Plasmonics with semi-metal nanostructures: experiments and modeling

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Plasmonics has attracted the attention of the scientific community, based on the capability of noble metal nanostructures to confine, enhance, polarize or absorb visible light at the nanoscale with spectral selectivity. During the last years, a quest has started with the aim of unveiling plasmonic materials beyond noble metals showing enhanced or specific properties such as switchability or lower optical losses.[1] Although plasmons rely on the excitation of free carriers, the optical effects sought for plasmonics can also be achieved with insulators or semi-metals thanks to electronic (excitonic, interband or interlevel) transitions, and interestingly they can be achieved in the ultraviolet-visible region of the spectra. Recently, such effects have been demonstrated for instance in organic polaritonic materials,[2-3] inorganic topological insulators,[4] the p-block elemental semi-metals antimony and bismuth and the covalent metal gallium.[5] These materials are specially interesting for the possibility of dynamic tuning of their electronic structure in their stable solid state or upon phase transition, therefore paving the way to switchable plasmonics.

In this presentation, we will explain how we unveiled the potential of semi-metal bismuth nanostructures for the development of switchable plasmonics in the ultraviolet-visible.[6-7] In particular, we will demonstrate the key role played by spectroscopic ellipsometry and advanced effective medium modeling in these findings.

We will show the correlation of the bismuth nanostructures switching properties (for both the amplitude and phase of light) with their shape, size, organization and their electronic properties. Especially, we will show experimentally the evolution of the optical properties of the bismuth nanostructures embedded in an inert matrix, when they are molten and solidified reversibly, while their shape, size and organization is unchanged. The optical switching is thus driven by a shift in the nanostructures optical resonances, which in turn is related with the change in their electronic properties at the phase transition: first dominated by interband transitions in the solid state and later following a Drude trend in the liquid state.

1. G. Naik, V.M. Shalaev, A. Boltasseva, “Alternative plasmonic materials: beyond gold and silver,” Adv. Mater. **25**, 3264-3294 (2013).
2. M.J. Gentile, S. Núñez-Sánchez, W.L. Barnes, “Optical field –enhancement and suwavelength field confinement using excitonic nanostructures,” Nano Lett. **14**, 2339-2344 (2014).
3. L. Gu, J. Livenere, G. Zhu, E.E. Narimanov, M.A. Noginov, “Quest for organic plasmonics,” Appl. Phys. Lett. **103**, 021104 (2013).
4. J.Y. Ou, J.K. So, G. Adamo, A. Sulaev, L. Wang, N.I. Zheludev, “Ultraviolet and visible range plasmonics in the topological insulator $Bi_{1.5}Sb_{0.5}Te_{1.8}Se_{1.2}$,” Nature Comm. **5**, 5139 (2014).
5. J. Toudert, R. Serna, “Interband plasmonics with p-block elements”, arXiv:1601.01606 (2016).
6. J. Toudert, R. Serna, M. Jiménez de Castro, “Exploring the optical potential of nano-Bismuth: Tunable surface plasmon resonances in the near ultraviolet to near infrared range,” J. Phys. Chem. C **116**, 20530-20539 (2012).
7. M. Jiménez de Castro, F. Cabello, J. Toudert, R. Serna, E. Haro-Poniatowski, “Potential of bismuth nanoparticles embedded in a glass matrix for spectral-selective thermo-optical devices,” Appl. Phys. Lett. **105**, 113102, 1-5 (2014).