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VIEWPOINT

Bismuth under intense laser pulses: a Fano-like interference description

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New time-resolved experiments by Misochko *et al* published in a recent issue of *J. Phys.: Condens. Matter* [1] have furthered our understanding of the complex behaviour of Bi far from equilibrium.

There has been a long-standing interest in the dynamical path from a coherent to a stochastic state. In 1955, Fermi, Pasta, and Ulam (FPU) [2] numerically tested the ergodicity hypothesis of statistical mechanics. By considering a chain of classical harmonic oscillators coupled with a quadratic nonlinearity they investigated how the energy in one mode spreads to the rest. The study was performed on the fastest computing machine at the time (MANIAC I at Los Alamos). Surprisingly, instead of a gradual, continuous flow of energy from the first vibrational mode to the higher modes, FPU found that the system cycled periodically, i.e. after a while the first mode was revived.

Nowadays, the availability of intense femtosecond laser pulses in small-scale laboratories enables the generation and study of coherent phonon states in real materials. Particularly interesting for applications are the large-amplitude phonons, as they can offer a unique way to manipulate lattice structures and shapes [3]. However, understanding large-amplitude coherent dynamics is a difficult task, as it involves both electronic and ionic degrees of freedom departing from their ground state.

Bi is an interesting system to probe. It is a semimetal that exhibits a delicate coupling between its electronic and ionic subsystems. This is evidenced by its α-arsenic A7 crystal structure, which is an almost perfect cubic structure with a slight elongation along the (111) diagonal (figure 1). The origin of this distortion is the Peierls effect, which is most commonly encountered in one-dimensional systems. In the report of Misochko *et al* [1], two coherent modes of different symmetries are excited and studied: a fully symmetric A_{1g} mode, where atomic motion occurs along the Peierls distortion direction, and a degenerate E_g mode, where motion occurs in the perpendicular plane (figure 1).

Various time-resolved studies on the Bi response obtained that low-amplitude coherent phonon dynamics showed the expected decay and thermalization. However, for above-threshold excitations, the recurrent dynamics of coherent phonons reminds one of the celebrated FPU paradox, showing a collapse and revival in the A_{1g} mode [4]. Such nonlinear behaviour brings into attention both lattice anharmonicity [5] and dynamical screening effects [6]

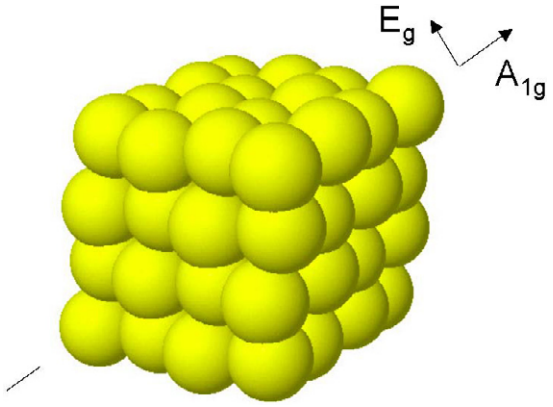

Figure 1. Structure of Bi.
(This figure is in colour only in the electronic version)

(i.e. weakening of the restoring force due to electronic excitations). The importance of one aspect over the other is currently a subject of dispute.

The complex experimental results of the large-amplitude coherent dynamics for the two different symmetry phonons are nicely explained now by Misochko *et al* [1] in the framework of a Fano interference between the discrete phonon levels and a continuum. This interpretation leads to the conclusion that the continuum mediating the interference involves *both* the electronic and ionic subsystems. The mechanism underlying the Fano interference can also explain the transition from small-amplitude coherent oscillations to the large-amplitude one. Interestingly, the nature of the continuum appears to depend on the time instant: while electronic aspects are important at short times, the effect of lattice anharmonicity dominates at longer times. It is likely that the mechanisms exposed in this time-resolved study of the Fano interference in Bi will be relevant in other materials.

Larger efforts are going on to time-resolve lattice dynamics by femtosecond x-ray pulses [7]. In the future it may be possible to combine optical experiments such as those published by Misochko *et al* [1] with lattice dynamics ones, and gain a deeper understanding about the interplay of electronic and ionic degrees of freedom under non-equilibrium conditions.

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