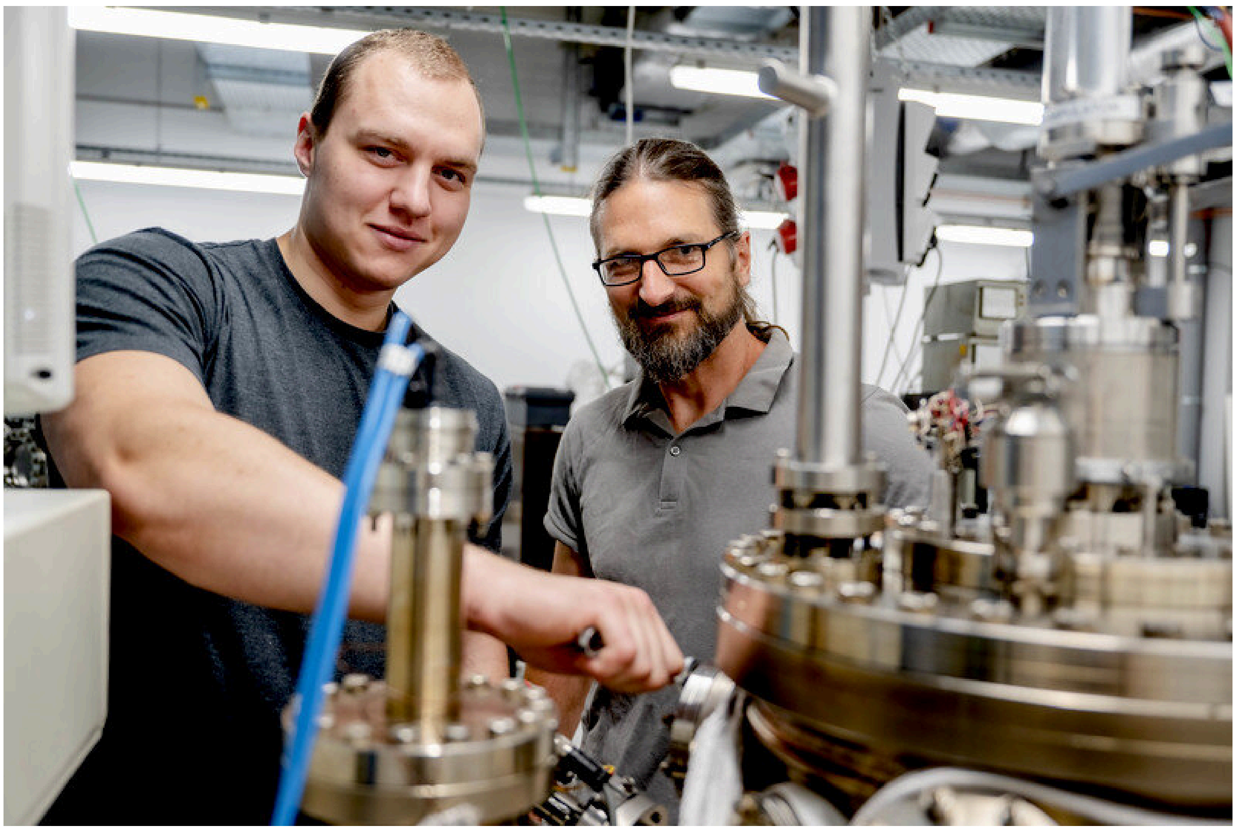
A new type of quantum bit in semiconductor nanostructures

July 25 2023, by Julia Weiler



The Bochum research team: Hans-Georg Babin (left) and Arne Ludwig. Credit: RUB, Marquard

Researchers have created a quantum superposition state in a semiconductor nanostructure that might serve as a basis for quantum computing. The trick: two optical laser pulses that act as a single terahertz laser pulse.

A German-Chinese research team has successfully created a quantum bit in a semiconductor nanostructure. Using a special energy transition, the researchers created a superposition state in a quantum dot—a tiny area of the semiconductor—in which an electron hole simultaneously possessed two different energy levels. Such superposition states are fundamental for quantum computing.

However, excitation of the state would require a large-scale free-electron laser that can emit light in the terahertz range. Additionally, this wavelength is too long to focus the beam on the tiny quantum dot. The German-Chinese team has now achieved the excitation with two finely tuned short-wavelength optical laser pulses.

The team headed by Feng Liu from Zhejiang University in Hangzhou, together with a group led by Dr. Arne Ludwig from Ruhr University Bochum and other researchers from China and the UK, report their findings in the journal *Nature Nanotechnology*, published online on 24 July 2023.

Lasers trigger the radiative Auger process

The team made use of the so-called radiative Auger transition. In this process, an electron recombines with a hole, releasing its energy partly in the form of a single photon and partly by transferring the energy to another electron. The same process can also be observed with electron holes—in other words, missing electrons. In 2021, a research team succeeded for the first time in specifically stimulating the radiative Auger transition in a semiconductor.

In the current project, the researchers showed that the radiative Auger process can be coherently driven. They used two different laser beams with intensities in a specific ratio to each other. With the first laser, they excited an electron-hole pair in the quantum dot to create a quasiparticle consisting of two holes and an electron. With a second laser, they triggered the radiative Auger process to elevate one hole to a series of higher energy states.

Two states simultaneously

The team used finely tuned laser pulses to create a superposition between the hole ground state and the higher energy state. The hole thus existed in both states simultaneously. Such superpositions are the basis for quantum bits, which, unlike conventional bits, exist not only in the states "0" and "1," but also in superpositions of both.

Hans-Georg Babin produced the high-purity semiconductor samples for the experiment at Ruhr University Bochum under the supervision of Dr. Arne Ludwig at the Chair for Applied Solid State Physics headed by Professor Andreas Wieck. In the process, the researchers increased the ensemble homogeneity of the quantum dots and ensured the high purity of the structures produced. These measures facilitated the performance of the experiments by the Chinese partners working with Jun-Yong Yan and Feng Liu.

More information: Jun-Yong Yan et al, Coherent control of a high-orbital hole in a semiconductor quantum dot, *Nature Nanotechnology* (2023). DOI: 10.1038/s41565-023-01442-y

Provided by Ruhr-Universitaet-Bochum