Peering into plasma mirrors

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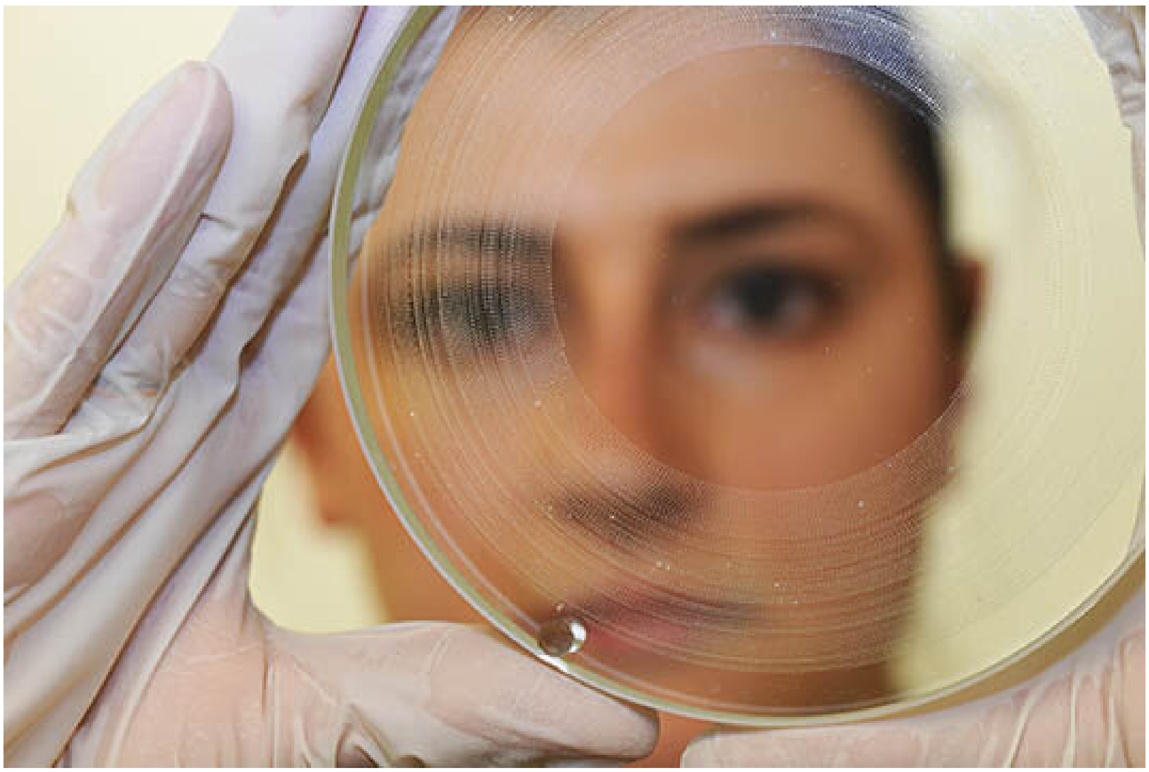

Attosecond flashes of light can be generated on glass surfaces through the process of ionization by a strong laser, which gives rise to a dense mixture of free-moving electrons and nearly quiescent atomic hulls. Every fragment on the glass surface marks the impact of a laser pulse. Credit: Thorsten Naeser

When light interacts with a mirror which is moving towards it at a speed close to the speed of light, its wavelength is shifted into the extreme ultraviolet region of the spectrum. This effect was first predicted by Albert Einstein. His theory was experimentally confirmed almost 100 years later, following the development of high-intensity laser light sources. Laser physicists at the Laboratory for Attosecond Physics (LAP) at Max Planck Institute for Quantum Optics in Garching (MPQ) and LMU have now characterized the phenomenon in detail under controlled conditions and exploited it to generate high-intensity attosecond light flashes. Moreover, they show that these pulses can be shaped with unprecedented precision for use in attosecond research.

As a rule, these ultrashort pulses are created by allowing coherent laser light to interact with a sample of a noble gas, such as xenon. However, this method has one serious drawback – the resulting pulses have low energies. An alternative approach to the generation of attosecond pulses makes use of relativistically oscillating mirrors. In this case, the light interacts not with a gas, but with a solid surface made of fused silica.

A small portion of the incident light serves to ionize the surface of the glass, thus creating a plasma – a dense cloud made up of free electrons and virtually immobile, positively charged atomic ions. This state of affairs can be compared to that found in normal metals, in which a fraction of the electrons can move freely through the material. In fact, this dense surface plasma behaves like a metal-coated mirror. The oscillating electric field associated with the light that impinges on this mirror causes the surface of the plasma to oscillate at peak velocities close to that of light itself. The oscillating surface in turn reflects the incident light. As a consequence of the Doppler effect, the frequency of the incoming light is shifted into the extreme ultraviolet (XUV) region of the spectrum – and the higher the peak velocities, the greater the frequency shift. Because the durations of mirror oscillations at maximum speed are extremely short, XUV light pulses lasting for a matter of attoseconds can be spectrally filtered out. Crucially, these flashes have a far greater intensity than those that can be generated by the conventional interaction in the gaseous phase. In fact, simulations suggest that they should reach photon energies on the order of kiloelectron volts (keV).

In collaboration with scientists from the ELI (Extreme Light Infrastructure) in Szeged in Hungary, the Foundation for Research & Technology – Hellas (FORTH) in Heraklion (Greece) and Umeå University in Sweden, the team led by professor Stefan Karsch has been able to gain new and valuable insights into the interaction of pulsed laser light with relativistically oscillating solid surfaces. They first analysed the intensity profile and energy distribution of the resulting attosecond pulses, and their dependence on the 'carrier envelope phase' of the driving input laser pulse in real time. "These observations permit us to define the conditions required for optimal generation of attosecond light pulses using the oscillating plasma mirror," says Olga Jahn, the first author of the study. "We were able to demonstrate that isolated attosecond XUV light flashes can indeed be produced from optical pulses consisting of three oscillation cycles." The LAP team's findings will enable the procedure required to generate attosecond pulses by means of plasma mirrors to be simplified and standardized. The comparatively high intensities achieved open up new opportunities for ultraviolet spectroscopy, and promise to unveil new aspects of molecular and atomic behavior.

More information: Olga Jahn et al. Towards intense isolated attosecond pulses from relativistic surface high harmonics, *Optica* (2019). DOI: 10.1364/OPTICA.6.000280

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