Magnetic quantum objects in a 'nano egg carton'

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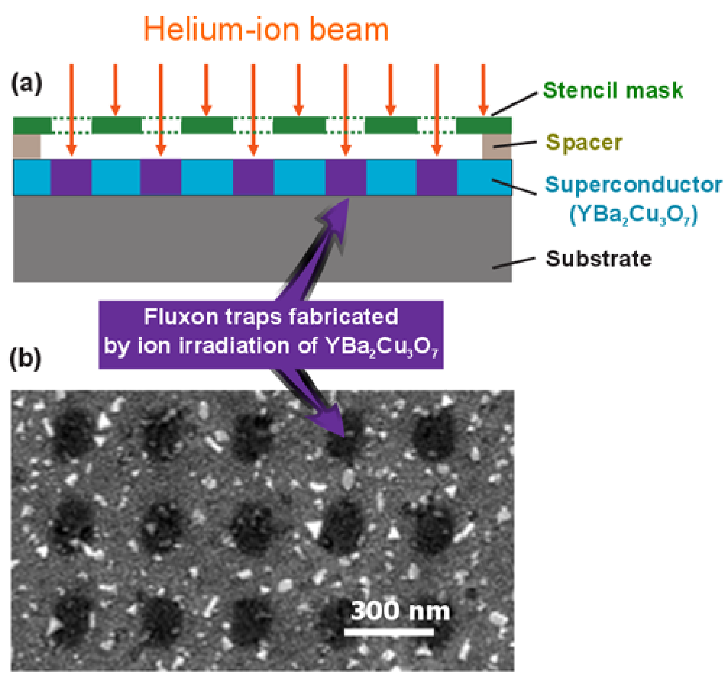

The principle of the fabrication of a "quantum egg-box" with a novel masked ion-beam technology, developed by the researchers. It allows to produce at the same time hundreds of thousands of traps for fluxons, magnetic flux quanta, in a superconductor.The picture at the bottom shows an electron-microscope image of the surface of the superconductor with some of these traps. Credit: Copyright: Wolfgang Lang, University of Vienna

Magnetic quantum objects in superconductors, so-called "fluxons," are particularly suitable for the storage and processing of data bits. Computer circuits based on fluxons could be operated with significantly higher speed while dissipating much less heat. Physicists working with Wolfgang Lang at the University of Vienna and their colleagues at the Johannes-Kepler-University Linz have developed a "quantum egg carton" with a novel and simple method. They realized a stable and regular arrangement of hundreds of thousands of fluxons—a groundbreaking development for circuits based on fluxons. The results appear in the journal *Physical Review Applied* of the American Physical Society.

Speeding up data processing in computers goes hand in hand with higher heat generation, which limits the performance of fast computers. Researchers therefore pursue digital circuits based on superconductors, materials that can transport electricity without loss when cooled below a certain critical temperature.

Magnetic quantum objects in superconductors

Inside a superconductor, a magnetic field can exist only in small quantized pieces called fluxons. These are particularly suitable for the storage and processing of data bits. In a homogeneous superconductor, the fluxons are arranged in a hexagonal lattice. Using modern nanotechnology, researchers at the University of Vienna and the Johannes-Kepler-University Linz have built artificial traps for fluxons. By means of these traps, the fluxons are forced into a predefined formation.

The importance of the non-equilibrium

Until now, the fluxons could only be observed in a thermodynamic equilibrium, i.e., in a uniform arrangement. "If we try to stack two eggs on top of each other in an egg carton and leave the adjacent pit empty, the egg would quickly roll down to an equilibrium state with exactly one egg in each pit," explains Wolfgang Lang from the University of Vienna. From the viewpoint of data processing, however, the fully filled egg carton contains little information and is therefore useless. It would be much more useful to place the eggs in a predefined pattern. In such a way, for example, QR codes recognized by smartphones could be realized in an egg carton—obviously, a large amount of information.

At the nanoscale, the researchers have now made a major step by demonstrating for the first time a stable non-equilibrium state of fluxons in an array of more than 180,000 artificial traps. Depending on the external magnetic field, the fluxons arrange themselves in terraced zones in which each trap either captures no fluxon, exactly one, or several fluxons. "Even after a period of days, we have observed precisely the same arrangement of fluxons—a long-term stability that is rather surprising for a quantum system," says Georg Zechner of the University of Vienna, the lead author of the study.

Nanopatterning of superconductors by ion beams

"Masked ion-beam irradiation allows for the fabrication of nanostructures in superconductors in a single step. It can be applied time efficiently to large areas, can be ramped up to an industrial scale and does not require any chemical processes," says Johannes D. Pedarnig of the Institute of Applied Physics at the Johannes-Kepler-University Linz. Depending on the mask used, virtually any desired structure can be patterned into the superconductor. The scientists are now planning further experiments on more sophisticated nanostructures, which should demonstrate the systematic transfer of fluxons from one trap to the next. This could be another pioneering step towards the development of fast computer circuits based on fluxons.

More information: G. Zechner et al, Hysteretic Vortex-Matching Effects in High- Tc Superconductors with Nanoscale Periodic Pinning Landscapes Fabricated by He Ion-Beam Projection, *Physical Review Applied* (2017). DOI: 10.1103/PhysRevApplied.8.014021

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