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Imaging the motion of electrons in 2D semiconductor heterostructures.

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Technological progress since the late 20th century has centered on semiconductor devices, such as transistors, diodes, and solar cells. At the heart of these devices, is the internal motion of electrons through semiconductor materials due to applied electric fields or by the excitation of photocarriers. Imaging the motion of these electrons would provide unprecedented insight into this important phenomenon, but requires high spatial and temporal resolution. Current studies of electron dynamics in semiconductors are generally limited by the spatial resolution of optical probes, or by the temporal resolution of electronic probes. In this talk, we combine femtosecond pump-probe techniques with spectroscopic photoemission electron microscopy to image the motion of photoexcited electrons from high-energy to low-energy states in a 2D InSe/GaAs heterostructure exhibiting a type-II band alignment. At the instant of photoexcitation, energy-resolved photoelectron images reveal a highly non-equilibrium distribution of photocarriers in space and energy. Thereafter, in response to the out-of-equilibrium photocarriers, we observe the spatial redistribution of charges, thus forming internal electric fields, bending the semiconductor bands, and finally impeding further charge transfer. By assembling images taken at different time-delays, we make a movie lasting a few tens of picoseconds of the electron transfer process in the photoexcited type-II heterostructure – a fundamental phenomenon in semiconductor devices like solar cells. Quantitative analysis and theoretical modeling of spatial variations in the video provide insight into future solar cells, electron dynamics in 2D materials, and other semiconductor devices.