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EDITORIAL

Ultrafast Imaging

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Ultrafast imaging is key for the real-time visualization of many transient events in physics, chemistry, and biology. The past decade has witnessed the blossom of new theories and technologies that have substantially propelled ultrafast imaging. The newly developed ultrafast imaging systems, in turn, have enabled unprecedented applications in both fundamental and applied sciences that unveil many new scientific discoveries ranging from carrier dynamics to brain functions. To date, ultrafast imaging marks an active frontier in both research and innovation.

This special issue of *Ultrafast Science* is composed of 2 review articles and 5 research articles showcasing recent advances in theories, technologies, and applications of ultrafast imaging. The topics of these articles cover broad areas, including ultrafast detectors, single- and multiple-shot ultrafast imaging, multiscale ultrafast imaging, computational ultrafast imaging, machine learning for ultrafast imaging, designs of ultrafast imaging devices or systems, as well as applications of ultrafast imaging in physics, chemistry, materials science, and engineering. A brief description of each paper follows.

Zeng and Lu et al. [1] review single-shot active ultrafast optical imaging (SS-AUOI). Following a brief introduction to this field, the article surveys major SS-AUOI approaches, including space division, spatial frequency division, wavelength division, and polarization division. Then, SS-AUOI by computational imaging, which is currently a hot research direction, is discussed in detail. This review is concluded with a prospect of SS-AUOI.

Inoue et al. [2] review basic theories and recent advances in light-in-flight (LIF) recording by holography for imaging of light propagation. Various developments in functional imaging techniques and the evaluation of LIF holography are presented, followed by a discussion on how space-division multiplexing and angular multiplexing techniques can extend the capability of LIF holography. Finally, the numerical models used to characterize LIF holograms are discussed in detail.

Hörmann and Visentin et al. [3] report an ultrafast holography microscopy technique to study the carrier diffusion processes in methylammonium lead bromide perovskites. By using ~100 diffraction-limited excitation spots over a wide field of view, this system captures the sample's photophysical heterogeneity. By averaging the signals from different spots, the system obtains a 10-fold increase in a signal-to-noise ratio compared to the single-spot counterpart. This high-sensitivity feature allows using lower excitation carrier densities to avoid spurious many-body kinetics.

Zhang et al. [4] exploit the collision-physics nature of recollision as a new path to study electronic structure and multielectron dynamics. By perturbing recollision trajectories with an infrared field, this work experimentally demonstrates all-optical measurements of photorecombination time delays using the Cooper minimum in argon and analyzes the relationship between recollision trajectories and the transition moment coupling the ground and continuum states. The study reveals the influence of an electron's parent ion on its recollision trajectories.

Marquez and Balistreri et al. [5] design a computational single-shot ultrafast imaging modality, termed compressed ultracompact femtophotography. In this proposed system, a chirped probe pulse maps a transient scene's temporal information to its spectrum. The modulated probe pulse is then spatially encoded by an optimized binary mask. Afterward, a super-dispersive metalens shears the wavelengths to different spatial positions on a 2-dimensional sensor. After data acquisition, a machine-learning-based reconstruction algorithm retrieves an ultrafast movie of the transient scene. Compressed ultracompact femtophotography's feasibility is verified by analytical modeling and numerical simulations.

Kornienko et al. [6] graft the periodic shadowing technique, which was originally developed for contrast enhancement in spectrometers, on streak cameras, to reduce the unwanted background signal generated by the space-charge effect. A sinusoidal mask separates the signal from the background in the spatial frequency domain during data acquisition. Applicable to all generations of streak cameras, this technique improves the dynamic range by 3 times, enhances the temporal resolution by 25%, and reduces the background noise levels by a factor of 50. The effectiveness of this method is verified in fluorescence lifetime imaging.

Barolak et al. [7] report a single-shot ultrafast ptychographic imaging system. The system generates 4 temporally separated femtosecond pulses, each phase-stamped with a different orbital angular momentum charge. These pulses incident at different angles to a 2-dimensional diffraction grating, which spatially duplicates each probe pulse. The diffraction intensities from multiple overlapping sections of a transient scene are recorded by a camera in a snapshot. Spatiotemporal information of the dynamic scene is reconstructed. At an imaging speed of billions of frames per second, this system captures the dynamics of conduction band electron population from 2-photon absorption in ZnSe pumped by a single femtosecond pulse.

We sincerely hope that these articles, which present exciting developments currently underway, will stimulate further advancement in ultrafast imaging. We thank all the authors for their valuable contributions and all the reviewers for their constructive comments.

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