- The study of NL effects during the propagation of optical pulses in PCFs have been a subject of great interest to the photonics community due to their novel potential applications they present.

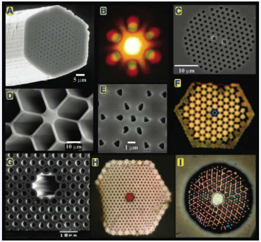


Figure: Images of the transversal section of different PCF structures. [Russell, Science **299**, 358 (2003)]

# *Example: self-frequency shift of solitons*

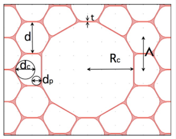



Figure: Cross section of the modeled hole-core photonic band gap fiber (HC-PBGF).

Conclusion: The input pulse gets compressed (or broadened of the spectrum), reaching its maximum compression at the onset of soliton fission. The resultant sub-pulse also gets compressed and broadened and, then follows the formation of a soliton which central wavelength redshifts during its propagation

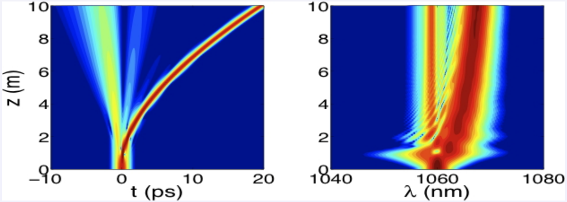



Figure: Temporal (left) and spectral (right) evolution of an input soliton pulse along its propagation in the modeled HC-PBGF.

[González-Baquedano et al., Optics Express **21**, 9132 (2013)]

# *Example: Proposal of a NL sensor*

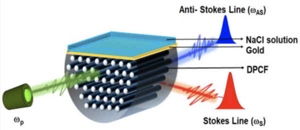



Figure: Proposed novel surface plasmon resonance (SPR) sensor based on four wave mixing (FWM) technique.

[N. Nallusamy et al. Sensors Letters **2**, June (2018)]

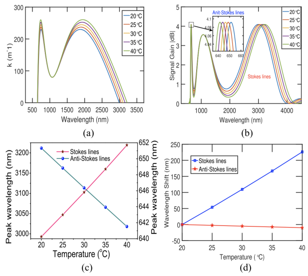



Figure: a) Phase mismatch, b) FWM spectrum, c) FWM-signal-peak wavelength, and d) wavelength shift.

Conclusion: The proposed NL sensor monitors Stokes and anti-Stokes photon wavelength shift under variation of temperature T and salinity S. The respective sensitivities are 11.31 and -0.49 nm/$^o$C for the Stokes and anti-Stokes lines, respectively. The extrinsic sensor can measure both T and S of an analyte simultaneously.