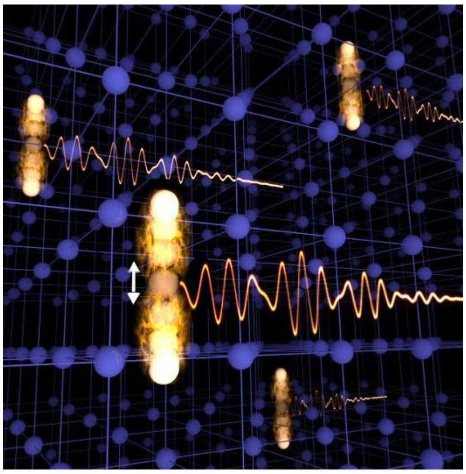
Strong fields make electrons tremble

Novel quantum motion of electrons generates record bandwidth radiation



Modern high-speed electronics relies on tiny semiconductor structures where strong local fields drive electrons towards ever higher velocities. Soon conditions could be reached under which a new quantum world may unfold. A team of physicists from Germany has now found that electrons in atomically strong electric fields do not move straight from one contact to the other, but perform a quantum quiver on a time scale of a femtosecond – the quadrillionth part of a second – and emit extremely broadband light. The results are reported in the latest issue of Nature Photonics (O. Schubert et al., Nat. Phot., *published online* (2014)).

85 years ago, Felix Bloch – one of the founding fathers of modern solid state physics – pointed out that electrons are quantum mechanical waves and should not move like classical particles. When an external electric field accelerates an electron, its wavelength shortens. Once the wavelength is comparable to the distance of neighbouring atoms in a crystalline solid, the wave should get reflected by the regular atomic lattice. This scenario should cause electrons to perform vibrations, called Bloch oscillations. Yet the direct observation of this counter-intuitive phenomenon in natural bulk semiconductors has been a challenge, since ultrafast scattering blurs the wave nature of the electron.

Researchers in the group of Rupert Huber at University of Regensburg have now found a way to apply an electric field for only tens of femtoseconds and to observe the electron dynamics before scattering becomes effective. The team exploits the oscillating carrier wave of an ultrashort laser pulse in the terahertz spectral range as a transient bias. The newly commissioned Regensburg high-field terahertz source generates peak fields of the order of ten billion volts per meter with a temporal precision better than one femtosecond. With an extreme slow-motion camera resolving processes faster than a single oscillation period of light, the researchers observed how oscillating electrons emit high-frequency electromagnetic radiation covering a broad spectrum of high-order harmonic frequencies of the terahertz pulse. The spectrum fills an unprecedented window from the microwave regime to the ultraviolet, setting an impressive bandwidth record for femtosecond sources.

In order to explain the underlying optically driven electron transport microscopically the groups of Stephan W. Koch and Mackillo Kira at University of Marburg in collaboration with Torsten Meier at University of Paderborn developed a full quantum many-body theory, going far beyond Bloch's seminal prediction. They show that the terahertz field simultaneously excites electrons across the forbidden energy gap of the semiconductor and accelerates them to perform Bloch oscillations. The results highlight quantum phenomena relevant for future semiconductor devices at teraflop clock rates and open the door to a novel regime of high-field transport on timescales of a single cycle of light. Moreover Bloch oscillations in bulk solids represent a unique light source for ultrafast science.

Original publication:

O. Schubert, M. Hohenleutner, F. Langer, B. Urbanek, C. Lange, U. Huttner, D. Golde, T. Meier, M. Kira, S. W. Koch und R. Huber, „*Sub-cycle control of terahertz high-harmonic generation by dynamical Bloch oscillations*“, Nature Photonics (*published online*) (2014)
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