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Press Release

An acoustic cage for electrons

International team of scientist develops new concept for trapping and manipulating electrons with sound waves

The ability to trap and control electrons and other quasi-particles for the study of isolated single particles as well as many-body systems in a solid-state environment can be of major importance for understanding the behaviour of correlated electrons in technologically relevant materials. Because of their – compared to atoms – extremely small masses, these point-like particles are very fast and mobile. This, however, makes them hard to hold in place. Now, an international team of scientists around Prof. Ignacio Cirac (Max Planck Institute of Quantum Optics, Garching), and Prof. Mikhail Lukin (Harvard University, USA) have investigated a new way of building a cage for electrons *(Physical Review X 7, 24 October 2017)*. According to their proposal electrons can be moved or held in place by electric potentials that are generated by acoustic waves on the surfaces of piezoelectric materials. Furthermore, by using counterpropagating acoustic waves lattice structures similar to optical lattices for neutral atoms can be generated.

On the one hand, the scientists provide a general theoretical framework with guidelines to meet the necessary requirements for an experimental realization. On the other hand, they investigate the potential of specific layered semiconductor devices as experimental platforms. On top of being of fundamental interest for the controlled study of quasi-particles in solid-state settings, the envisioned setup represents a new way for quantum simulations of condensed matter, with the ultimate potential to study yet unexplored parameter regimes, thanks to specific system properties such as ultra-light particle masses, intrinsic electron-phonon cooling and strong inter-particle interactions.

The basic setup described in the paper consists of a layered structure: a thin, quasi two-dimensional film of a semiconducting material such as gallium arsenide, deposited on a substrate, is covered with a piezoelectric material. Two “interdigital transducers” (IDTs), consisting each of two thin film electrodes, are patterned on its surface. They generate counterpropagating “surface acoustic waves” (SAWs), which in turn induce a time-dependent periodic electric potential. This acts on the electrons that are confined in the semiconducting layer. The potential depth is controlled by the power, the lattice spacing by the frequency of the voltage applied to the IDTs.

SAWs have already been used successfully to change the position of an electron or to trap it for the few nanoseconds it takes the soundwaves to ripple along the surface. The new approach instead proposes a quasi-stationary trapping potential. “If the frequency of the sound wave is high enough, the electron’s potential landscape can effectively be described by a time-independent pseudolattice,” explains Johannes Knörzer, doctoral candidate in the Theory Division of Prof. Cirac at MPQ. “The electrons cannot adiabatically

Press & Public Relations
Dr. Olivia Meyer-Streng

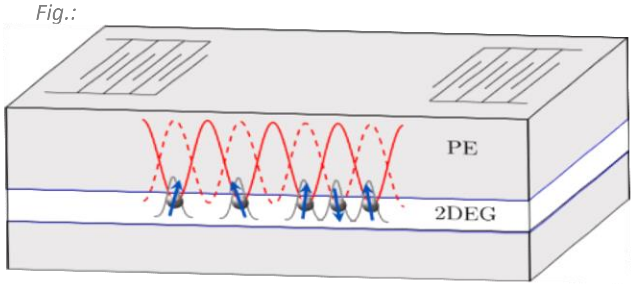
Phone: +49 89 32 905-213
E-mail:
olivia.meyer-streng@mpq.mpg.de

Hans-Kopfermann-Str. 1
D-85748 Garching

Phone: +49 89 / 32 905-0
Fax :+49 89 / 32 905-200

follow the rapidly oscillating force, and so they will effectively be trapped close to a potential minimum."

Fig.:



In a piezo-electric solid (PE), counter-propagating surface-acoustic waves generate a time-dependent, periodic electric potential for electrons confined to a two-dimensional plane, i.e. a two-dimensional electron gas (2DEG); the resulting acoustic lattices are one- or two-dimensional, depending on the geometry of the setup. At high SAW frequencies, the potential can be effectively described by a ***time-independent*** *pseudo-lattice. The motion of electrons at potential minima can be described by a harmonic oscillator, superimposed by small-amplitude, high-frequency micro-oscillations. (Graphic: from the original publication)*

One focus of the paper is the description of detailed conditions for dynamically trapping and cooling single particles in SAW-induced potentials. "The calculations imply, for example, that a very low temperature is required. Our theoretical treatment is, to some extent, reminiscent to that of trapped ions," Johannes Knörzer points out. The other focus is the simulation of quantum many-body systems by a system of electrons trapped in acoustic lattices. "The effective dynamics of the electrons in the sound lattices can be captured by the Fermi-Hubbard model, very much like for fermionic ultracold atoms in optical lattices," Knörzer adds.

The team analyses the viability of the concept for different heterostructures which support high-velocity sound waves. The calculations apply not only to electrons, but also to a variety of so-called "quasiparticles", such as excitons or holes, that arise in modern solid-state systems. "The wish to gain deeper insight into the properties and interactions of these particles is our motivation to search for trapping mechanisms that bring the generality and flexibility of optical lattices to the solid-state setting," resumes Prof. Ignacio Cirac. "Our ultimate goal is to understand the behaviour of correlated electrons in technologically relevant materials and molecules. This would pave the way towards building a universal quantum simulator." *Olivia Meyer-Streng*

Original publication:

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Contact:

Prof. Dr. J. Ignacio Cirac
Honorary Professor TU Munich and
Director at the Max Planck Institute of Quantum Optics
Hans-Kopfermann-Str. 1, 85748 Garching, Germany
Phone: +49 (0)89 / 32 905 - 705
E-mail: ignacio.cirac@mpq.mpg.de

Johannes Knörzer
PhD, Theory Division
Max Planck Institute of Quantum Optics
Hans-Kopfermann-Str. 1, 85748 Garching, Germany
Phone: +49 (0)89 / 32 905 - 315
E-mail: johannes.knoerzer@mpq.mpg.de

Dr. Olivia Meyer-Streng
Press & Public Relations
Max Planck Institute of Quantum Optics
85748 Garching, Germany
Phone: +49 (0)89 / 32 905 - 213
E-mail: olivia.meyer-streng@mpq.mpg.de