All-Optical Ultrafast Valley Switching in Two-Dimensional Materials

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Electrons in two-dimensional materials possess an additional quantum attribute, the valley pseudospin, labeled as K and K analogous to the spin up and spin down. The majority of research to achieve valleyselective excitations in valleytronics depends on resonant circularly polarized light with a given helicity. Not only acquiring valley-selective electron excitation but also switching the excitation from one valley to another is quintessential for bringing valleytronics-based technologies in reality. Present work introduces a coherent control protocol to initiate valley-selective excitation, de-excitation, and switch the excitation from one valley to another on the fly within tens of femtoseconds — a timescale faster than any valley decoherence time. Our protocol consists of three time-separated two-cycle linear pulses, polarized along the same direction. For efficient valley switching, the electric field waveform of the employed pulses are tailored by tuning the CEP. Our scheme is equally applicable to both gapped and gapless two-dimensional materials. Monolayer graphene and molybdenum disulfide are used to test the universality. Thus, our protocol is versatile as it relies on CEP-controlled nonresonant pulses and equally applicable to hexagonal gapped and gapless 2D materials. Moreover, our protocol is resilient to significant parameters in an experimental setup as it is oblivious to the wavelength of the pulses, time delay among pulses, and the dephasing time. The laser pulses used in our protocol have been recently employed to explore electron dynamics in solids. Therefore, our protocol of valley switching is within reach of experimental feasibility. Additionally, the present work can be extended to realize logical operations using valley pseudospins — similar to the recent experimental work in graphene using real and virtual charge carriers. We also test our protocol with CEP-controlled single-cycle pulses, and our findings remain qualitatively the same. To end, high-harmonic spectroscopy and time-resolved angleresolved photoemission spectroscopy could be employed to read the outcomes of the valley switching. Present work goes beyond the existing paradigm of valleytronics, and opens an alternative realm of valley switch at petahertz rate.

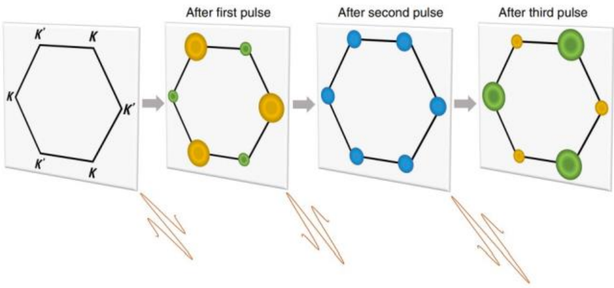

Figure 1. Schematic of an all-optical ultrafast valley switch in a two-dimensional material.

References

[1] Rana N *et al* 2023 Phys. Rev. Applied **19, 034056.**