Laser pulse turns glass into a metal

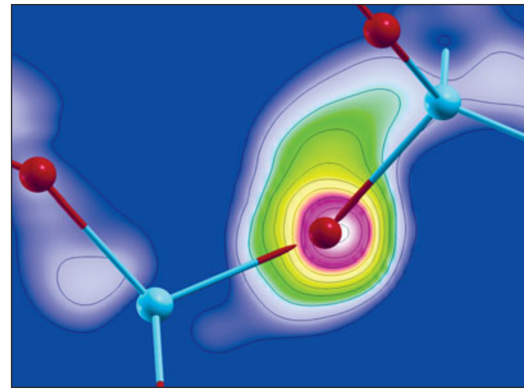
For tiny fractions of a second, quartz glass can take on metallic properties when it is illuminated by a laser pulse. This effect has the potential to be used to build logical switches, which are much faster than current microelectronics. Taking a step in this direction, Georg Wachter of Vienna University of Technology (TU Wien), Shunsuke A. Sato of the University of Tsukuba, and their colleagues have now explained this peculiar effect, as described in the August 22 issue of *Physical Review Letters* (DOI: 10.1103/PhysRevLett.113.087401; 087401).

Quartz glass, which does not conduct electric current, is a typical example of an insulator. With ultrashort laser pulses, however, the electronic properties of glass can be fundamentally changed within femtoseconds (1 fs = 10^{-15} seconds). If the laser pulse is strong enough, the electrons in the material can move freely. For a brief moment, the quartz glass behaves like metal. It becomes opaque and conducts electricity. This change of material properties happens so quickly that it can be used for ultrafast light-based electronics.

Quantum mechanically, an electron can occupy different states in a solid material. It can be tightly bound to one particular atom or it can occupy a state of higher energy in which it can move between atoms.

"The laser pulse is an extremely strong electric field, which has the power to dramatically change the electronic states in the quartz", says Wachter. "The pulse cannot only transfer energy to the electrons, it completely distorts the whole structure of possible electron states in the material."

That way, an electron which used to be bound to an oxygen atom in the glass can suddenly change over to another atom and behave almost like a free electron in a metal. Once the laser pulse has separated electrons from the atoms, the electric field of the pulse can drive the electrons in one direction, so that electric current starts to flow. Extremely strong laser pulses can cause a current that persists for a while, even after the pulse has faded out.


Computer visualization of electron flux.

"Modeling such effects is an extremely complex task, because many quantum processes have to be taken into account simultaneously," says Joachim Burgdörfer of TU Wien. The electronic structure of the material, the laser-electron interaction, and also the interactions between the electrons have to be calculated with supercomputers. "In our computer simulations, we can study the time evolution in slow motion and see what is actually happening in the material," says Burgdörfer.

In today's transistors, a large number of charge carriers move during each switching operation, until a new equilibrium state is reached, where this takes some time. When the materials properties are changed by the laser pulse, the switching process results from the change of the electronic structure and the ionization of atoms. As transistors usually work on a time scale of picoseconds (10^{-12} seconds), laser pulses could potentially switch electric currents a thousand times faster.

The calculations show that the crystal structure and chemical bonds in the material have a significant influence on the ultrafast current. Therefore, according to the researchers, experiments with different materials will be carried out to see how the effect can be used even more efficiently.