Observing atomic motions in space and time in low-dimensional nanomaterials by four-dimensional electron diffraction

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In the last decades, **low-dimensional nanometer-sized crystalline structures** have been widely studied because of their appealing physical properties, which strongly depend on the interaction between electronic and lattice degrees of freedom. Compared with bulk materials, the reduced dimensionality has profound effects not only on the ground state properties, but also on the dynamical behavior. Electron relaxations, phase transitions, atomic vibrations, and molecular rearrangements, which crucially determine the functionality of future nanodevices, generally occur on femtosecond (10^{-15} s) to picosecond (10^{-12} s) time scale. In this scenario, the observation of **atomic motions in space and time** becomes fundamental and requires the probing of the transient changes of the system with femtosecond temporal and atomic spatial resolutions.

Ultrashort electron pulses, which exhibit a de Broglie wavelength in the order of picometers, allow for achieving such resolutions both in diffraction as well as imaging. In this contribution, we employ a novel technique called **four-dimensional electron diffraction and microscopy**, to map the spatiotemporal behavior of atomic motions in several low-dimensional nanomaterials. Here, an ultrashort *photon pulse* is used for exciting the dynamics and an ultrashort *electron pulse* is applied to probe the system as a function of time delays. Our investigation spread from physics, to materials science, up to biology. In particular, in GaAs quantum dots, we have been able to visualize for the first time the *coherent* "ballistic" behavior of lattice vibrations (phonons) when they travel within the dots. We found that this behavior dominates the energy transport when the dot dimension is comparable to the length scale for quantum confinement (< 12 nm). These results, which have been chosen by *Nano Letters* to be the cover of the 11th issue of 2014 (see figure), are fundamental for the understanding of energy conversion in nanoscale materials suitable for thermoelectric applications.