Kolloquium

Prof. Dr. Peter Hommelhoff
FAU Erlangen-Nürnberg

Electrons driven in strong optical near-fields: from light-field based current generation in graphene to novel laser-based particle accelerators

physikalisches

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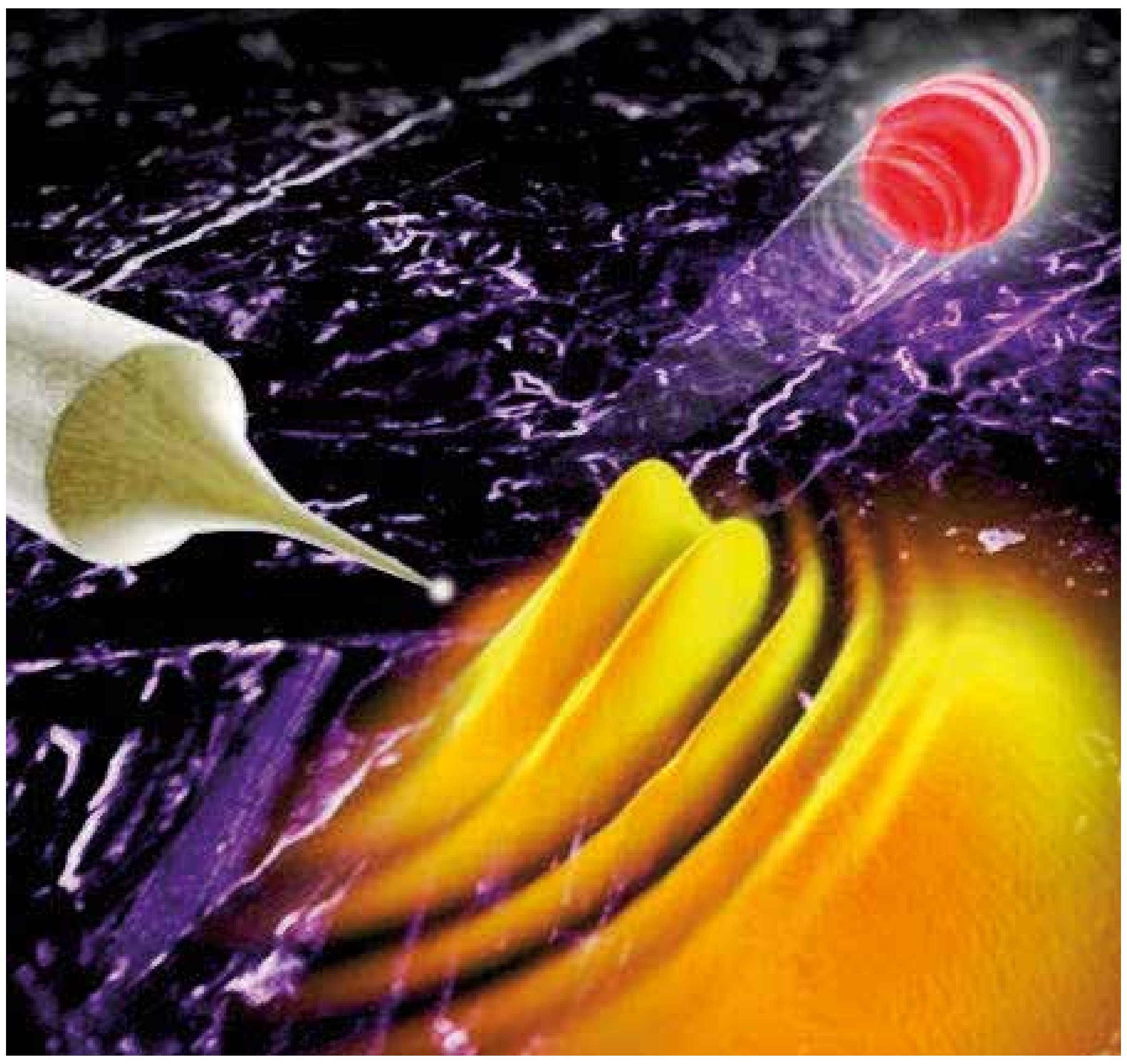
Laser pulses as short as a few optical cycles can nowadays be generated routinely. In addition, the optical carrier field can today be well-controlled. This allows direct control over electrons on timescales as short as femtoseconds (10^{-15} s) and even attoseconds (10^{-18} s). On these stunningly short time scales, electrons exhibit beautifully their coherent wave nature.

Three examples of such laser-based electron control will be discussed: the fully coherent control of electrons laser-emitted from sharp needle tips, the field-induced excitation of electrons within the 2-dimensional material graphene and, last, the acceleration of free electrons in an electron beam in the near-field of transparent photonic structures. In the case of the tips, we observe electron matter wave interference and other hallmarks of strong-field physics well known from atoms and molecules in a gas phase – for the first time at a solid. In the case of graphene, we observe that electrons inside of the material can be excited by an intriguing interplay of intraband and interband effects, including Landau-Zener-Stückelberg interferometry and a subsequent laser phase-dependent excitation. In the last case, we observe efficient acceleration and deflection of electrons by virtue of the laser-excited near-fields at a photonic structure. Acceleration gradients in excess of 1 GeV/m are observed so that compact laser-based particle accelerators become an attractive potential application. These experiments explore laser-electron interaction on new time and length scales and in systems that may allow merging optics and electronics in one platform. In addition, applications in time-resolved electron-based imaging and novel particle accelerator technology are plentiful.



Above: A few-cycle laser pulse (red) interacting with a sharp needle tip. Two electron wavepackets (yellow) are emitted by the few-cycle laser pulse, which, on the way to the detector, start to overlap and exhibit matter wave interference. We can detect and control these fully coherent electron dynamics by virtue of the laser field shape.