

[Emerging Device Technology](#) > **The quantum properties of Josephson devices based on oxide superconductors**

Collaboration with University of Birmingham Physics department and University of Cambridge department of Materials Science.

Ordinary computers use the binary number system based on binary digits or “bits” 1 and 0 because it is easy to represent that using the presence or absence of a voltage or charge stored on a capacitor. If you want to carry out a computation, you add, subtract or multiply the voltage levels using transistors connected to form logic gates. For very large computations this can take a very long time as the calculation have to be done one at a time on all the different combinations of numbers.

A quantum computer uses that fact that a quantum system with two states can be put in a superposition, meaning that it exists in both states and all possible combinations in between at the same time. This is the famous Schrodinger’s cat problem. You imagine put a cat in a box with some of its favourite food which you have poisoned, but the food is under a cover which won’t open unless a radioactive isotope you have attached to the lock decays and that has a 50% probability during the time of the experiment. After you close the box, whilst you are waiting for the appointed time, is the cat alive or dead? You don’t know, but in our world we would say that it is one or the other. For a quantum system you say that it is both! Opening the box and measuring the system forces it to be in one state or the other. This is not a theory or a piece of philosophy for a quantum system, but a scientific fact. This fact means that because your quantum bits or qubits are in a superposition state, you can carry out all parts of a computation in parallel rather than one after another. This is particularly important for calculations involving large numbers like code breaking or simulations of large systems. The potential advantage you gain with this can be seen by noting that a typical microprocessor in a personal computer has 24 million transistors on a single chip, a quantum computer consisting of a few hundred qubits would be better than this. One with a few thousand would be better than any computer that exists today.

How does superconductivity come into this? First of all superconductors are naturally large scale quantum systems, so they are ideal for making solid state circuits for this application. Secondly quantum systems are very delicate. Heat radiation never mind electrical interference is sufficient to destroy quantum effects and so any quantum computer will need to operate at very low temperatures anyway, so superconductors become a natural choice.

$n\Phi_0 = LI_s$

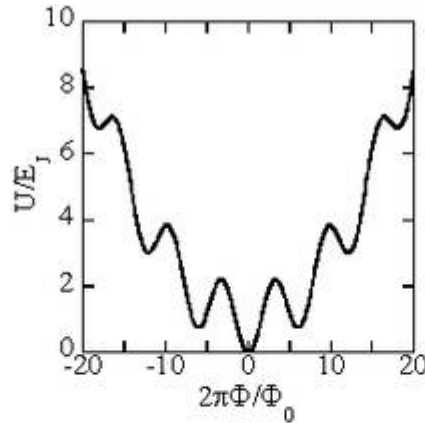


Flux is quantised in superconducting loops

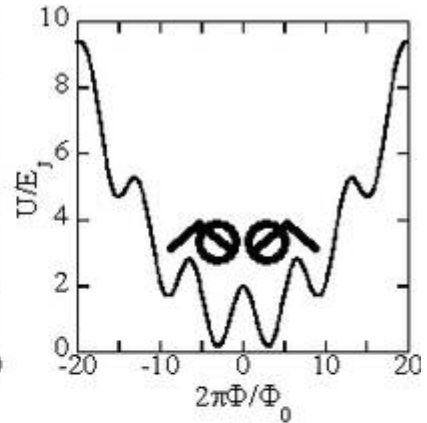
Finite flux is maintained by a spontaneous supercurrent I_s

Energy =

$$\frac{1}{2} LI_s^2 = \frac{(n\Phi_0)^2}{2L}$$



Add a junction and flux is no longer quantised



Apply bias flux $=\Phi_0/2$ to obtain a doubly degenerate ground state

Figure 1 Flux is quantised in superconducting loops, but a loop containing a Josephson junction forms the basis for a quantum bit.

There are several ways of making a qubit using superconductors, but the one we are interested in uses the Josephson effect and superconducting loops. Here the superconducting loop contains a number of weak links which depends upon the design. When a magnetic field corresponding to a half flux quantum threading the loop is applied, a circulating current is set up which can either flow clockwise or anticlockwise. When the ring is cooled down sufficiently and the weak links have been tuned to have the right properties, it enters the “Schrodinger’s cat” state which is a superposition of the two current directions. Such a device is known as a persistent current qubit+. This has been demonstrated experimentally by measuring the magnetic fields generated by the two states as you force the system to oscillate between one and the other. If you measure how long you can do this for, then that tells you how bad the interference from the outside world is and whether you can stay in the quantum regime long enough to carry out a quantum computation.

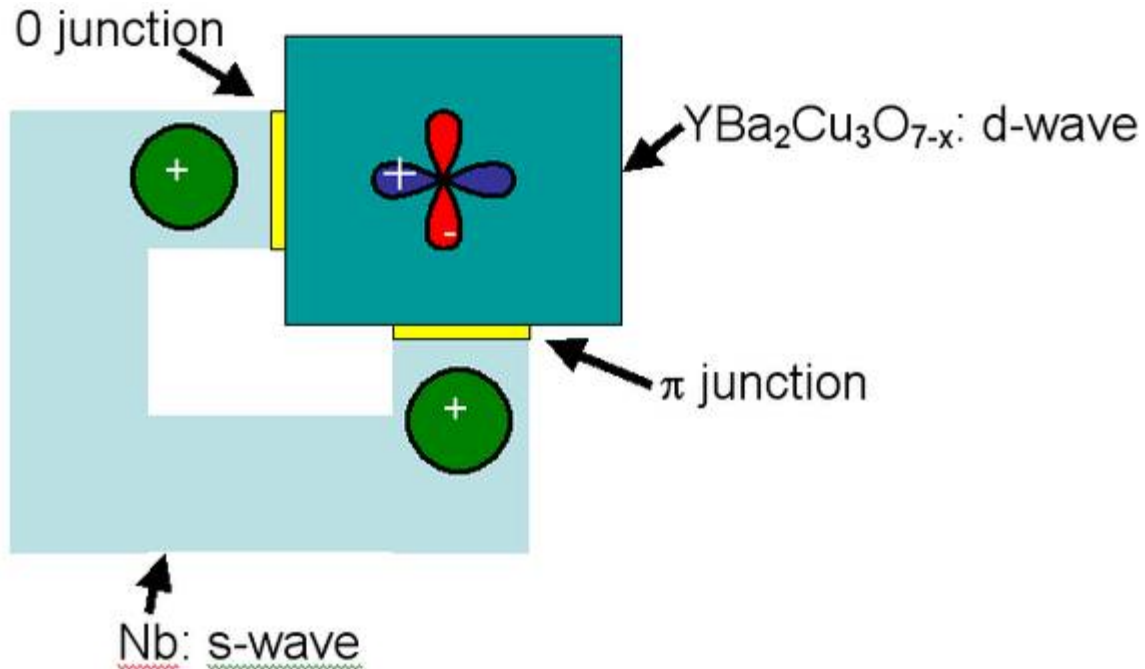


Figure 2 Schematic of a superconducting loop with an intrinsic phase bias of π .

In our work we are investigating ways of using oxide superconductors such as $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ (YBCO) which are d-wave superconductors to avoid having to apply the half flux quantum flux bias. In a d-wave superconductor the phase of the superconducting order parameter depends on crystallographic direction, so by fabricating two Josephson junctions so the supercurrent flowing through one is at right angles to the other an intrinsic π phase shift is induced in the loop. This can generate the doubly degenerate ground state required for a persistent current qubit.

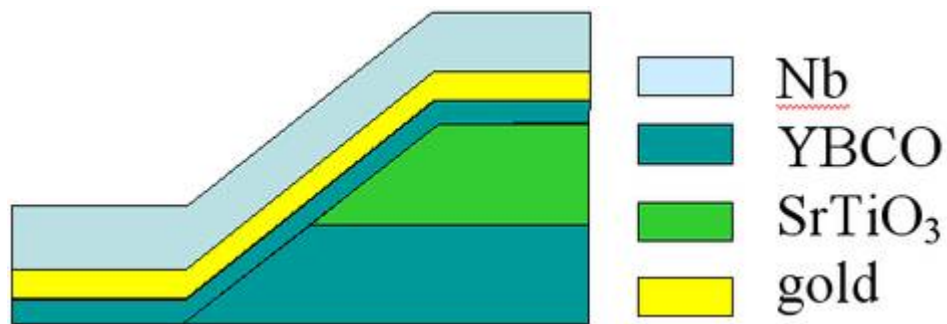


Figure 3 Schematic of a Nb/Au/YBCO ramp junction

In order to fabricate these structures we are setting up a Nb/Au/YBCO ramp junction technology similar to that developed by Smilde et al*. This requires the following steps:

- Pulsed laser deposition (PLD) of YBCO/SrTiO₃ bilayers
- Patterning of ramp structures by photolithography and ion milling
- Deposition of a thin YBCO layer on the ramp by PLD followed by in-situ gold evaporation
- Niobium counter-electrode sputtering.
- Junction definition by photolithography and ion milling.



Figure 4 Left pulsed laser deposition of YBCO. Right in-situ thermal evaporation of gold

+ I. Chiorescu, Y. Nakamura, Cjpm Harmans, and J. E. Mooij, Science 299 1869 (2003).

*H. J. H. Smilde, H. Hilgenkamp, G. Rijnders, H. Rogalla, and D. H. A. Blank, Appl. Phys. Lett. 80 4579 (2002)