NAIST® Research Highlights

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NAIST researchers theoretically examined how terahertz spectroscopy would help analyse electrons and electron holes, as well as electronic plasma, and how they behave around the exciton Mott transition – the point at which electron-hole pairings disappear.

Terahertz spectroscopy

Probing exciton transitions

Electron interactions in semiconductors have been theoretically calculated using terahertz absorption spectra

Terahertz radiation — between the mid-infrared and microwaves regions — is an important transition point on the electromagnetic spectrum, and can be used to visualize the boundary between quantum and classical physics. It is a band with many potential applications, from biotechnology to the development of low-energy optoelectronic devices.

Researchers at NAIST conducted a theoretical study examining electronic plasma (an electrically-charged gas made up of free-flowing carriers) and paired electron-hole structures in optically excited semiconductors, seeking to understand how terahertz spectroscopy might help visualize phenomena[1].

“The issue of electron interactions is very difficult and has been studied for five decades,” states Takeshi Inagaki, who worked on the study with colleague Yen Thi Hai Le at the NAIST Graduate School of Materials Science. “We needed a new way to tackle this problem.”

When light shines on an optically excited semiconductor, electrons in the valence band are excited to the conduction band, leaving holes in the valence band. This process is analogous to the movement of electrons through different energy bands in a hydrogen atom. As the negatively-charged electrons move, Coulomb’s law means they remain bound to their positively-charged electron holes — creating electron-hole pairs called excitons.

Inagaki and Le used numerical analysis to examine three-dimensional electron systems in cuprate semiconductors under terahertz (THz) radiation. They were particularly interested in electron interactions around the exciton Mott transition; the point at which electron-hole pairs disappear because the density of the electrons and holes, and the density of the ionized electronic plasma, have reached certain critical levels.

“We developed a computer program to calculate THz absorption spectra for different exciton densities,” explains Inagaki. “NAIST has a high-spec computing system which made this job fairly straightforward.”

A previous experimental study had shown that the spectral component left by electron movements from the 1s to 2p energy band remained the same regardless of exciton density. The researchers were able to explain this phenomenon using their new theory.

They also found that the exciton Mott transition was clearly visible using THz radiation, observing a sudden increase in the densities of both the electronic plasma and the electron-hole pairs just before the spectra from exciton structures abruptly disappeared. At a certain level of ionization density, both excitons and electronic plasma co-exist, the semiconductor becomes metallic and electric current flows.

“Understanding the nature of the system near the exciton Mott transition is very useful,” states Inagaki. “It will help us incorporate electron interaction effects into new, low-energy devices.”

Reference

1. Le, Y. T. H. & Inagaki, T. J. Density dependence of the terahertz absorption spectra in optically excited semiconductors. *Physica Status Solidi B* advance online publication, 25 November 2014 (doi: 10.1002/pssb.201451191).

More information about the group’s research can be found at the Theoretical Condensed Matter Physics Laboratory webpage: http://mswebs.naist.jp/english/courses/1438/