Strong Field Attosecond Optoelectronics

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Optoelectronics is extending to the highly non-linear regime and the attosecond time domain. A recent impact of this capability of controlling the response of above band gap electrons under strong fields is the emergence of high harmonic generation (HHG) in crystal[1-6]. 2D and 3D semiconductors exhibit properties of high electron mobility that allow to drive intense electron currents coherently in the conduction band. HHG are emitted when those electrons recombine to the valence band. HHG in crystals can not only revolutionize attosecond science but also prepares a new generation of ultrafast visible to X-ray optoelectronic devices.

Here, I will review our recent progresses on HHG in semiconductors. As a first illustration I will summarize recent results on HHG from doped MgO crystal in XUV spectral range. We will see how vacancies and doping can effectively tailor the HHG response. I will also show a strong laser polarization dependence that can be used to gate isolated attosecond pulses. I will draw perspectives for UV attosecond phase characterization to investigate the attosecond timing of the electron current. This is relevant for the metrology of optoelectronic switches operating in the petahertz regime.

Then, I will show how nano-structuration of semiconductors can be used to induce spatial confinement of the harmonic emission. First, nanoscale beam carrying orbital angular momentum are generated[7]. In a second experiment, enhancement of several orders of magnitude of the HHG emission in a semiconductor waveguide is observed[8]. Our all semiconductor HHG nano-emitters can work sustainability over days and can be used as ultrafast petahertz optoelectronic devices. In addition, hot electrons emitted coherently from the nanostructure have been measured using PEEM microscopy. The emission is localized in a few 100 nm spot with a discrete electron kinetic energy distribution correlated with the HHG spectral emission.

Finally, I will conclude by drawing a perspective about how these various 2D and 3D crystals, with unique properties, can be used to control electronic currents at petahertz frequencies.

References:

[1] Ghimire, S. *et al.* Observation of high-order harmonic generation in a bulk crystal. *Nat. Phys.* **7,** 138–141 (2011).
[2] Luu, T. T. *et al.* Extreme ultraviolet high-harmonic spectroscopy of solids. *Nature* **521,** 498–502 (2015).
[3] Ndabashimiye, G. *et al.* Solid-state harmonics beyond the atomic limit. *Nature* **534,** 520–523 (2016).
[4] You, Y. S., et al. Anisotropic high-harmonic generation in bulk crystals. *Nat. Phys.* **13,** 345–349 (2017).
[5] Liu H. et al. High-harmonic generation from an atomically thin semiconductor. Nature Physics **13**, 262–265 (2017).
[6] Yoshikawa, N., et al. High-harmonic generation in graphene enhanced … Science, **356,** 736-738 (2017).
[7] Gauthier et al., "Orbital angular momentum from semiconductor high-order harmonics" (2018) Optics Letters **44**(3) 546-549 (2019)
[8] D. Franz et al. "All semiconductor enhanced high-harmonic generation from an isolated nanostructure" Nature Scientific Reports **9,** 56632, (2019)