Waveform Controlled Electron Emission from Isolated Nanoparticles near Optical Damage Threshold

S. Zherebtsov1,2, P. Rupp1, F. Süßmann1,2, Q. Liu1, L. Seiffert1, J. Stierle1, V. Mondes1, J. Plenge1, A. Kessel1, S. A. Trushin1, B. Ahn1,2, D. Kim3,5, C. Graf4, E. Rühl1, T. Fennel1, M. F. Kling1,2

1. Max-Planck-Institut für Quantenoptik, Garching, Germany
2. Physik Department, Ludwig-Maximilians-Universität München, Garching, Germany
3. Institut für Physik, Universität Rostock, Rostock, Germany
4. Physical Chemistry, Freie Universität Berlin, Berlin, Germany
5. Physics Department, POSTECH, Pohang, Republic of Korea
6. Max Planck Center for Attosecond Science, Pohang, Republic of Korea

Intense laser fields of well-defined waveform are a powerful tool for studies of sub-cycle resolved electron dynamics in solids and nanostructured materials. Few-cycle laser pulses have been applied for attosecond control of electron emission from isolated nanoparticles [1], nanotips [2], and for control of electrical currents in dielectrics [3]. Here we present results of our studies on intensity dependent waveform controlled electron emission from isolated nanospheres in the range from low intensities in the nonadiabatic tunnelling regime to the nonlinear optical response of the nanoparticles.

![Fig. 1 Cutoff in the electron emission spectra measured in 95 nm diameter SiO₂ nanoparticles at different laser intensities (filled black circles in (a) and filled blue circles connected with a solid blue line in (b)). For comparison the results of the M'C calculations are shown as filled red circles connected with a solid red line. The shaded area in (b) illustrates systematic uncertainty in determining the cutoff.](image)

In our experiments, intense laser pulses of 4.5 fs pulse duration centered at 720 nm were focused onto a SiO₂ nanoparticle beam. The nanospheres of narrow size distribution were inserted into the gas phase by aerosol preparation and aerodynamic lens focusing. Single-shot phase-tagged velocity map imaging was utilized for studies at relatively low laser intensities in the range (0.7–4.5)×10¹³ W/cm² (Figure 1(a)), while at higher laser intensities (1–3.5)×10¹⁴ W/cm² stereo time-of-flight detection was used (Figure 1(b)) [4]. For the intensity range (1.7–15)×10¹³ W/cm² the measurements show a nearly constant scaled cutoff energy \( E_c/U_p \) with an average cutoff value of 53.0 \( U_p \). Here \( U_p = e^2E_c^2/(4mu^2) \) is the ponderomotive potential of an electron in the laser field. These results are in good agreement with a trajectory-based Mean-field Mie Monte-Carlo (M'C) model that considers atomic Ammosov-Delone-Krainov (ADK) tunnel ionization in the surface layer and linear optical response of the nanoparticle. The model identifies backscattering from the nanoparticle surface in highly dynamic near field as acceleration mechanism for the energetic emission. For the lowest intensities the model predicts lower cutoff energies as compared to the experiment. This discrepancy may be attributed to the Keldysh parameter being on the order of one and the adiabatic tunnelling regime not strictly applicable. For high laser intensities above \( \sim 1.5 \times 10^{14} \text{ W/cm}^2 \) the scaled cutoff energy monotonically increases with intensity reaching value of 100 \( U_p \). This intensity dependence is ascribed to a phase transition between bound and free electrons with plasma shell formation at intensities close to the optical damage threshold.

References