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Controlling and observing atomic motion in solids with light

Light is electromagnetic radiation which is characterised either by its wavelength or frequency in the electromagnetic spectrum. Depending on the wavelength or the frequency, light can interact in various different ways with matter, allowing for the study of various properties in the condensed matter, such as structural dynamics in solids. In particular, in the so-called pump-probe experiments, it is possible to first excite the solid under study by a pump laser of certain wavelength and probe it afterwards with another light source of different wavelength giving information on the excited properties. This methodology, by appropriate choices of the pump and probe wavelengths, allows us to both control and observe atomic motion in solids.

In solid materials the atoms are typically ordered in a repeating manner, and this periodic arrangement of the atoms is known as the crystal structure of a solid. However, only at absolute zero temperature, the atoms are exactly "frozen" in their positions, and at non-zero temperatures these atoms oscillate back and forth in different directions around their equilibrium positions in the crystal. Due to the symmetric arrangement of the atoms in a crystal structure, these vibrations can only occur in certain directions, which are also known as the different phonon modes of a crystal. The frequency of vibration of these phonon modes is typically in the order of few terahertz. If a pump laser light source is taken with a frequency close to the frequency of a phonon mode, it is possible to exert a force on the atoms by the electric fields of the laser pulse, such that the atoms in the crystal start to coherently vibrate along a certain vibrational mode.

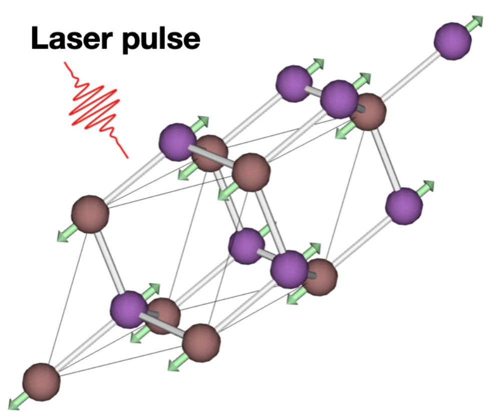

***Figure 1**: Coherent vibrational mode in a crystalline InSb solid excited by a ultrashort THz laser pulse.*

The distance between the atoms in a crystalline solid is in the order of 10^{-10} m. This length scale is in the order of the wavelength of the electromagnetic radiation known as X-rays. When these X-rays scatter from a periodic array of atoms, they exhibit phenomena known as diffraction. This diffraction of the X-rays from a crystalline solid depends on the relative distances between the atoms in the crystal. Therefore, if the pump laser pulse, exciting the coherent vibration of the atoms in the solid, is synchronised with the X-rays in a pump-probe setup, it is possible to both control and observe the atomic motion in a crystal lattice.

In my project, I have done theoretical modelling on the interaction between a THz pump laser pulse and the phonon modes of a zincblende semiconductor InSb, and studied the effect of these phonons on the X-ray diffraction intensity. This study has been fruitful for understanding the fundamental interaction between THz laser pulses and phonons, and has pawed a way for a new ultrafast experimental technique, which would allow us to gain insight into the so-called anharmonic properties of phonons. These anharmonic properties are not at present well characterised, and they are needed, for example, as material parameters for the development of next generation solar cells.

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