Ultrafast Carrier Dynamics Revealing a Dimensional Crossover in $Ni_3In_2S_{2-x}Se_x$ Topological Semimetals

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Abstract

Topological semimetals host symmetry-protected band crossings that generate unconventional quasiparticles and anomalous electronic responses. In multiband systems, these crossings may form nodal lines that transform into massive Dirac or Weyl states upon strengthening spin–orbit coupling or breaking crystalline symmetry, as observed in Kagome materials. Here, we examine the alloy-controlled evolution of nonequilibrium carrier dynamics in the shandite Kagome semimetal $Ni_3In_2S_{2-x}Se_x$ using polarization- and fluence-resolved ultrafast pump–probe spectroscopy. Selenium substitution enhances spin–orbit interaction and induces negative chemical pressure, driving a crossover from weakly three-dimensional to predominantly two-dimensional electronic behaviour. The transient response shows clear polarization anisotropy and systematic fluence dependence, indicating orbital- and momentum-selective relaxation channels that evolve with composition. Increasing Se content further modifies relaxation lifetimes and signal amplitudes, consistent with spin–orbit–entangled interactions and Fermi surface reconstruction. These results establish polarization-resolved ultrafast spectroscopy as a sensitive probe of alloy-driven dimensional crossover and spin–charge coupling in Kagome semimetals.

Figures

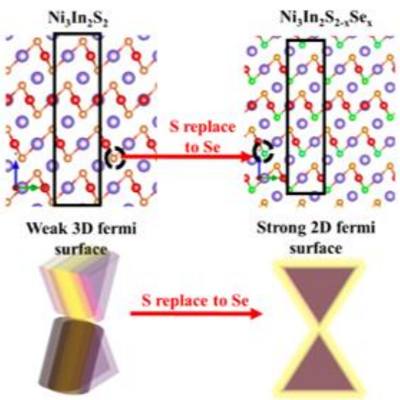

Figure 1: Schematic crystal structure of layered $Ni_3In_2S_2$ and its isovalent Se-substituted series, illustrating enhanced electronic anisotropy and a proposed Fermi-surface dimensional crossover from weakly three-dimensional (3D) to strongly two-dimensional (2D) with increasing Se content.

References

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