

## Multi-photon transitions between energy levels in a current biased Josephson tunnel junction

Research conducted by a team headed by Professor Alexey Ustinov and Dr Andreas Wallraff at the Physikalisches Institut III at the University of Erlangen-Nuremberg in Germany, is shedding light on quantum mechanics of macroscopic systems. Their study of superconducting devices may help to make use for computation the quantum phenomena, which are hindering the miniaturisation of conventional microchips. Superconducting junctions are now seen as the best candidates for replacing semiconductor transistors in future quantum computers.

### Nanocomputers – hindered by quantum effects

Recent years have borne witness to the amazing growth rate in computer power. This rapid progress is mainly due to the continual miniaturisation of one of the most fundamental components of a computer, the transistor.

As the transistor size decreases, more can be integrated into a microchip to improve the computational power. This miniaturisation, however, is now approaching its limit. If microchips were smaller still, to a scale of tens of nanometres, their operation would be disrupted by the emergence of a variety of quantum phenomena. The tunnelling of electrons through barriers between wires occurs at this scale and the discreteness of the electrical charge represents a key problem.

To allow computational science to advance, an alternative to transistor technology must be found, where components function through quantum effects, rather than in spite of them.

### The researchers aims

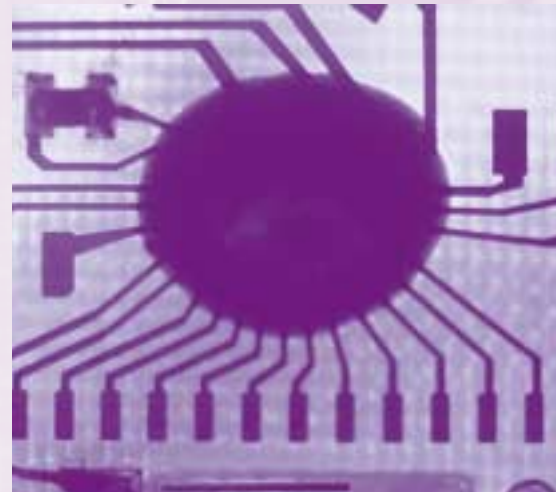
Professor Ustinov and his team have tried to understand the quantum tunnelling effect for a macroscopic state using a superconducting Josephson junction. The team excited the junction with microwaves and measured the decay of its superconducting state in order to investigate the interplay between the single-photon and multi-photon

transitions across the junction energy levels. Continuing these experiments with pulsed microwaves the team hopes to obtain information on phase decoherence – destruction of the coherence of a macroscopic quantum state – thought to be a major issue for quantum computing.

### ULT a necessity

Macroscopic quantum tunnelling in a Josephson junction can only be observed below a cross-over temperature  $T^*$ , which ranges for different junctions between 50 and 300mK. The experiments must be conducted at ultra low temperature (ULT), because, since only in the  $T < T^*$  regime that quantum processes dominate over thermal fluctuations. To observe this macroscopic quantum tunnelling effect, the team used a Kelvinox™ 100 dilution refrigerator.

The dilution fridge was fitted with special electronic filters and attenuators mounted at the 1K-condensing stage. Low temperature performance, available space and the stability of the system allowed the team to perform this type of experiment. In addition, various rf filters at room temperature and at the 1K pot region are necessary to reduce external electromagnetic interference. In order to perform this experiment, cold dc magnetic shields, special wiring for dc lines (thermocoxes and copper powder tubes) and several stages of cold attenuators in the microwave lines had to be mounted.



In quantum information technology, coherent control of quantum bits (qubits) is required. As well as the qubits already demonstrated, for example, in ion-trap, cavity QED, and NMR experiments, several kinds of solid-state qubit implementations have been proposed for possible use in an integrated quantum circuit. The most promising have been so far Josephson junction circuits, which have been recently successfully tested by several groups as qubits in quantum information processing.

By exciting the Josephson junction state in a quantum well, through microwave frequencies 10 – 40 GHz, the Erlangen team have shown that single and multi-photon transitions were generated. This photonic absorption caused the current-biased junction to switch into a non-zero voltage state. These multi-photon transitions could be the additional cause of phase decoherence in microwave driven superconducting qubits. At the same time, they offer an opportunity to manipulate the quantum state of a qubit and hence the quantum information of the future quantum computer.

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