Femtosecond pump-probe coherent X-ray diffraction imaging of ultra-fast processes

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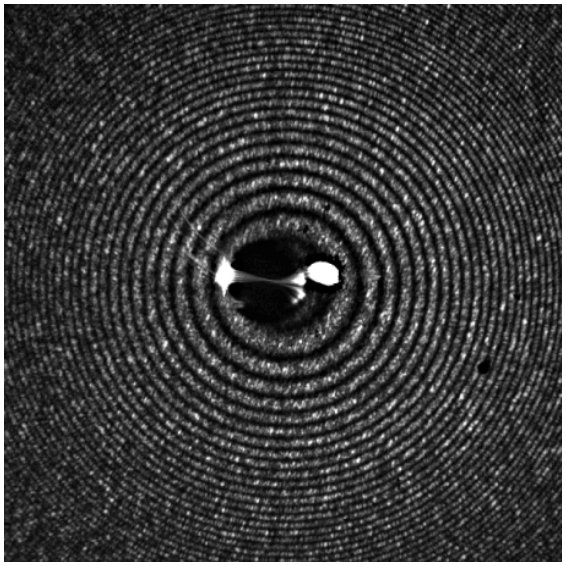
The intense, ultra-fast X-ray pulses produced by free electron lasers offer unique opportunities to study the dynamics of complex transient phenomena in materials. In particular, the high spatial coherence of these sources permit the use of coherent diffraction imaging to produce snapshots of the evolution of fast dynamic processes through time. The short wavelength of X-ray radiation allows probing the evolution of processes throughout the bulk of a sample, at spatial resolutions from the nanometer scale using current sources through to inter-atomic length scales using future hard X-ray FEL sources.

In the X-ray regime, time-resolved pump-probe experimental methods are challenging, requiring complex X-ray optical systems and diagnostics to synchronise the X-ray pulses that initiate a process and then probe it at a precisely defined time delay. We have developed and demonstrated a simple holographic technique in which the same X-ray pulse both pumps and probes the sample. The sample is placed near an X-ray mirror, which reflects the pulse back on to the sample after it initiates (or pumps) the reaction. The time delay is encoded by mirror separation to an accuracy of 1 fs, the sample structure is holographically recorded to sub-wavelength accuracy, and analysis of holograms recorded at different time delays yields information on the sample evolution through time. We have applied the technique to measure the explosion of hydrocarbon particles and other samples in intense FEL pulses. We observe sample explosion occurring well after initial sample heating, supporting the notion that X-ray flash imaging can be used to achieve high resolution beyond radiation damage limits for biological and other samples.