Next-level electron dynamics through optimal control and plasmonic fields

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Synopsis In this computational study we investigate strong-field processes – such as above-threshold ionization and high-harmonic generation – driven by plasmonically enhanced near-fields of various nanostructures. We model the dynamics with computational tools of various levels of sophistication, and combine these with optimal control theory in order to design new ways to shape the spectra of emitted photoelectrons and photons.

Imaging and controlling of electron motion is made possible by "attosecond science", the science of dealing with such short timescales that even electrons look like they are from a slow-motion video. This field has already generated significant advances in nanoscale spatial and atto-/femtosecond temporal imaging techniques such as laser-induced electron diffraction or attosecond laser pulses [1]. We have already previously developed schemes for controlling laser-driven electron dynamics of gas-phase strong-field processes used in the above mentioned technologies [2].

A promising route for future development of these technologies is found in strong-field processes in nanomaterials and nanodevices. Especially in nanodevices, the electric field of the driving laser can be intensified by an order of magnitude and it is spatially highly non-homogeneous (Fig. 1). Not only does this provide a more complex playground for strong-field phenomena but also new possibilities for controlling electron dynamics with laser pulses. We focus on modelling these phenomena with various levels of sophistication ranging from semiclassical models to many-body quantum mechanics and from electrostatics to time-dependent Maxwell's equations. To control the electron dynamics we aim to employ quantum optimal control theory (QOCT) [3] and combine it with machine learning techniques for increased experimental compatibility (Fig. 2).

These nanostructure-enhanced strong field processes are expected to increase efficiency and controllability of strong-field processes used in imaging applications [4]. In this respect, precise models and computational control schemes compatible with experiments can not only shed light on the physics of the phenomena but also provide new directions for development of attosecond imaging machinery.

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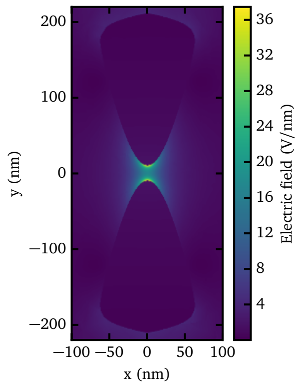

Figure 1. Electric field near a gold nanostructure is significantly intensified, suggesting possibility for significant enhancement in strong-field phenomena.

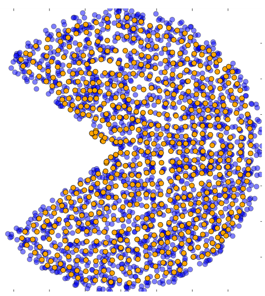

Figure 2. A neural network (orange dots) can be taught to represent an experimentally feasible subset of the optimization space (blue dots).

References

[1] See, e.g., M. Meckel et. al., Science **320**, 1478 (2008) and F. Krausz and M. Ivanov, Rev. Mod. Phys **81**, 163 (2009)

[2] J. Solanpää et al., Phys. Rev. A **90**, 053402 (2014) and J. Solanpää, M. Ciappina, and E. Räsänen, arXiv:1607.03079, sub. to J. Mod. Opt.

[3] See, e.g., C. Brif, R. Chakrabarti, and H. Rabitz, New J. Phys. **12**, 075008 (2010).

[4] See, e.g., M. Ciappina et al., Opt. Express **20**, 26261 (2012)