# From perturbative to strong-field emission: energy-resolved ultrafast laser-induced electron emission from sharp metal tips

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We investigate electron emission from sharp metal tips induced by few-cycle femtosecond laser pulses. Laser-triggered nanoscale electron emitters should be ideal electron sources for e.g. ultrafast electron diffraction, but should also give insight into fundamental questions of light-matter interaction. Recently, a variety of experiments has been done in this field [1]. Because of the complexity of the system and the non-linear behavior involved, different experimental parameters can favor very different emission processes. Intimately linked to the processes is the question of energy width and emission duration. Here we present energy-resolved measurements that enable us to uniquely identify these processes.

In our experiment, $\sim$ 6 fs infrared laser pulses of up to a few nJ pulse energy are focused tightly onto the apex of atomically clean tungsten tips. We observe three qualitatively different emission processes. At low laser intensity and with a small negative DC voltage applied to the tip, three- or two-photon above-barrier emission dominates (multiphoton photoemission). With large bias voltages, one-photon photo-excitation and subsequent tunneling through the barrier sets in (photoassisted field emission). At high laser intensities, peaks corresponding to the absorption of up to 9 photons are observed (above-threshold photoemission, ATP). With increasing intensity, we observe a shift of the first ATP peak towards smaller kinetic energies, reflecting the ponderomotive energy of electrons in the laser pulse. From this shift and the knowledge of the laser parameters we infer a local electric field enhancement factor of about 6 at the tungsten tip apex. Here our experiment is situated in a regime where a perturbative description of the emission process is not sufficient anymore. We present a numerical simulation that shows good qualitative agreement with the experiment and reveals that the temporal structure of the laser electric field is resolved in the emission current.

[1] Hommelhoff et al., PRL **96**, 077401 (2006), PRL **97**, 247402 (2006); Ropers et al., PRL **98**, 043907 (2007); Barwick et al., New J. Phys. **9**, 142 (2007); Tsujino et al., APL **94**, 093508 (2009); Yanagisawa et al., PRL **103**, 257603 (2009)