SQUID - Superconducting QUantum Interference Device

- Introduction
- History
- Operation
- Applications

Introduction

- Very sensitive magnetometer
- Superconducting quantum interference device based on quantum effects in superconducting loop
- Useful for many purposes in physics, biology and medicine

History

- 1962: British physicist Brian David Josephson discovers Josephson effect, invents Josephson junction, SQUID
- 1973 Nobel Prize (with Leo Esaki and Ivar Giaever)

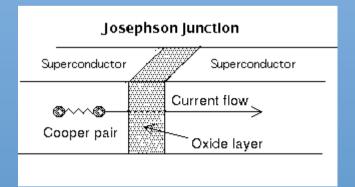


http://www.tcm.phy.cam.ac.uk/~bdj10/

Operation – Josephson effect

• The Josephson effect occurs when an electric current (Cooper pairs) flows between two superconductors separated by a thin non-superconducting layer through quantum tunnelling.

Junction is called a Josephson junction. Can only support a certain maximum (critical) current in a superconducting state.

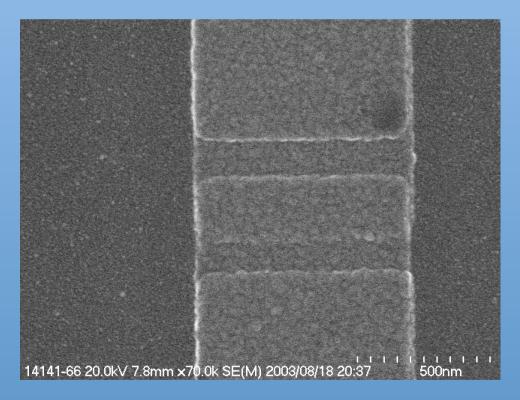


http://www.albanet.com.mx/articulos/josephson.gif (modified)

Operation – Josephson junctions

- Types of Josephson junctions:
 - Tunnel junctions, barrier is an oxide insulator
 - Semiconductor junctions
 - Dayem bridge junctions, based on a constriction.

Josephson junction



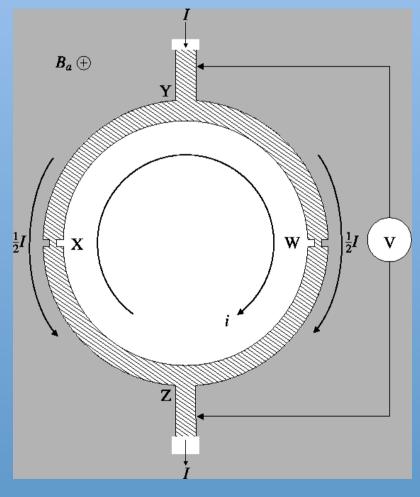
http://cr.physics.ed.ynu.ac.jp/labs/magne/shimazu/031101/results.html

Operation – Superconducting loop

- A SQUID consists of a loop of superconductor with one or more Josephson junctions, called weak links.
- Inner diameter of loop ~ 100 μ m..
- Generally made from either an alloy of lead and gold or indium, or pure niobium.
- Ceramic superconductors such as yttrium-bariumcopper-oxide also possible, but difficult to manufacture.

Operation – DC SQUID

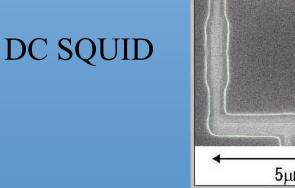
- Current made to flow around the loop through both Josephson junctions.
- Electrons tunnel through the junctions, interfere.
- Magnetic field through the loop causes a phase difference between electrons, affects current through the loop.

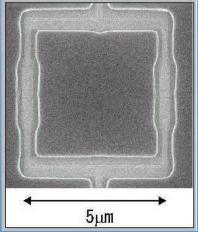


http://www.cmp.liv.ac.uk/frink/thesis/thesis/node47.html

Operation – DC SQUID

- Flux (magnetic field) through the loop induces a current around the loop. This affects the current flowing through the loop, because the net current through each junction is no longer the same.
- Resulting potential difference across the loop can be measured.





http://cr.physics.ed.ynu.ac.jp/labs/magne/shimazu/031101/results.html

Operation – RF SQUID

- Also called AC SQUID
- Only one Josephson junction.
- Radio frequency oscillating current
- Measure interactions between the superconducting ring and an external resonant LC circuit
 - External inductor induces current in SQUID ring, and when the Josephson junction enters the resistive state it damps the LC circuit.

Operation – Interference

- Background magnetic fields can be a problem.
 - Shielded room: expensive and cannot easily be moved.
 - Gradiometer measures gradient of field rather than absolute value. Interfering magnetic sources generally much further away, so vary less.
 - Measure ambient magnetic field and subtract from measurements.
 - Damping coils to cancel out the background field.
 - Johnson noise: magnetic field created by thermal motion of surrounding particles.

Applications

- Biomagnetism
- Scanning SQUID microscopy
- Geophysics

Applications – Biomagnetism

- Processes in animals produce small magnetic fields (10⁻¹² 10⁻⁹ tesla).
- Fields associated with neural activity can be imaged by machines based on an array of SQUIDs, magnetoencephalography (MEG).
 - Generally use gradiometer DC SQUIDs.
 - Advantage: higher temporal resolution images can be acquired in millisecond intervals, and respond rapidly to changes in neural activity. PET and MRI have a temporal resolution on the order of 1 second, higher spatial resolution.

Applications – Biomagnetism

Neuromag-122TM



http://www.neuromag.com/products/122hw.html

Neuromag VectorviewTM



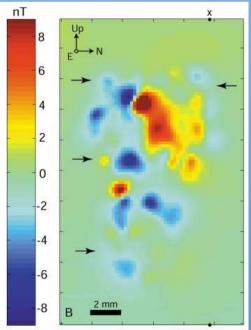
http://www.neuromag.com/pdf/viivibrochyr_apr03_v4.pdf

Applications – Biomagnetism

• SQUIDs can also be used to measure heartbeat; called a magnetocardiogram.

Applications – Scanning SQUID microscopy

• By scanning a SQUID probe over a sample, a high-resolution image of its magnetic field structure can be obtained.



SQUID microscopy image of 1mm slice of Martian meteorite



http://www.gps.caltech.edu/tempfiles/magnetic_microscopy/SQUIDmicroscope.jpg

http://www.gps.caltech.edu/tempfiles/magnetic_microscopy/

Applications - Geophysics

- Measure movement of the Earth's magnetic poles, variations in the thickness of the crust.
- Oil prospecting, earthquake prediction, geothermal energy surveying.
- Require portable containers with sufficient insulation to carry liquid helium.
 - High temperature superconductors would help.
- Methods of reducing magnetic noise needed.

Conclusions

• SQUIDs are likely to be used increasingly in the future as they become cheaper and more versatile due to the development of high-temperature superconductors and better cooling systems.

Notes

• Notes and copies of these slides are available at http://www.mcs.vuw.ac.nz/~walbraandr/squid.html

References

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- http://en.wikipedia.org/wiki/Josephson_effect
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