Title	Light-field-driven currents in graphene
Authors	Takuya Higuchi[1], Christian Heide[1], Konrad Ullmann[2], Heiko B. Weber[2] & Peter Hommelhoff[1]
Publication	*Nature* 550, 224–228 (12 October 2017) *doi:10.1038/nature23900*
Abstract	The ability to steer electrons using the strong electromagnetic field of light has opened up the possibility of controlling electron dynamics on the sub-femtosecond (less than 10^{-15} seconds) timescale. In dielectrics and semiconductors, various light-field-driven effects have been explored, including high-harmonic generation, sub-optical-cycle interband population transfer and the non-perturbative change of the transient polarizability In contrast, much less is known about light-field-driven electron dynamics in narrow-bandgap systems or in conductors, in which screening due to free carriers or light absorption hinders the application of strong optical fields. Graphene is a promising platform with which to achieve light-field-driven control of electrons in a conducting material, because of its broadband and ultrafast optical response, weak screening and high damage threshold. Here we show that a current induced in monolayer graphene by two-cycle laser pulses is sensitive to the electric-field waveform, that is, to the exact shape of the optical carrier field of the pulse, which is controlled by the carrier-envelope phase, with a precision on the attosecond (10^{-18} seconds) timescale. Such a current, dependent on the carrier-envelope phase, shows a striking reversal of the direction of the current as a function of the driving field amplitude at about two volts per nanometre. This reversal indicates a transition of light–matter interaction from the weak-field (photon-driven) regime to the strong-field (light-field-driven) regime, where the intraband dynamics influence interband transitions. We show that in this strong-field regime the electron dynamics are governed by sub-optical-cycle Landau–Zener–Stückelberg interference, composed of coherent repeated Landau–Zener transitions on the femtosecond timescale. Furthermore, the influence of this sub-optical-cycle interference can be controlled with the laser polarization state. These coherent electron dynamics in graphene take place on a hitherto unexplored timescale, faster than electron–electron scattering (tens of femtoseconds) and electron–phonon scattering (hundreds of femtoseconds). We expect these results to have direct ramifications for band-structure tomography and light-field-driven petahertz electronics.
Laser Quantum Product	**venteon** power
Institute	[1]Laser Physics, Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstrasse 1, D-91058 Erlangen, Germany. [2]Applied Physics, Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstrasse 7, D-91058 Erlangen, Germany.