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Capturing ultrafast electron heating from single-ion impact in solids

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Low to medium energy ions in the keV regime have become a standard tool to tailor material properties, enable nanostructuring and analysis at the nanoscale. Yet, accessing the intrinsic ultrafast response of solids to a single ion impact has long been hindered by the difficulty of generating and precisely timing short, monoenergetic ion pulses in this energy regime. We present a synchronized ion-pump/laser-probe scheme that overcomes this limitation by combining femtosecond photo-ionization of a geometrically cooled gas jet with a miniaturized buncher. This approach delivers monoenergetic keV ion pulses as short as ~4 ps (FWHM) and enables direct, picosecond-resolved probing of the target system response launched by single-ion excitation. Using suspended graphene membranes as targets and a sub-work-function probe pulse in a 2PPE-like scheme, we observe a robust secondary-electron signal that appears exclusively under spatiotemporal overlap of ion and laser pulses.
Supported by first-principles calculations, analysis of the enhancement in electron yields at pump-probe correlation quantifies a transient electronic temperature of approximately 2000 K within a few picoseconds after impact, establishing a direct metric for ion-induced hot-electron heating in solids. Our results demonstrate the feasibility and diagnostic power of synchronized ultrashort ion pulses for time-resolved studies of ion–matter interactions. Looking ahead, realistic optimizations point toward sub-picosecond ion pulses (⍰0.5 ps) and broader applicability across projectile species and materials classes, opening a route to directly observe non-equilibrium electronic dynamics following ion impacts.

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