SUPERCONDUCTING QUANTUM INTERFERENCE PROXIMITY TRANSISTOR (SQUIPT)

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INTRODUCTION

The superconducting quantum interference proximity transistors, abbreviated SQUIPTs, are interferometers based on a Josephson junction (JJ) that use the superconducting proximity effect to achieve high sensitivity in the measurement of magnetic fields. Here is given a general overview of the latest discoveries regarding the aforementioned transistors, since understanding the characteristics of these devices is important for realizing their potential for application in different fields.

THEORETICAL ASPECTS

- Josephson effect is a phenomenon that induces superconduction correlations in a normal metal or insulator when it is positioned between two superconductors nearby. A supercurrent flowing through this device which is called a Josephson junction (JJ), is induced without applying any voltage. This is interesting since it's showing quantum behavior at the macroscopic scale.
- The proximity effect of the currents in neighboring superconductors is producing an increase in resistance and reduces the density of states (DOS) at low energies and opens a gap in the normal metal.

ω-SQUIPT

ω-SQUIPT is a three-terminal Josephson interferometer where the normal metal is in a form of a T-shaped nanowire connecting two superconducting loops. The cross-section of the normal metal is much smaller than the cross-section of the surrounding loops, as shown in Fig. 1. The central part of the T-shaped nanowire is a tunnel coupled to a normal metal probe.

Strambini et al. (2016) argue that there are two types of ω-SQUIPTs: Type A, which is symmetric, and type B which has lower symmetry relating to the length of the T-shaped area and resistances of all three parts. [2]

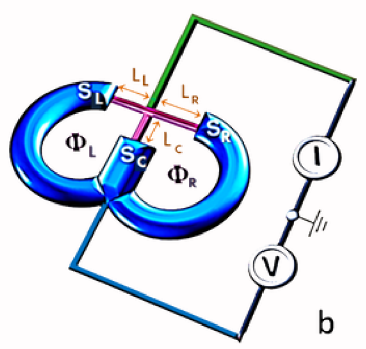

FIG 1. A three-terminal double-loop Josephson interferometer based on the proximity effect considered by Strambini et al. [2]

T-SQUIPT

This type of interferometer uses topological insulators (TIs), materials that are insulating in their core but can have the flow of electrons on their periphery. Conventional SQUIPT designs have a ring structure, but for the Topological SQUIPT no ring structure is needed. The model is composed of two superconducting ends connected by a 2D topological insulator (see Fig. 2). Transport through TI happens through channels at its edges. In the presence of a small magnetic field, superconducting currents emerge. On one edge, there is a normal probe that is tunnel coupled through a tunnel barrier. Having a probe grants examination of DOS on the said edge. [3]

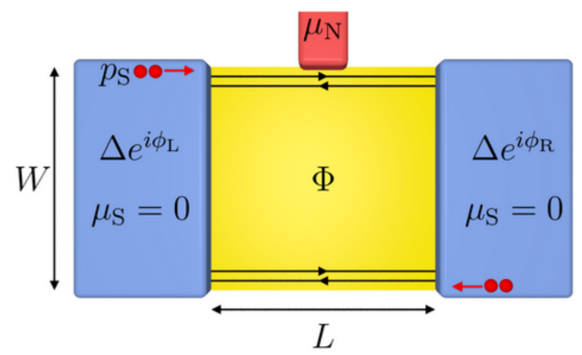

FIG 2. Scheme of the T-SQUIPT as proposed by Bours et al. [3]

L-SQUIPT

Inductive superconducting quantum interference proximity transistor or the L-SQUIPT is the latest model that solves the limitations that previous devices encountered including:

a) low coupling between the magnetic field and the conducting loop,
b) need for nearly sinusoidal current-phase-relation,
c) operating at high temperatures at cost of reduced sensitivity.

This model of interferometer consists of two superconducting rings, each with a normal metal breaking the loop, as shown in Fig. 3. The first loop does magnetic flux-to-phase drop conversion, while the second is completely protected from the external magnetic field by using a superconducting plate. The shape of the device allows L-SQUIPT to bias the second junction that is supposed to be in the short limit.

It is shown that the quantum-limited noise is lower compared to the other devices. [8]

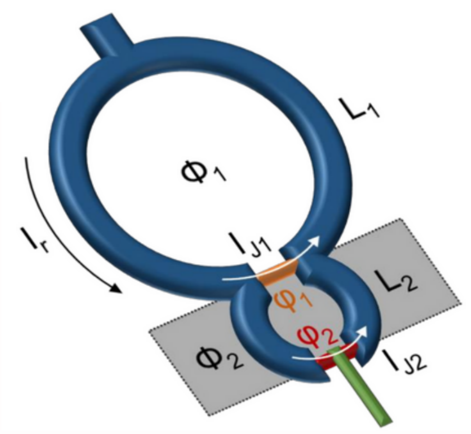

FIG 3. A schematic illustration of the transistor theoretically investigated by Paolucci, Solinas, and Giazotto [8]

CONCLUSION AND DISCUSSION

SQUIPTs are innovative devices that find application in several fields. It is suggested that they can be utilizable as gradiometers or magnetometers, as well as radiation detectors. The superconducting weak-link radiation detector [6] could be useful in astrophysics.

SQUIPTs are appealing for several reasons. They are good for measurements on the nanoscale levels due to low dissipation and high sensitivity. Construction is vastly flexible; instead of a normal metal, it can be constructed using different materials such as graphene and nanotubes. SQUIPTs can provide phase control of the thermal conductivity at very low temperatures by modifying applied magnetic flux [7]. Previously mentioned interferometers based on topological insulators can be used for creating a thermal diode for electronic heat flow. [3] Heat management is extremely important, especially when it comes to quantum technology since heat can disrupt quantum states.

Besides being attractive from the fundamental physics point of view, can be crucial for potential application in radiation sensing, thermal logic, and the next generation of electronic machines - quantum computers. Quantum computing is currently in the spotlight since there are several difficulties preventing the creation of proper quantum computers, that are supposed to solve certain problems a lot faster than the classical ones.

I would suggest an in-depth analysis of different combinations of superconductors and normal metals or nanomaterials and measuring the sensitivity of the devices at different temperatures.

REFERENCES

[1] W. Belzig *et al.*, Superlattices Microstruct. **25**(5), 1251 (1999).
[2] E. Strambini et al., Nat. Nanotechnol. **11**(12) 1055 (2016).
[3] L. Bours *et al.*, Phys. Rev. Appl. **10**(1), 014027 (2018).
[4] L. Bours *et al.*, Phys. Rev. Appl. **11**(4), 044073 (2019).
[5] F. Vischi *et al.*, Phys. Rev. B **95**(5), 054504 (2017).
[6] P. Virtanen, A. Ronzani, and F. Giazotto, Phys. Rev. Appl. **9**(5), 054027 (2018).
[7] E. Strambini, F. S. Bergeret, and F. Giazotto, Appl. Phys. Lett. **105**(8), 082601 (2014).
[8] F. Paolucci, P. Solinas, and F. Giazotto, arXiv:2203.03948 (2022).