Highly sensitive Superconducting QUantum Interference Proximity Transistor (SQUIPT)

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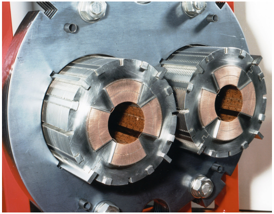
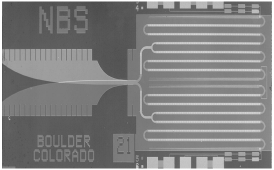
Superconductivity: a bridge to the quantum world

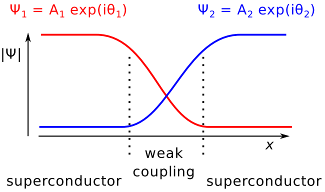
Superconductivity encompasses many phenomena of fundamental and technological interest. Zero electrical resistance, perfect diamagnetism and the fundamental couplings between charge current and magnetic degrees of freedom have been exploited for biomedic, particle physics, metrology and quantum computation applications.



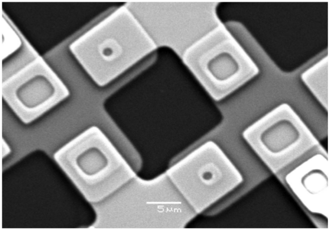


The phase degree of freedom

Superconductivity can be described as a manifestation a macroscopic fermionic condensate, whose wavefunction is spatially characterized by both an amplitude and a phase.



In a Josephson weak link two superconducting banks are weakly coupled across a non-superconducting element (oxide barrier, constriction or normal metal).

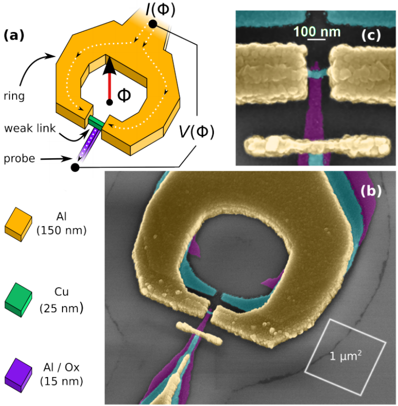


The phase difference across the weak link determines the amplitude of supercurrent flowing through it.

Interference phenomena are possible!

The SQUIPT concept

Superconducting QUantum Interference Proximity Transistor



Magnetic flux sensor

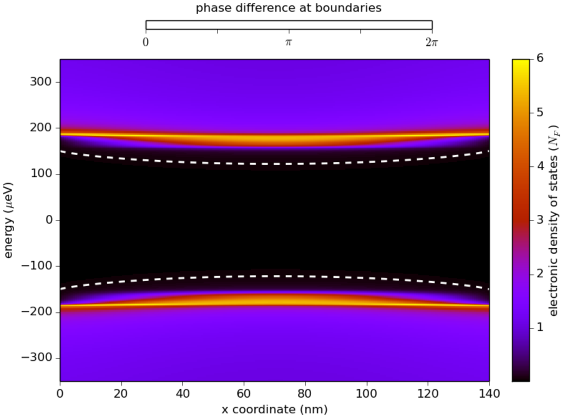
It is based on a tunnel junction between a **probe electrode** and a **normal metal weak link** embedded in a **superconducting ring**.

The current – voltage characteristics are modulated by the applied magnetic flux with period $\Phi_0 = h/2e$ (flux quantum).

- High magnetic responsivity
- Micrometric size
- Ultra-low power ($\simeq 100\,\mathrm{fW}$)

Proximization of the normal metal weak link

The physical core of the device is a normal metal nanowire in clean contact with the superconducting ring terminals.



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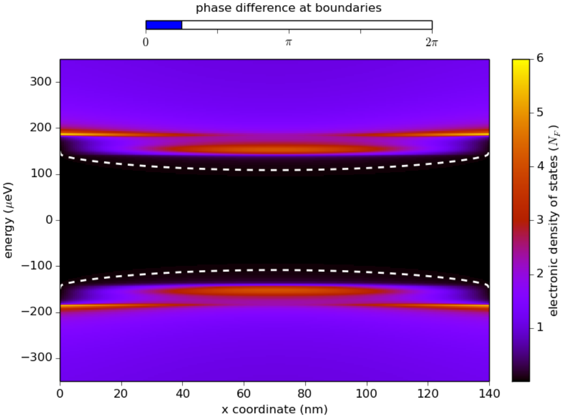

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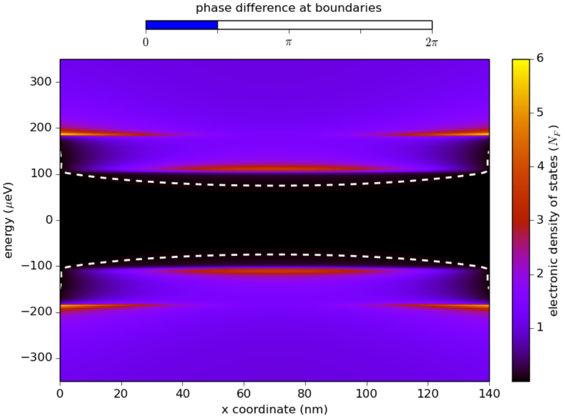

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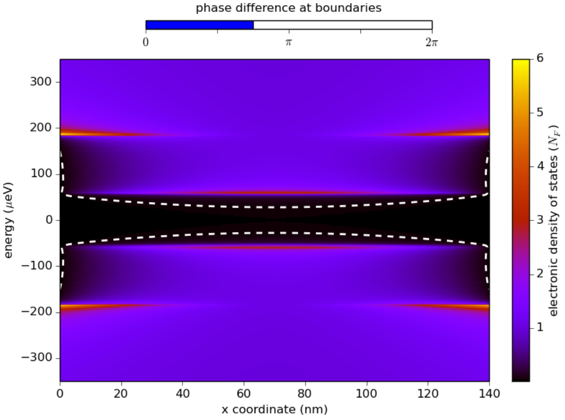

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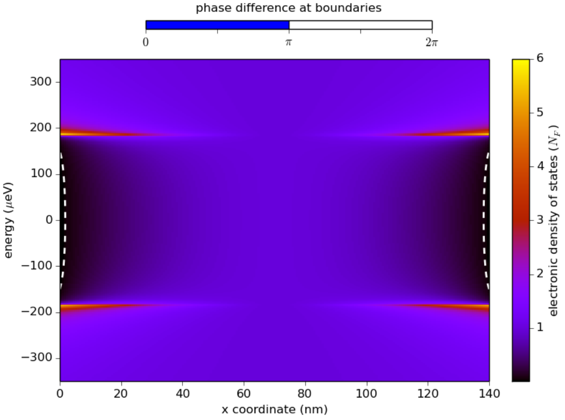

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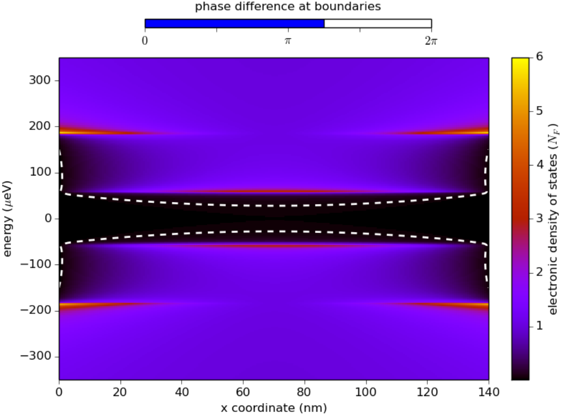

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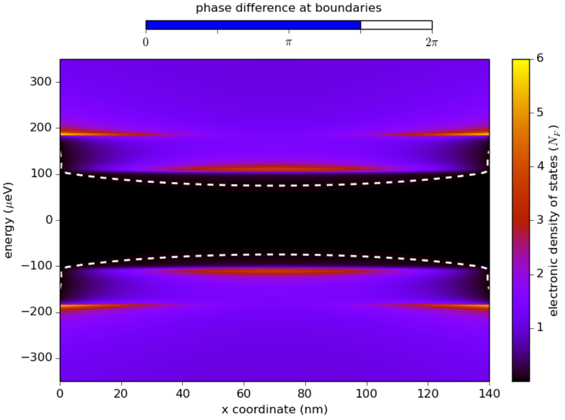

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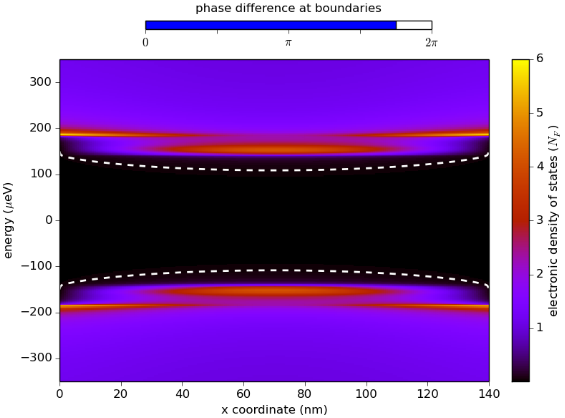

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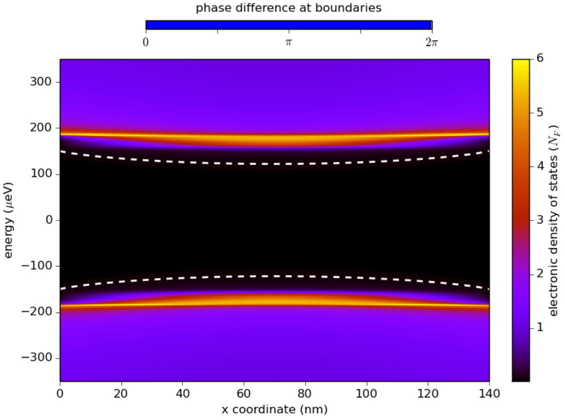

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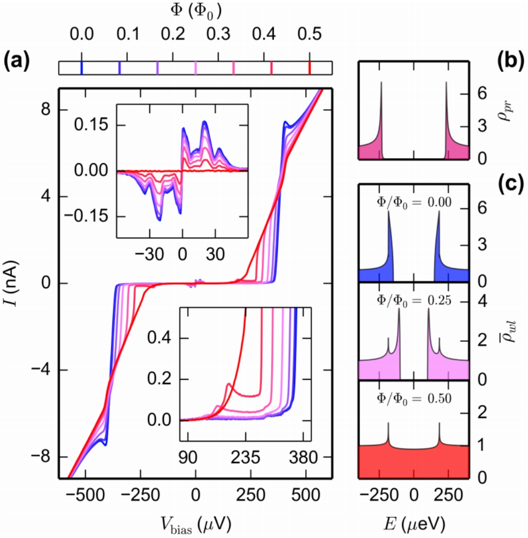
Transport spectroscopy

The voltage width of the "interdiction" branch is proportional to the sum of the gaps in the density of states of the **probe (b)** and of the **proximized weak link (c)**.

At higher bias the device shows ohmic transport behaviour with $R_T \approx 55\,\mathrm{k}\Omega$.

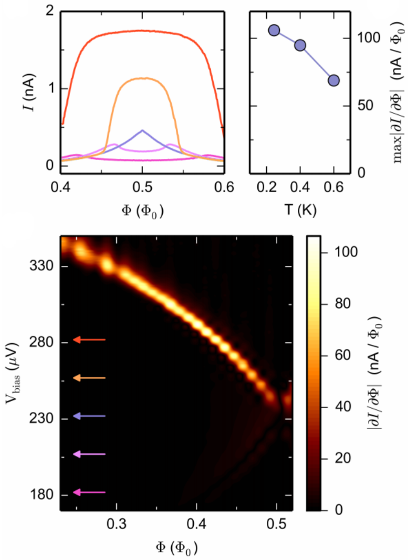


Responsivity under fixed voltage bias

Fixed voltage

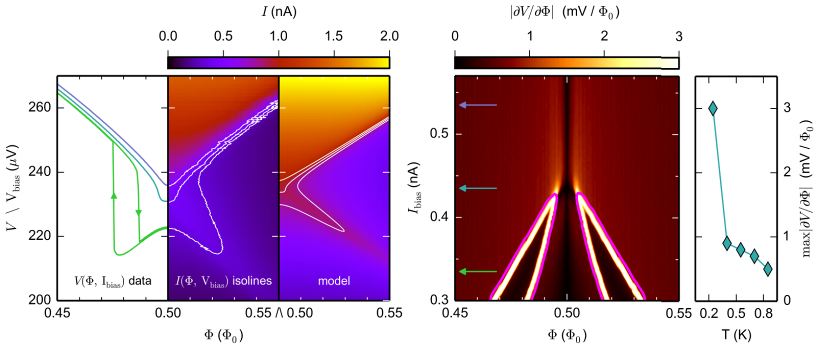
This readout setup exploits the abrupt onset of quasiparticle conduction as the "interdiction" branch is modulated by the applied magnetic flux.

- max $|\partial I/\partial\Phi| \simeq 110\,\mathrm{nA}/\Phi_0$
- $\mathrm{V_{bias}}$ tunes the optimal flux for maximal response
- Current responsivity is only moderately suppressed by temperature increase



Responsivity under fixed current bias

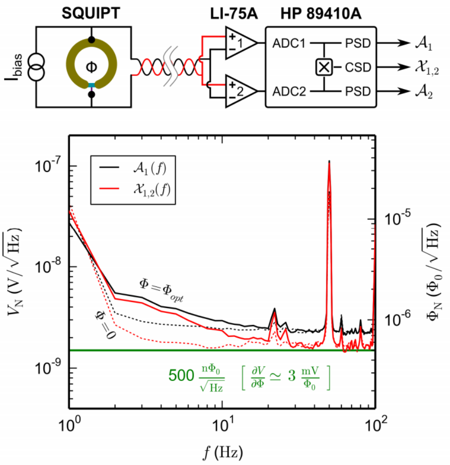
This readout setup measures the voltage developed across the device when polarized by a fixed (and low) current.



- Hysteresis at lower $\mathrm{I_{bias}}$
- Eliminated increasing $\mathrm{I_{bias}}$

- max $|\partial V/\partial\Phi| \simeq 3\,\mathrm{mV}/\Phi_0$
- Best responsivity at low T

Flux resolution performance



White-noise floor measured from the X-Correlated Power Spectral Density between two low-noise room-temperature voltage preamplifiers connected to the current-biased SQUIPT.

- Flux resolution: $\Phi_N \simeq 500\,\mathrm{n}\Phi_0/\sqrt{\mathrm{Hz}}$
- Spin resolution: $S_N \simeq 24\,\mu_B/\sqrt{\mathrm{Hz}}$

Conclusions

We exploited the superconducting proximity effect to realize a highly sensitive magnetic flux sensor for low-temperature applications, characterized by *micrometric size* and *ultra-low power dissipation*.

We demostrated both fixed-voltage and fixed-current operation reaching (at 250 mK) record responsivity value for this device class, respectively $110\,\mathrm{nA}/\Phi_0$ and $3\,\mathrm{mV}/\Phi_0$.

These figures lead to magnetic flux resolution $\Phi_N \simeq 500\,\mathrm{n}\Phi_0/\sqrt{\mathrm{Hz}}$, corresponding to a spin resolution $S_N \simeq 24\,\mu_\mathrm{B}/\sqrt{\mathrm{Hz}}$, suitable for the investigation of small magnetic population on the micrometric scale.

Complete article

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