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Real time 4D imaging of energy flow towards intelligent designer materials.

Intelligent designer materials with exactly tailored properties and function are centerpiece to future technological developments with impact across many areas of society including medicine and biochemistry, energy and information processing, just to name a few. Unfortunately, such materials are rarely found serendipitously but rather need to be manufactured and tailored using the principles revealed by science. The basic requirement to understand and control functionality is therefore our ability for probing and understanding the dynamics of interactions between photons, electrons and chemical bonds starting from the fastest "triggering" events, on the attosecond time scale, and at the shortest relevant length-scales, on the Ångstrom length scale. The need for such new photonics tools has been recognized globally [1] since society's ability to design molecular assemblies and materials directly relies on the development of new quantitative experimental tools that can track time-evolving structural changes and electronic excitations in a comprehensive manner. The much needed experimental tools consist of specialized light sources in combination with new detection methodologies. While light sources are now available [2] which combine the required temporal resolution with element specificity, currently available detection technology is not adequate to exploit the full potential of these new methodologies which hampers progress severely. We propose a remedy with a radically advanced detection technology which permits attosecond temporal probing with single photon element selectivity in real time. The envisioned detection technology is phase-sensitive 4D detection (2D space, time and energy) and will have breakthrough consequences for many areas of science and industry. State of the art are time of flight cameras, such as from heliotis.ch, which feature on chip demodulation and pixel fill factors of 80% to decrease the data transfer rate from 90 billion samples/s to manageable 5000 frames/s with full amplitude and phase information. Based on this already existing technology, the decisive next step will be the combination of lock-in detection with energy dispersive readout and single photon detection sensitivity in the water window soft X-ray region. Single photon detection capability in this photon energy range would require engineering of well depths and new concepts beyond silicon drift detectors which achieve energy resolutions of 1 eV compared to the currently available 134 eV. The soft X-ray water window is defined between the C and O absorption edges of materials (294 eV to 534 eV) and is so important since it contains the fundamental absorption edges of organic matter (C, N, O) [3]. A camera with 4D single photon sensitivity would enable attosecond temporal resolution imaging of energy flow and molecular transformation with molecular fingerprinting accuracy within electronic sensors and magnetic storage materials, biological tissue or biochemical assemblies. I.e. we could "see"and therefore "follow"the flow of energy from one atom to the next in real time and for the first time. Such capability would profoundly impact fundamental science and, at the same time, radically advance and transform many areas of industry and technology.

1. Report of the Basic Energy Sciences Advisory Committee, United States Department of Energy.
2. S. M. Teichmann, F. Silva, S. L. Cousin, M. Hemmer, J. Biegert, "0.5 keV soft X-ray attosecond continua" , Nature Commun. in press; arxiv.org:1604.00631.
3. S.L. Cousin, F. Silva, S. Teichmann, M. Hemmer, B. Buades, J. Biegert, "High flux table-top soft X-ray source driven by sub-2-cycle, CEP stable, 1.85 μm 1 kHz pulses for carbon K-edge spectroscopy", Opt. Lett. 39, 5383 (2014).

Summary

We propose a radically advanced methodology which will permit seeing and following the energy flow inside biochemical assemblies, quantum materials and sensors in real time and with element selectivity. This advance will draw from 4D single photon imaging in the soft X-ray regime in combination with on chip phase sensitive detection. Such capability will profoundly impact fundamental science and, at the same time, radically advance and transform many areas of industry and technology.

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