Scientists develop quantum metamaterial from complex twin qubits

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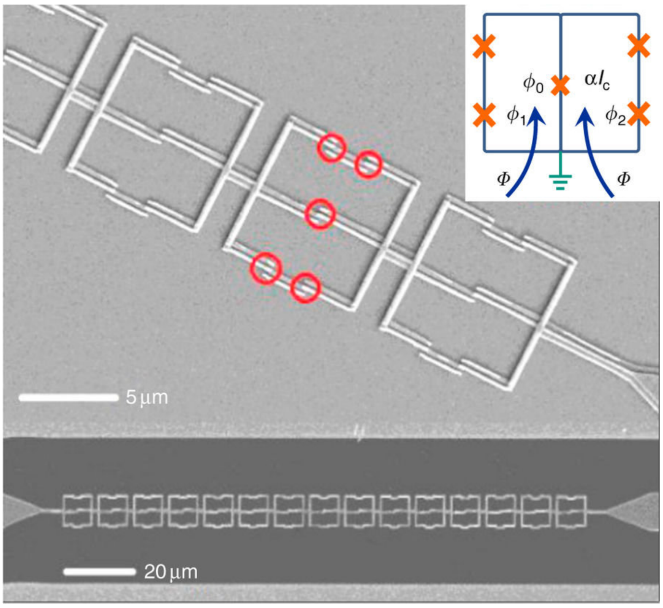


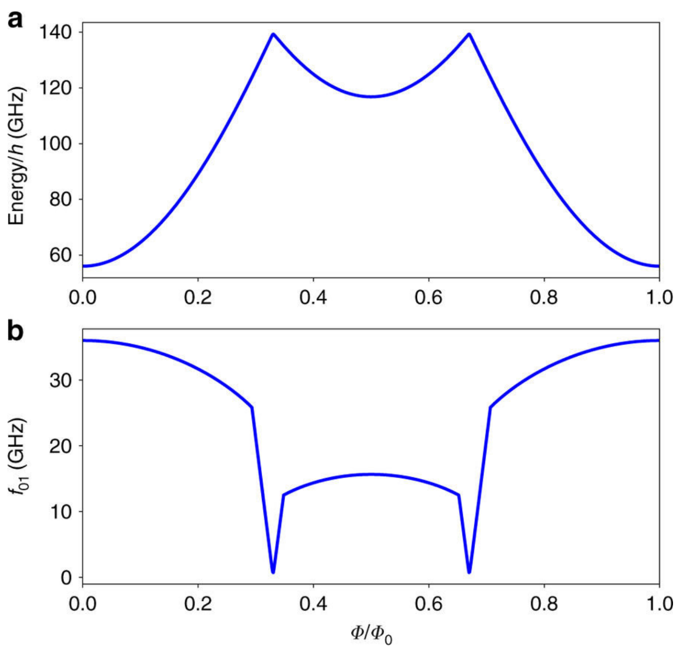
Superconducting quantum metamaterial consisting of an array of 15 twin qubits embedded in a coplanar wave guide. An SEM image of twin flux qubits (above) and a whole structure (below) are shown. Each qubit consists of two superconducting loops sharing one common central Josephson junction (?-junction) and four identical Josephson junctions located on the outer parts of the loops. The ?-junction allows the magnetic flux to tunnel between the loops. The inset is a schematic of a single meta-atom--the twin flux qubit; the phases on nodes are shown Credit: NUST MISIS

An international team consisting of Russian and German scientists has made a breakthrough in the creation of seemingly impossible materials. They have created the world's first quantum metamaterial that can be used as a control element in superconducting electrical circuits.

Metamaterials are substances whose properties are determined by the structural arrangement of the atoms. Each structure is hundreds of nanometers, and has its own set of properties that disappear when scientists try to separate the material into its components. Such a structure is called a meta-atom (not to be confused with the common atoms of Mendeleev's Periodic Table). Any substance consisting of meta-atoms is called a meta-material.

Until recently, another difference between atoms and meta-atoms was that the properties of conventional atoms were described by quantum mechanics equations, while meta-atoms were described by classical physics equations. However, the creation of qubits led to the opportunity to construct metamaterials consisting of meta-atoms whose state could be described quantum mechanically. However, this research required the creation of unusual qubits.

An international team of scientists has created the world's first so-called "twin" qubit, as well as a metamaterial on its basis. Thanks to the outstanding properties of the new material, it will be possible to create one of the key elements in superconducting electronic devices.

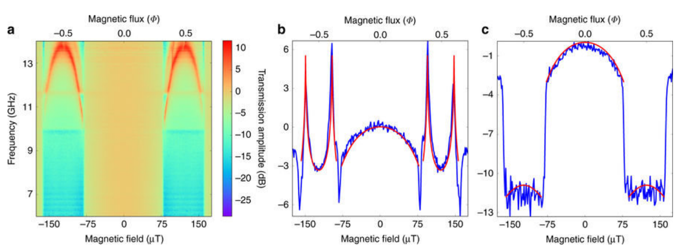


The energy of the ground state (a) and the transition energy hf01 of the twin qubit calculated from the Hamiltonian of Eq. (1) (b). The parameters ??=?0.72 and C?=?5.2 fF and the Josephson energy is E J ?=?50?GHz. These dependencies are ?0 periodic and symmetric with respect to ?/?0?=?0.5. The minimum point of the (b) plot corresponds to the transition of the central junction phase ?0 from zero to ?. Credit: NUST MISIS

Kirill Shulga, a researcher at the NUST MISIS Laboratory of Superconducting Metamaterials and the first author of the project, noted that a conventional qubit consists of a scheme that includes three Josephson junctions. The twin qubit, however, is composed of five junctions that are symmetric to the central axis (see diagram).

"Twin qubits were supposed to serve as a more complex system than the conventional superconducting qubits. The logic here is quite simple: a more complex (artificially complex) system, with a large number of degrees of freedom, has a higher number of factors that can influence its properties. When changing some external properties of the environment where our metamaterial is located, we can turn these properties on and off by turning the twin qubit from one state with certain properties to another with other properties," he said.

This became apparent during the experiment, as the whole metamaterial consisting of twin qubits switched over between two different modes.



a The measured dependence of the amplitude of transmission coefficient t (normalized to the value at zero field) on applied dc magnetic field (proportional to the bias current in the coil, lower axis) and frequency f. The upper horizontal axis translates the field in magnetic flux ? per qubit single loop. The transmission t displays the sharp changes under variation of the magnetic flux ?. One can see two different ranges of microwave propagation, nearly flat transmission around zero field and sharp resonant enhancement of the transmission near 11-14?GHz at magnetic flux ??~?±?0/2. b A cross-cut of a at the fixed frequency of 13?GHz. The sharp peaks correspond to coherent tunneling between quantum states in the twin qubits (see text). c A cross-cut of a at the fixed frequency of 10?GHz. The sharp jumps correspond to a transition between zero and ? phase on the central junction of the twin qubit (see text). Red curve is a fit to the theoretically predicted dependence Eq. (12) Credit: NUST MISIS

"In one of the modes, the chain of qubits transmits electronic radiation in the microwave range very well while remaining a quantum element. In another mode, it turns the superconducting phase by 180 degrees and locks the transmission of electromagnetic waves through itself. Yet it still remains a quantum system. So with the help of a magnetic field, such a material can be used as a control element in systems for quantum signals (separate photons) in circuits, from which developing quantum computers consist of," said Ilya Besedin, an engineer at the NUST MISIS Laboratory of Superconducting Metamaterials.

It is hard to accurately calculate the properties of one twin qubit on a standard computer compared to the properties of a standard qubit. It is possible to reach the limit of complexity, a level close to or surpassing the capabilities of modern electronic computers, if qubits become several times more complex. Such a complex system can be used as a quantum simulator, i.e. a device that can predict or simulate properties of a certain real process or material.

As the researchers note, they had to sort out lots of theories to correctly describe the processes that occurs in quantum meta-materials. The article, "The Magnetically induced transparency of a quantum metamaterial composed of twin flux qubits," is published in *Nature Communications*.

More information: K. V. Shulga et al,

Magnetically induced transparency of a quantum metamaterial composed of twin flux qubits, *Nature Communications* (2018). DOI: 10.1038/s41467-017-02608-8

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