Terahertz radiation can induce insulator-to-metal change of state in some materials: study

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Image showing a scanning electron microscope image of damaged vanadium dioxide in the gap of a terahertz metamaterial made of gold. The damage results when strong field enhancement of incident terahertz radiation in the gaps leads to a rapid increase in the energy density following the field-driven insulator-to-metal transition. Image Credit: Mengkun Liu / Mario D'Amato

(Phys.org) -- A team of researchers at Boston University (BU), Massachusetts Institute of Technology (MIT) and a number of other institutions recently observed that certain materials undergo an insulator-to-metal transition under the influence of terahertz (THz) radiation. The study, under the direction of Richard Averitt, professor of physics at Boston University, and Keith Nelson, professor of chemistry at MIT, was published earlier this month in the journal *Nature*.

The research team achieved a first by demonstrating the use of THz light pulses to control the phase (state of matter) of a material. In this case, the researchers were able to change vanadium dioxide (VO2), from an insulating electronic state to a conducting electronic state.

Terahertz-frequency radiation lies between infrared radiation and microwave radiation in the electromagnetic spectrum and shares properties with each. Terahertz radiation can penetrate a wide variety of non-conducting materials, such as clothing, paper, cardboard, wood, masonry, plastic and ceramics, although the penetration depth is typically less than that of microwave radiation. According to Harold Hwang, a post-doctoral physical chemist at MIT, electrons moving in a THz electric field can gain considerable energy (charges accelerate in an electric field). Says Hwang, "Sub-picosecond THz pulses can allow us to initiate strong changes in a material. In the case of VO2, the THz pulse actually distorts the potential in which electrons lie, freeing them up to make the material a better conductor." However, to do this requires very strong THz fields: In this case, the researchers used an antenna-like structure called a split ring resonator to concentrate the electric field of a THz pulse in a small area, increasing the electric field from hundreds of kilovolts per centimeter to about 4 megavolts per centimeter.

"Electric fields of this magnitude can drive not only the phase transition in VO2, but also strong nonlinear responses in many different systems," says Hwang. "This opens the door to , high-field THz control over electronic and magnetic responses in superconductors, magneto-resistive materials and other correlated electron systems, THz-induced ballistic electron transport in semiconductors, and THz-driven structural change in insulating crystals and glasses.

Hwang adds that, because THz frequencies match the resonant frequencies at which neighboring atoms and molecules in crystal lattices vibrate against each other, THz pulses can drive the lattice vibrations directly—possibly to large amplitudes. THz light can drive electrons and whole atoms and molecules far from their equilibrium locations in a crystal lattice, which can lead to phase transitions in electronic state and/or crystal structure. This can occur by literally moving the atoms into the positions they occupy in a new crystalline phase. Experimental attempts at THz-induced structural phase transitions are currently under way.

Research interest in the THz region of the electromagnetic spectrum has increased significantly over the last decade, due to the promise THz light shows in applications ranging from security screening, to bio imaging, to electronics.

The BU and MIT groups and their collaborators have demonstrated the ability to induce a phase transition that changes the conductivity of a VO2 film by two orders of magnitude. Further studies have shown conductivity changes of several orders of magnitude in semiconductors. “This shows a lot of promise in being able to detect THz radiation, since the change in conductivity can be read out with conventional electronics,” adds Hwang. “We are hopeful that this kind of technology will lead to more sensitive and cheaper THz detectors, possibly leading to practical THz imaging systems for use in several sectors in industry.”

Another promising application of this research is for making Mott-based field-effect transistors (FET) that potentially might overcome intrinsic scaling limitations that currently are being encountered in Silicon (Si)-based transistors. “Electric field switching in the Mott transistors might be a potential substitute for the Si-based FET, in some applications,” says Mengkun Liu, a post-doctoral researcher at UCSD who was a graduate student in Boston University’s Physics Department for this study. “We showed that the THz electric field switching dynamics, investigated by our methods, could be on the order of a few picoseconds. This suggests that transition metal oxide transistors could be used for fast device switching in a wide frequency range (from DC all the way to optical frequency).”

More information: “Terahertz-field-induced insulator-to-metal transition in vanadium dioxide metamaterial,” Mengkun Liu, Harold Y. Hwang, Hu Tao, Andrew C. Strikwerda, Kebin Fan, et al., *Nature* 487, 345-348; doi:10.1038/nature11231

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