Field-effect metallic superconducting electronics

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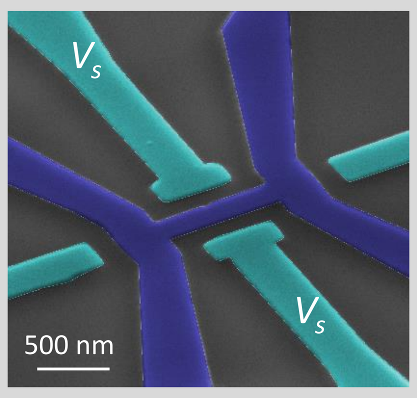
Motivations

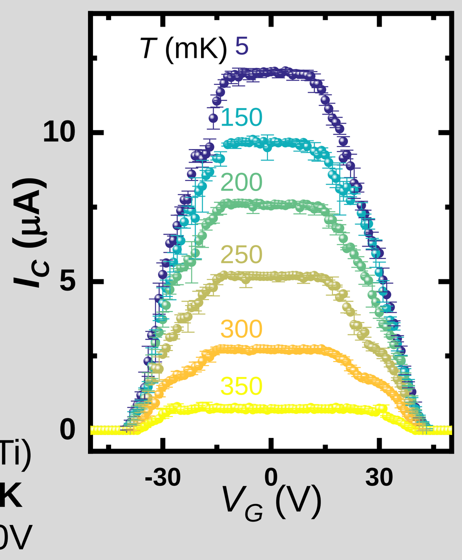
Until now no clue has been provided on the possibility to affect metallic superconductors via field-effect. Here we present some results about the suppression of the supercurrent in metallic superconductor devices due to the application of an electrostatic field [1,2,3]. In particular, we analyze the effect on two types of Josephson junction: Dayem bridge constrictions [4,5] and Superconducting/Normal metal/Superconductor (SNS) junctions [3]. Moreover, recent experimental works [2] seem to suggest that the field-effect affects the macroscopic phase of the Cooper pair condensate in a new fascinating way.

I. Discovery of the field-effect on superconductors



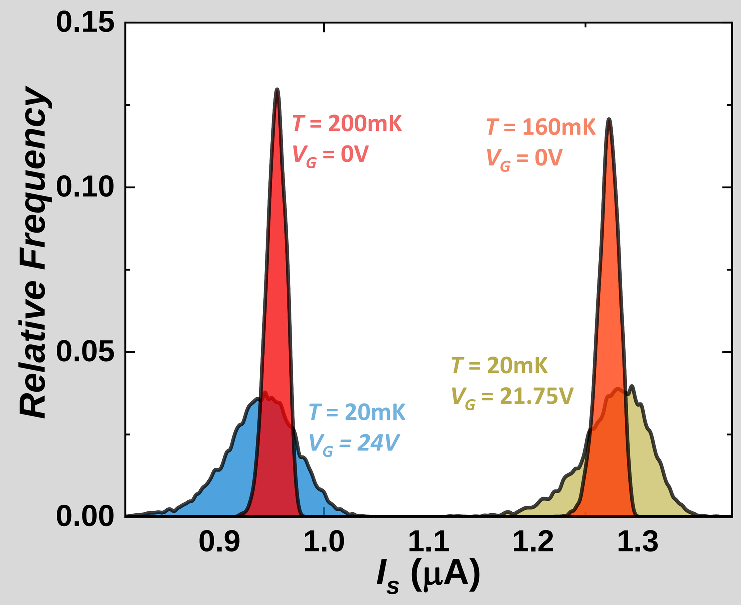
Pseudo-colour SEM image of a representative Ti Field-Effect Transistor (FET). The transistor core is shown in blue and the Ti side gates are in cyan.

First observation of a field-effect on a Bardeen–Cooper–Schrieffer (BCS) superconductor [1].



Material: Titanium (Ti)
Crit. Temp. T_C: **0.55K**
V_G^C: 40V

III. Heating effect?

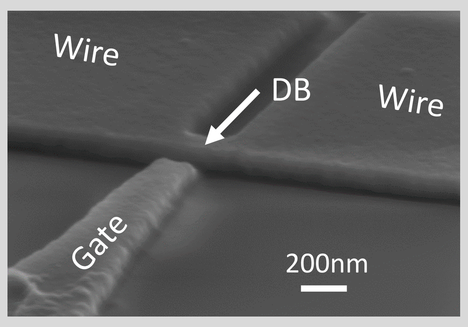


The effect of gating on the switching current probability distribution cannot be explained in term of a heating effect. In particular, the standard deviation is larger than in the absence of gating.

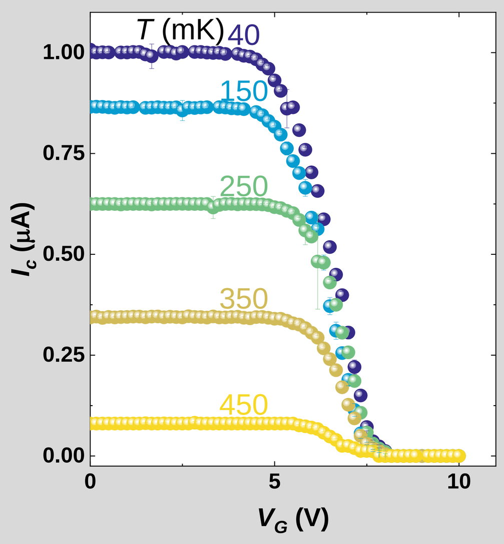
II. Universality of the effect

We report the effect in different materials (Ti [4,5], Al[4], V, NbN) and different geometries like wires [1], Dayem bridges (DB) and Superconductor/Normal metal/Superconductor (SNS) junctions [3].

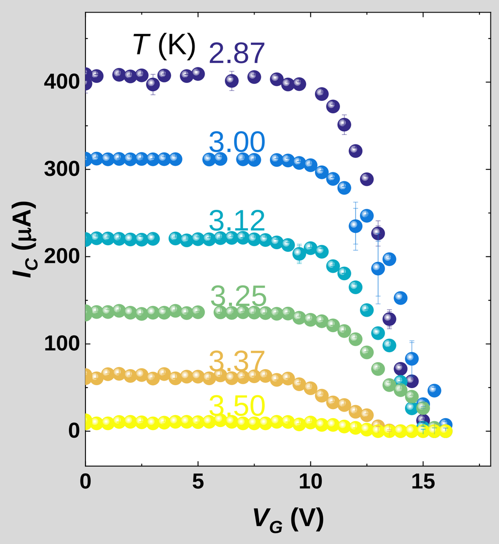
A Dayem bridge (DB) is a thin-film Josephson junction made up of a wire interrupted by a short constriction with smaller lateral dimensions



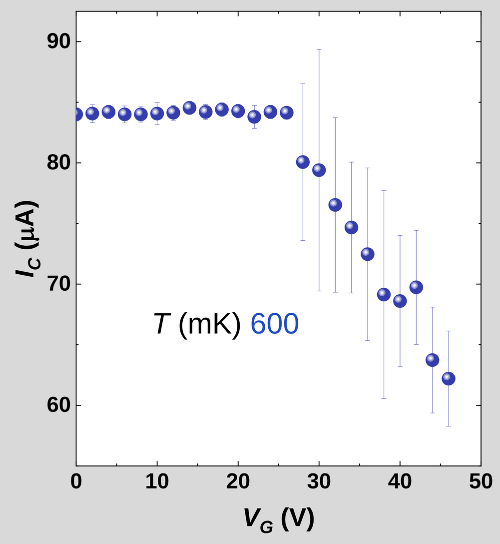
SEM image of a typical Dayem bridge junction.



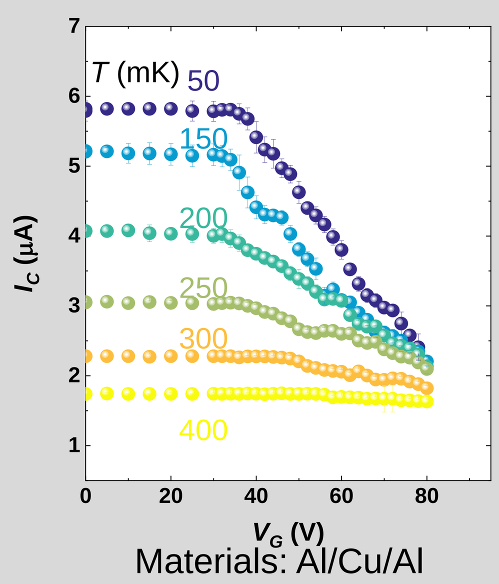
Material: Titanium (Ti)
Crit. Temp. T_C: **0.53K**
V_G^C: 8V
Image from [4].



Material: Vanadium (V)
Crit. Temp. T_C: **3.6K**
V_G^C: 15V

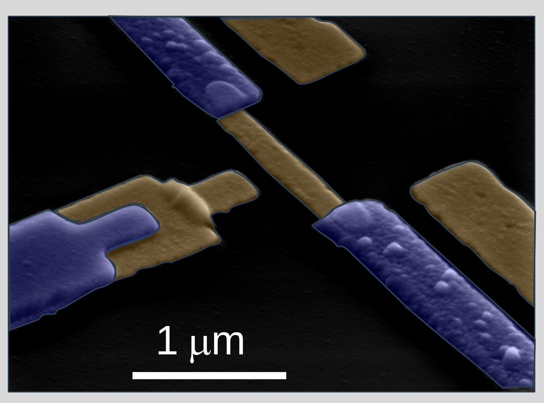


Material: Niobium Nitride (NbN)
Crit. Temp. T_C: **10.5K**
V_G^C: >100V (estimation)



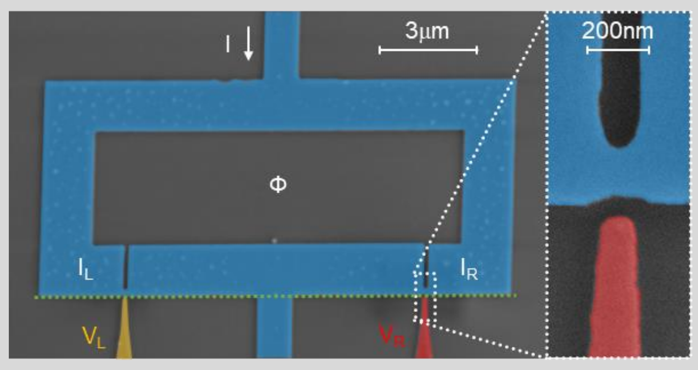
Materials: Al/Cu/Al
Crit. temp. T_C: **1K**
V_G^S: 80V

Our results on a SNS junction [3] suggest that the field effect is quite general and does not rely on the existence of a true pairing potential, but rather the presence of superconducting correlations.



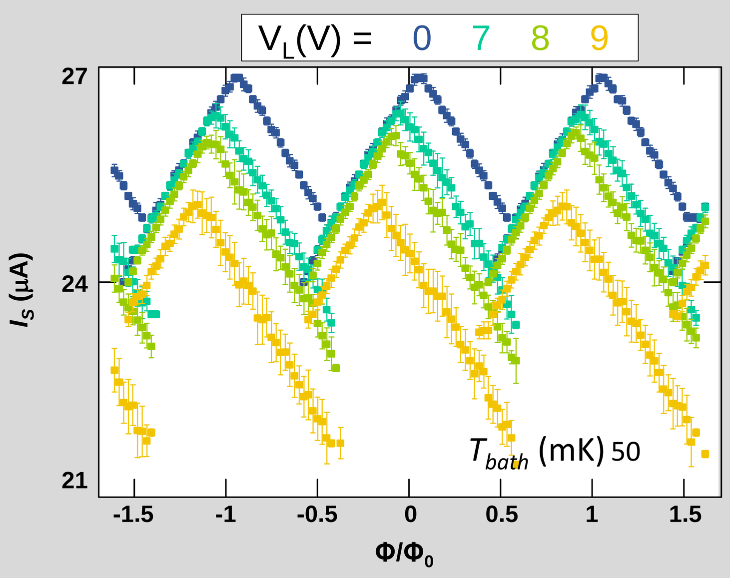
SEM image of the SNS junction, In blue it is shown the superconducting material (Al); in orange the normal metal (Cu)

IV. Coupling of electric field and superconducting phase



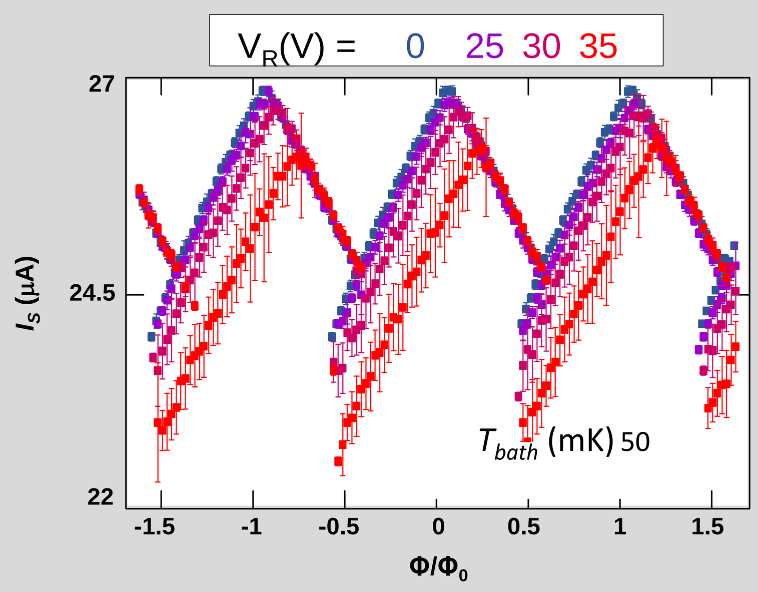
We have fabricated a Superconducting Quantum Interference Device based on two Dayem bridges by a single-step of lithography followed by titanium evaporation [2]. The two junctions are gated independently by correspondent electrodes.

We found the presence of field-effect, affecting the characteristics of switching current VS magnetic flux $I_S(\Phi)$.

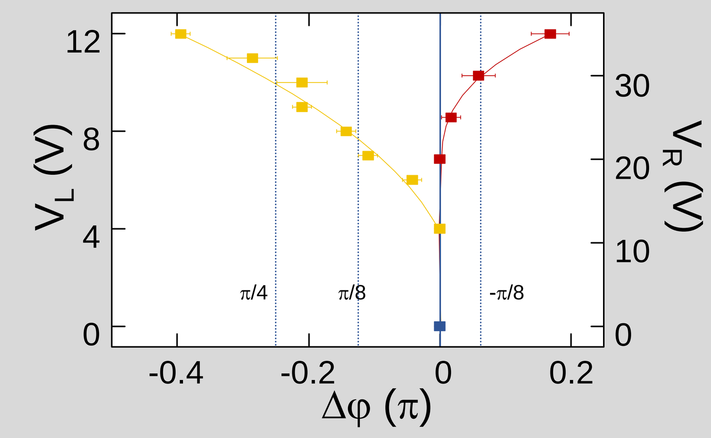


At low gate voltages, the $I_S(\Phi)$ curve slides along one branch meanwhile fluctuations appear in the other branch. The sliding direction depends on which junction is gated.

At higher voltages, the I_S is suppressed below the single junction critical current and the fluctuations are present in both the branches. This can be modelled by a field-induced phase fluctuations.



The device can be used as phase shifter for classical or quantum computation [2].



V. Future perspectives

- **Quantum Information Applications: field-effect control of phase/flux Qubits, Gatemons.**
- **High sensitivity Sensors: single photon detectors, bolometers etc.**
- **All-metallic high-speed superconducting electric field-controlled electronics RSFQ logic.**
- **Caloritronics: interferometers, etc.**

Bibliography

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