Efficient extreme-ultraviolet multi-band high-order wave mixing in silica

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The recently discovered emission of high-order harmonics from solids [1] under intense laser-pulse irradiation is testing our understanding of strong-field solid-light interactions, while simultaneously opening avenues towards new all-solid coherent short-wavelength table-top sources.

High-harmonic generation from solids holds a strong appeal as a coherent, short-wavelength light source: extreme-ultraviolet pulses generated in solids impose less stringent requirements on the vacuum apparatus, provide a prospective of shrinking down the physical size of setups, and the possibility of high-harmonic generation at higher repetition rates, while exhibiting similar spectral and temporal characteristics as high harmonics generated in gases.
To date, broadband spectra from solids have been generated well into the extreme ultraviolet [2], but the comparatively low conversion efficiencies still lag behind those of gas high-harmonic sources, and have hindered wider-spread applications.

In this contribution, we overcome the low conversion efficiency of all-solid high-harmonic sources through efficient extreme-ultraviolet wave mixing by crossing an intense fundamental 800-nm pulse with its second harmonic under a small angle in a fused silica substrate. We develop a few-level model, which fully reproduces the experimentally observed far-field patterns (Fig. 1) as well as the scaling of all extreme-ultraviolet wave mixing orders as a function of driving intensity. Moreover, our model reveals that the laser-driven population transfer between the valence band and the two lowest conduction bands causes the large conversion-efficiency increase. This laser-driven population transfer physically resembles an injection current. Thus our contribution supports the only recently proposed mechanism of injection-current-driven high-harmonic generation [3] as the underlying cause of extreme-ultraviolet emission in solids.

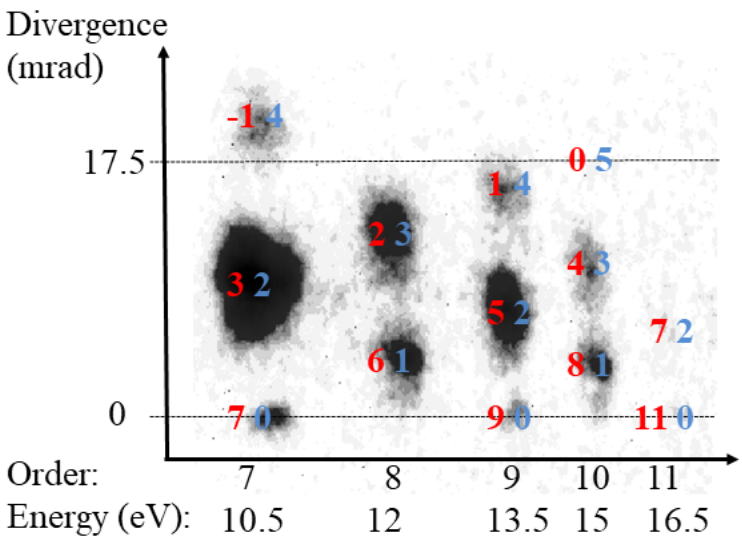

Figure 1: Typical far-field resolved extreme-ultraviolet emission. Numbers on the wave mixing orders indicate the photon combinations of 800-nm (red) and 400-nm (blue) photons that lead to the extreme-ultraviolet emission.

[1] S. Ghimire, et al., *Nature Physics,* **2011**, 7, 138.
[2] T. T. Luu, et al., *Nature*, **2015**, 521, 498.
[3] P. Juergens, et al., *Nature Physics*, **2020**, https://doi.org/10.1038/s41567-020-0943-4.