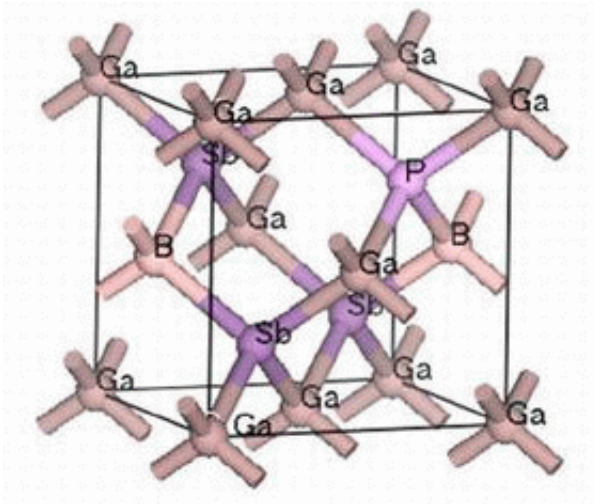


Scientists tailor light waves to desired frequencies

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The resonant frequency of a GaSb crystal lattice can be shifted by substituting some of the Ga and Sb atoms (representing one type of dipole) with B and P atoms (representing a different type of dipole). Image credit: Liao, Chungpin, et al.

The ability to control light is vital for many of today's technologies, most notably in communications and advanced computing. For example, by using materials from mirrors to nanoparticles, scientists can alter light's speed with refraction, use diffraction to bend light, use electric fields to rotate light's polarization, and more.

One of the newest ways to control light is to tailor its frequency

(wavelengths per unit of time) to a desired rate. This ability would be valuable for researchers creating a variety of optical and electro-optical applications.

Generally, the resonant frequency (or natural tendency of an object to vibrate at a certain frequency) is thought to be a fixed property of natural and man-made materials. However, in the past few years, scientists and engineers have used a few “artificial” techniques for shifting the resonant frequency of a material. By implanting molecules or compounds, which act as artificial dipole moments, or by embedding quantum dots, scientists can tailor a material to exhibit a desired frequency.

Recently, scientists have used simulations to demonstrate a clever “classical” method for shifting resonant frequencies. Chungpin Liao and Hsien-Ming Chang from National Formosa University in Taiwan numerically incorporated electric dipoles in a host material lattice to achieve a collective beating of the various dipoles. This “collective dipole engineering” enabled them to create predetermined resonance peaks around desired frequencies where no natural frequencies existed.

“This newly generated oscillation is associated with no corresponding physical oscillators,” Liao explained to *PhysOrg.com*. “Namely, no physical oscillators at that new frequency exist. And thus the new oscillation appears to be generated by phantom dipoles. In other words, it is of much advantage when the type of physical resonators of the desired frequency is not available.”

The scientists explained that the method was guided by the Clausius-Mossotti equation, which describes optical dispersion by treating an individual atom as a light-reacting dipole (a pair of electric charges). In this model, the electron cloud oscillates around the nearly motionless nucleus. By mixing different types of dipoles, Liao and Chang showed

that researchers could create previously nonexistent shifted resonance in the original material.

“The technique is like entangling two kinds of springs of different natural oscillation frequencies together, in many different probable fashions,” Liao explained. “By doing this, a third (or more) collectively created new oscillations would emerge. So, this general phenomenon happens every day all around us. We simply attempted to secure an effective way to apply it in the optics and electro-optics areas.”

The scientists demonstrated this frequency alteration using quantum mechanical simulations with CASTEP (Cambridge Sequential Total Energy Package), a program that can simulate electronic, optical and structural properties of materials without requiring experimental input.

The scientists started with a gallium-antimony crystal lattice (acting as original dipoles with a natural frequency) and then replaced four gallium and four antimony atoms in the lattice with four boron and four phosphorous atoms, respectively. This change created previously nonexistent dipoles, which resulted in a shifted resonance. The shift shown in the simulation closely matched that predicted by the Clausius-Mossotti equation.

Liao and Chang’s work has shown the feasibility of using collective dipoles, whether in the form of molecules, crystal defects, or nanostructures, to modify the optical properties of a material by shifting its resonance. Beyond that, the scientists hope that the method will provide a way for optics applications to use light for their desired purposes. Liao has a long list of uses:

“For example, applications could include a spectrally-precise mirror or beam dump; using a variable Brewster angle (at an incident angle on a material, the shining TM [transverse magnetic] wave will encounter no

reflection) for light-guiding in integrated optics for communication; and new optical elements—for example, new lenses, prisms, etc.

“Also, this ability could be used for efficient resonance absorptions for new solar cells and solar heaters; high-refractive-index materials for the making of efficient single-layer, wide-spectrum light reflection (not multi-layer, single-wavelength as in today's technology); light-trapping and its applications; and variations of materials' colors and their refraction patterns.”

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