Final Report on OTKA project 64303/IN

Experimental research. – To gain experimental insight into the sub-cycle dynamics of multi-photon-induced photoelectron emission femtosecond time-resolved measurements were carried out on a polycrystalline gold surface with pulses of a Ti:sapphire laser to explain the recently found, unexpectedly low carrier-envelope phase dependence of the photoemission process in this particular case [1]. In the higher-order interferometric autocorrelation distribution additional short side wings appeared suggesting that ultrafast dynamics of hot electrons reduce the carrier-envelope phase dependence of the photoemission electron yield produced by few-cycle laser pulses [1]. Other metals can be investigated with this simple and fast method to pave the way towards the construction of a solid-state-based direct carrier-envelope phase detector, also of interest to the partner institute (Max Planck Institute for Quantum Optics, MPQ)

We also contributed to femtosecond laser development efforts to push the limits of the energy of pulses directly coming from a Ti:sapphire oscillator. As a result of the collaboration pulse compression of so-called chirped-pulse oscillators was carried out together with pulse characterization [2,3] in Germany. Thus, based on the know-how acquired at MPQ, one of us (P. Dombi) set up a so-called long-cavity Ti:sapphire oscillator that delivers femtosecond pulses with 250 nJ pulse energy and 3 MHz repetition rate in Budapest [4,5]. This unique light source delivers ideal driving pulses for several applications. These types of high-energy, high repetition rate ultrafast lasers also pose some laser technological challenges (e.g. how to compress their to below 10 fs) which were also investigated [5] with the help of equipment from MPQ. During these tests a new type of backscattering mechanism from optical fibres was found that seems to be unique to this parameter regime. We published several experimental results related to these experiments in femtosecond laser pulse generation and compression [4,5] that could not have been achieved without the cooperation with MPQ. In addition, we have upgraded the pump laser of the existing novel laser oscillator to a commercial solid-state system.

Theoretical research. – Based on the collaborative research plan, on the basis of an exactly solvable model of classical electrodynamics we have determined the high-harmonic spectrum of a few-cycle Ti:sapphire laser radiation scattered on a plasma layer [6]. The spectra obtained qualitatively differ from each other depending on the carrier-envelope phase difference of the incoming pulse. We have generalized the calculation to relativistic intensities, and in addition, we have included the effect of a homogeneous external magnetic field. The spectrum of the magneto-Raman scattering can in principle be used to measure the mentioned absolute phase.

After discussions with researchers at MPQ, we also proposed a novel way of tailoring electron pulses with the help of ultrashort, carrier-envelope phase controlled laser pulses and surface plasmons [7]. The new scheme allows for controlling photoelectron emission from metals spatially, spectrally and temporally thus providing a unique tool for time-resolved pump-probe-type studies with an electron beam. These developments can have significant impact on the currently developed ultrafast electron diffraction method which holds promise of uniting atomic resolution in space and attosecond resolution in time in material science. We are also investigating new ways of generating attosecond pulses with surface harmonics which has the advantage that much less energetic femtosecond pulses can be converted to attosecond oscillation than before.

We have also analysed the reflection and transmission of a few-cycle femtosecond Ti:Sa laser pulse impinging on a metal nano-layer [8], also of interest to researchers at MPQ. It has been shown that in general a non-oscillatory frozen-in wake-field appears following the main pulse with an exponential decay and with a definite sign of the electric field. In the framework of our investigations concerning the physics of surface plasmon polaritons, we have worked out a new model which confirms the existence of enhanced electromagnetic fields bound to a thin metal layer evaporated on a glass substrate. Our latest result in attophysics has been to show that the above-threshold electron de Broglie waves, generated by an intense laser pulse at a metal surface, are interfering to yield attosecond electron pulses [9]. Owing to the inherent kinematic dispersion, the propagation of attosecond de Broglie waves in vacuum is very different from that of attosecond light pulses, which propagate without changing shape. The clean attosecond structure of the current at the immediate vicinity of the metal surface is largely degraded due to the propagation, but it partially recovers at certain distances from the surface. Accordingly, above the metal surface, there exist "collapse bands", where the electron current is erratic or noise-like, and there exist "revival layers", where the electron current consist of ultrashort pulses of attosecond duration [9]. The attosecond structure of the electron photocurrent can, perhaps be used for monitoring ultrafast relaxation processes in single atoms or in condensed matter. We expect that these concepts will be realized experimentally at MPQ which is the world leading lab in experimental attophysics.

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