Ultrafast Kapitza-Dirac Effect in a Femtosecond Enhancement Cavity

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The Kapitza–Dirac (KD) diffraction of free electrons by an optical standing wave has so far been demonstrated only with low-repetition-rate lasers, typically kilohertz-rate amplified systems. Here we report the first observation of ultrafast KD diffraction at a repetition rate of 100 MHz, enabled by a femtosecond enhancement cavity (fs-EC).

The fs-EC, seeded by a near-infrared frequency comb, enhances two counter-propagating pulses that form a transient standing wave with peak intensities exceeding $10^{13}\,\mathrm{Wcm^{-2}}$ at the focus. Xenon atoms are ionized in this field, and the resulting photoelectrons are detected by velocity-map imaging (VMI) [1,2]. An interferometer placed before the cavity generates a second standing wave at the same position with a tunable delay. While the first standing wave ionizes the gas at the antinodes, the weaker delayed standing wave diffracts the emitted electrons in its spatially periodic ponderomotive potential, giving rise to the ultrafast KD effect [3]. Since the direct and diffracted electron wave packets overlap in momentum space, they interfere, providing access to the femtosecond phase evolution of the photoelectron wave packet.

In contrast to conventional kilohertz-rate amplified systems, which for ultrafast KD experiments were thus far effectively limited to the high-intensity tunneling regime, our approach accesses a lower intensity range ($< 10^{13}\,\mathrm{Wcm^{-2}}$). Despite the much lower yield of the multiphoton ionization processes that dominate there, the 100 MHz repetition rate provides sufficient event rates.

In this regime, prominent Freeman resonances offer both sensitivity to atomic structure and an intrinsic intensity filter that suppresses focal-volume averaging.

References

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