Ultrafast signatures of Dirac – flat-band hybrid states from time-resolved ARPES

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Hybridization of highly itinerant Dirac electrons with localized flat-band states is predicted to yield emergent phenomena such as exotic heavy-fermion behaviour. Epitaxial graphene resting on a flat-band system at the graphene-SiC(0001) interface offers a promising platform, yet direct spectroscopic signatures - such as avoided crossings in equilibrium ARPES - have remained unresolved. We solved this problem using time-resolved ARPES where evidence of hybridization manifested in three key observations: (1) accelerated Dirac-carrier relaxation due to an increased scattering phase space, (2) transient charging of the Dirac cone enabled by direct optical excitation from the flat bands, and (3) ultrafast charge transfer back into the flat bands on timescales set by the interlayer coupling strength. We further demonstrate that the degree of hybridization can be tuned via the atomic number of the atoms intercalated at the graphene-SiC interface, establishing a controllable platform for investigating exotic correlated ground states. Our results thus provide a clear dynamical fingerprint of hybridization in a system where equilibrium probes have proven inconclusive.