Flux flow in $YBa_2Cu_3O_{7-\delta}$ grain boundary Josephson junctions

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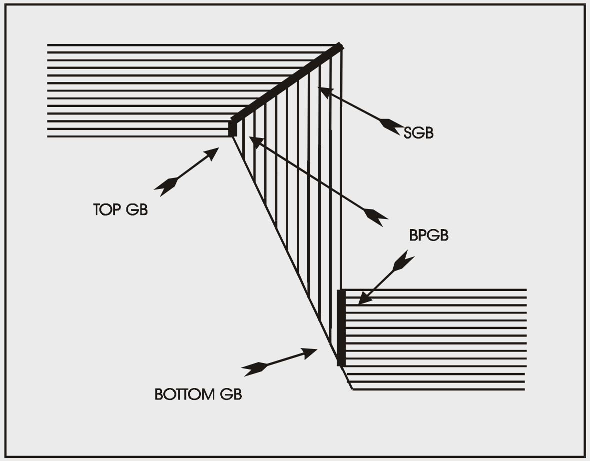
Outline

- *Observation of linear branches in the IV characteristics of long $YBaCu_3O_{7-\delta}$ step edge Josephson junctions by applying a control current. The observed phenomenology is discussed in terms of flux flow in long Josephson junction*

- *Preliminary results on the appearance of linear branches in long $YBaCu_3O_{7-\delta}$ biepitaxial junction.*

YBCO step-edge junction on a perovskite substrate

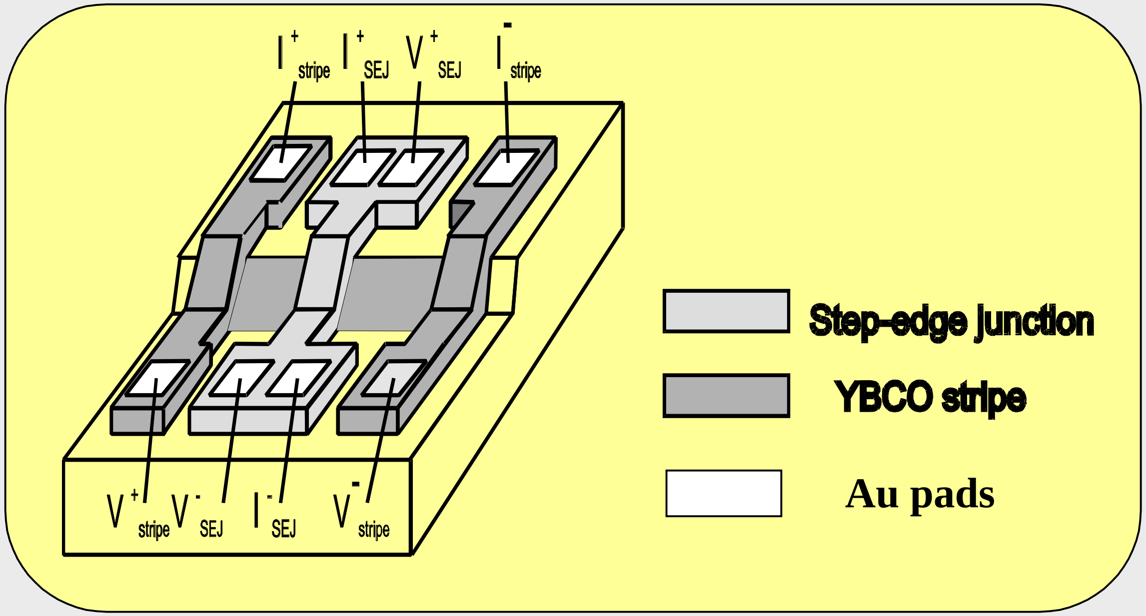


- *The grain boundary which nucleate at the top edge of the step is essentially of the Symmetric type*
- *At the bottom edge instead the grain boundary is mostly of the basal plane type.*

Top GB

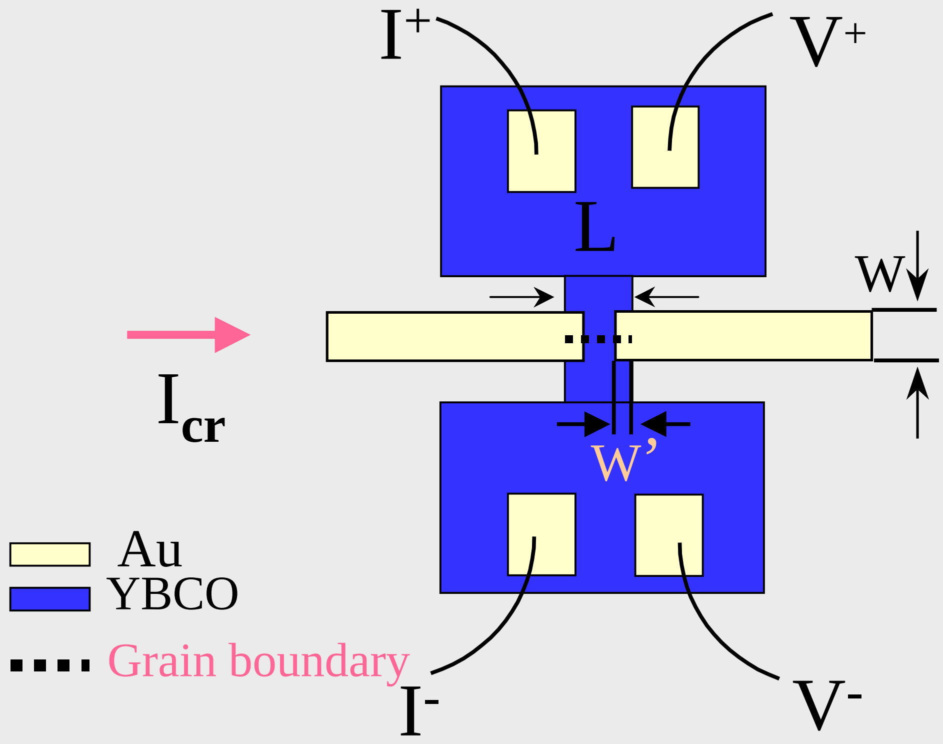
Bottom GB

A method to study separately the transport properties of the top and bottom grain boundary



- *The step-edge junctions are fabricated using tilted A_r ion milling to define the electrodes and the microbridges. Due to the shadowing effect of the step, a continuos YBCO stripe remains along and at the bottom of the step on both sides of the microbridges.*
- *This fabrication procedure allows a study of the transport properties of the isolated top GB and a comparison with the properties of the step edge as a whole. Within the accuracy of the measurement the IV characteristic of the top GB is identical to that of the SEJ.*
- ***The Josephson properties of the the SEJ are therefore determined by the Top Grain Boundary***

Layout of the device

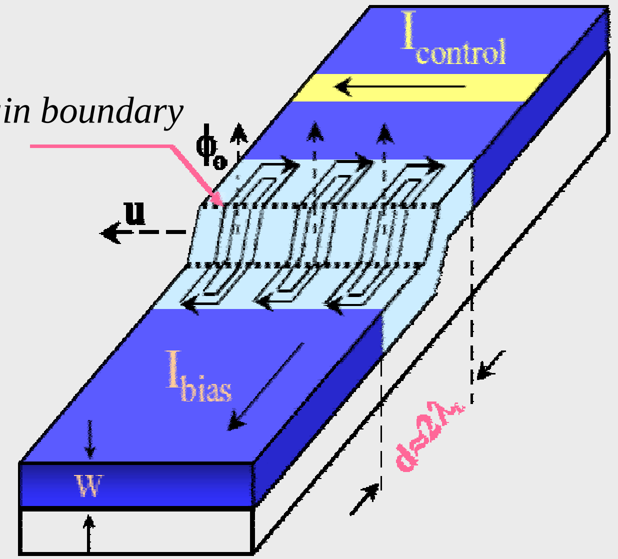


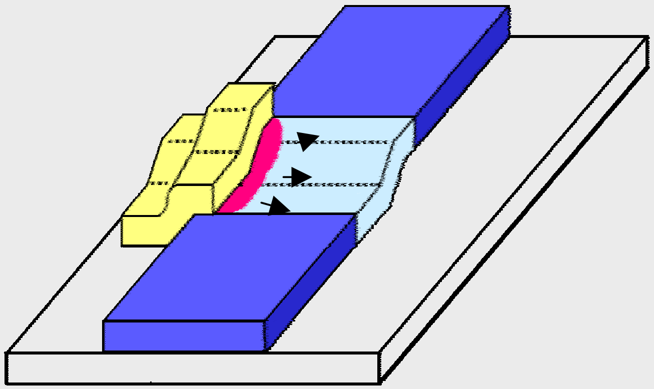
Substrate: $LaAlO_3$ (100)

Step height: 250 nm
YBCO Film thickness: 150 nm
Junction width: 4-12 μm
Au contacts area :
W*W'= 4x2 μm^2 and 8x4 μm^2

We have realized a ***4 terminal Josephson device based on a YBCO step edge Josephson junction and two current injection Au/YBCO contacts***, situated at the sides of the junction.

Which is the effect of the control current ?



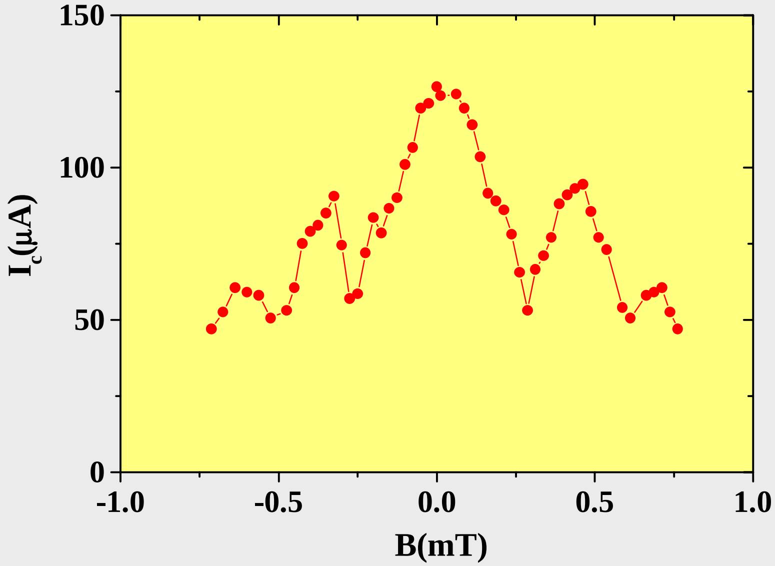


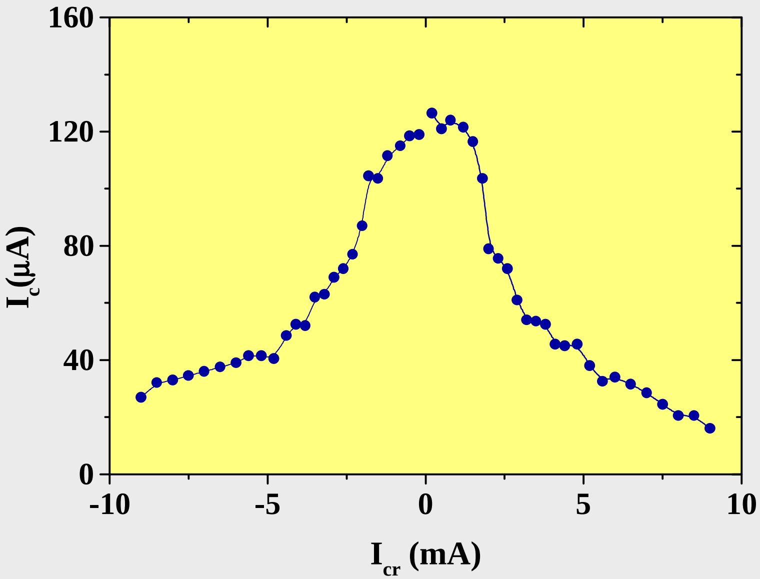
- *Due to misalignment of the control current, related to the lithographic process, and also to the intrinsic non planar geometry of the step-edge junction, the injection current density is not symmetric with respect to the grain boundary.*
- *Then **the current I_{cr} generates a non vanishing magnetic field** in the junction plane that adds to that of the bias current.*
- ***I_{cr} induces** local non equilibrium in the YBCO electrodes, due to quasi particle injection through the Au/YBCOinterfaces*

Josephson current dependence

on the external magnetic field

on the control current

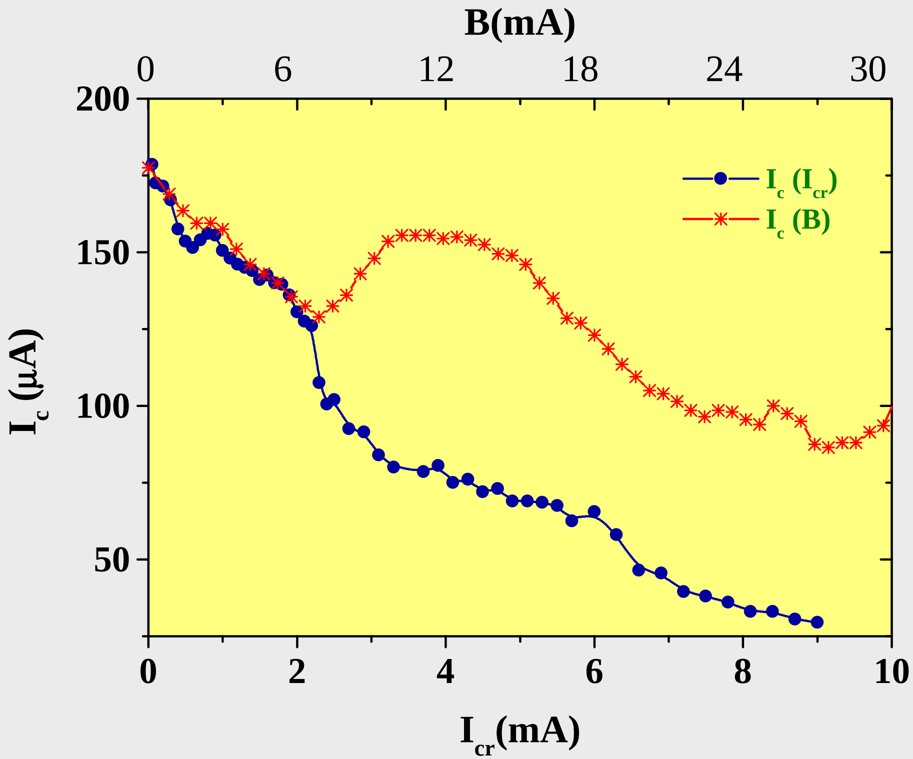




*The **diffraction pattern** taken at 27 K is quite regular with a central maximum and well defined secondary lobes.* **$(L/\lambda_j = 4)$**

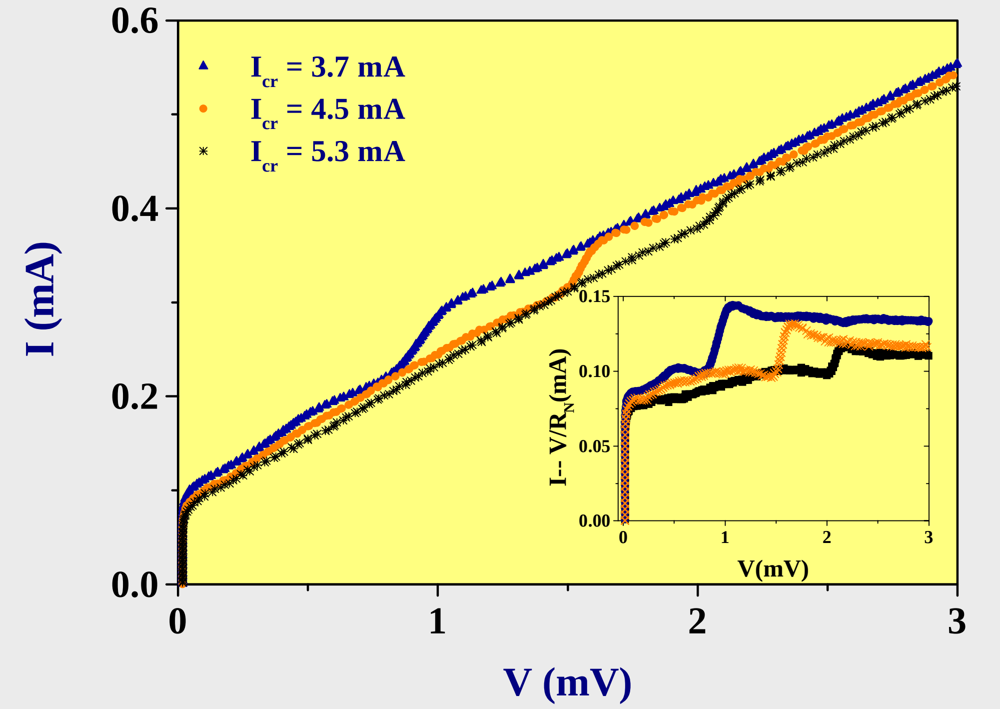
*I_c decreases monotonically at increasing I_{cr} (data at T = 27 K). This behaviour is due to the **combined action of magnetic field and nonequilibrium**.*

How to separate the nonequilibrium effect from the magnetic field contribution?



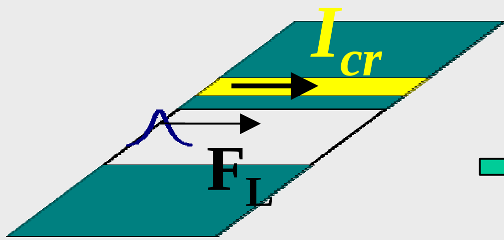
In the figure (T=4.2 K), the horizontal axes have been set in order to stress out the similarity of the plots of Ic vs I_{cr} and of I_c vs B at low currents .
The scaling factor is $s = (I_{coil} / I_{cr}) \approx 3$ *and it is independent on the temperature.*

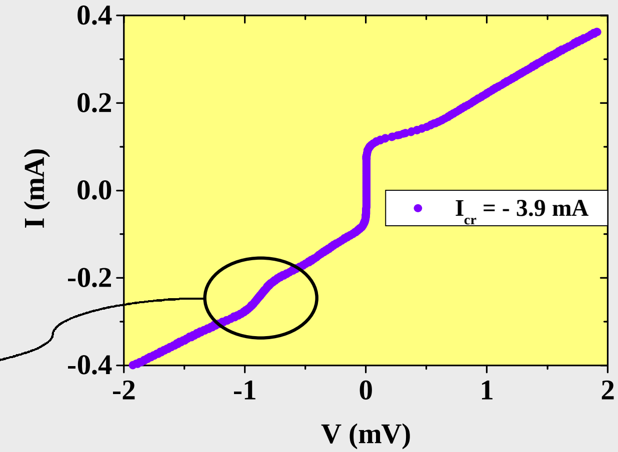
IV characteristics as a function of the control current



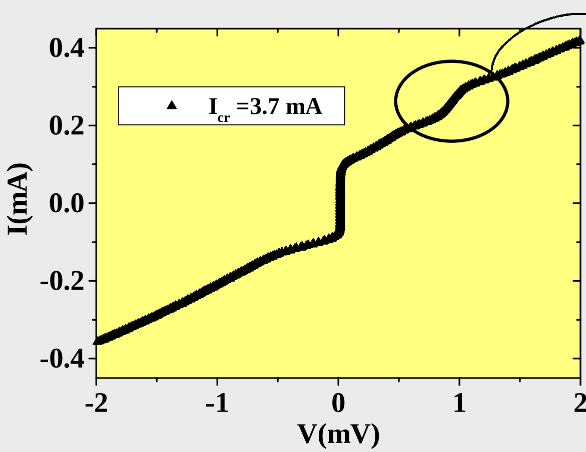
- *For values of I_{cr} larger than about 3 mA at 4.2 K, the IV characteristic clearly exhibits linear branches. The inset shows the same structures after subtracting the background current $I_{bg} = V/ R_N$.*
- *For a fix value of I_{cr} the linear structure appears only on one branch of the IV curve*
- ***The linear branches do not appear in presence of an external magnetic field***

IV curves for opposite values of the control current

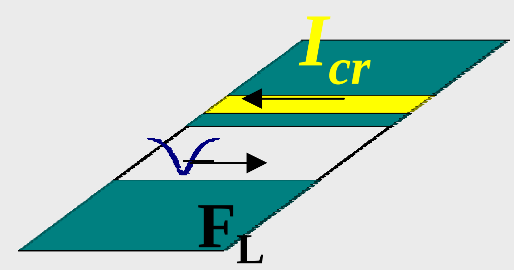




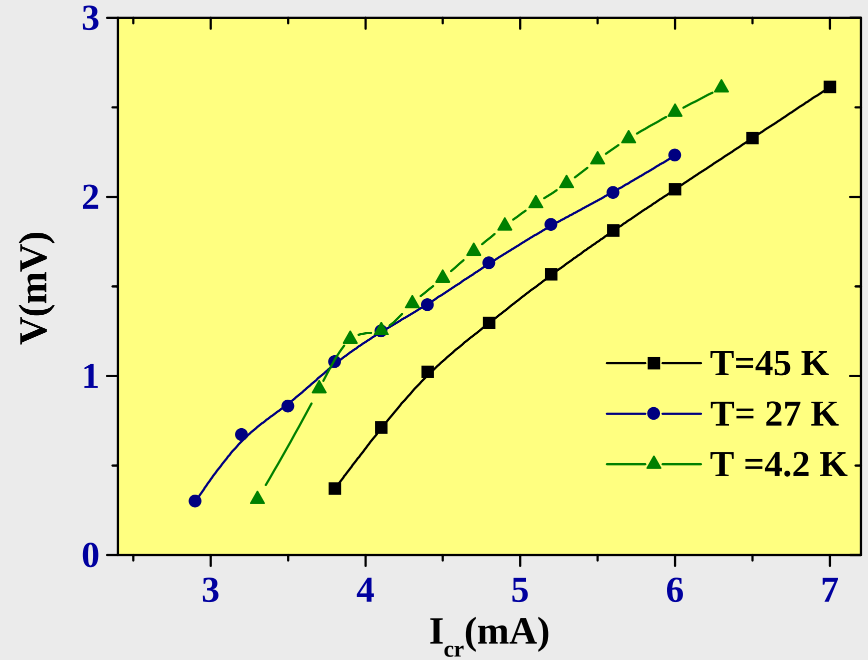
Fluxon injected from the right edge propagating towards the left



Antifluxon injected from the right edge propagating towards the left

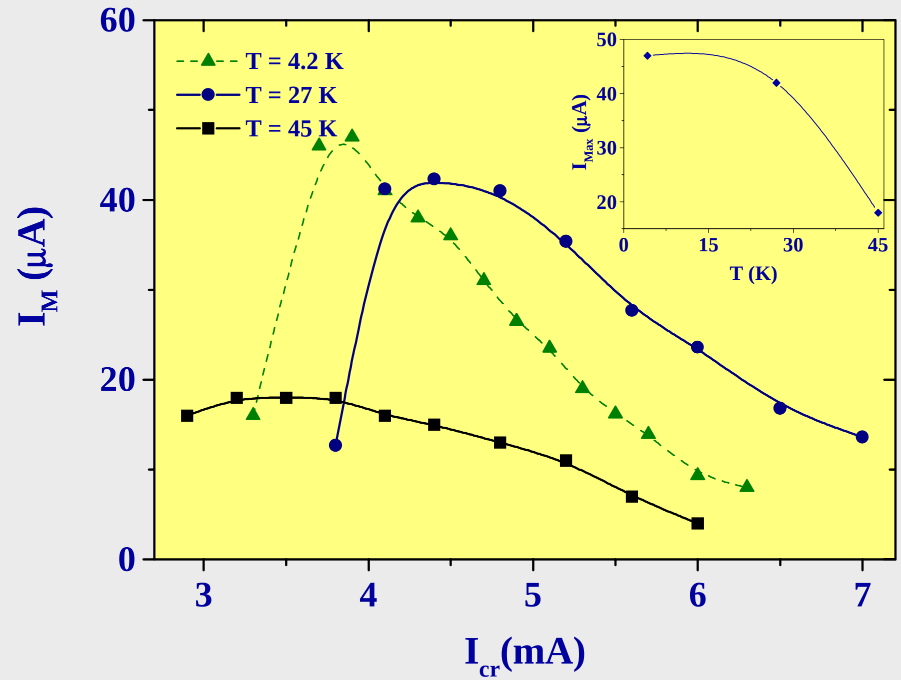


Voltage position of the linear branches as a function of the control current



- *Step voltage V_m as a function of I_{cr}.* ***V_M increases proportionally to I_{cr}****, with minor deviations at low V_M values.*
- *The plot of V_M vs I_{cr} shows that the 2 mV* ***tunability range of V_M*** *leads to a band of* ***± 500 GHz around 1 THz****.*
- *The expression for the linewidth of a Josephson oscillator at a temperature T is given by* $\Delta\nu = \frac{4\pi k_B T}{\Phi_o^2}\frac{R_D^2}{R_S}$ *where R_D is the dynamical resistance at the bias point , R_S is the static resistance corresponding to the same bias point and k_B is the Boltzmann constant.For the linear branch shown above we get at T = 4.2 K , taking R_D = 2.7 Ω and R_S =7Ω ,* ***Δν ≈ 170 MHz****.*

Dependence of the step amplitude on the control current

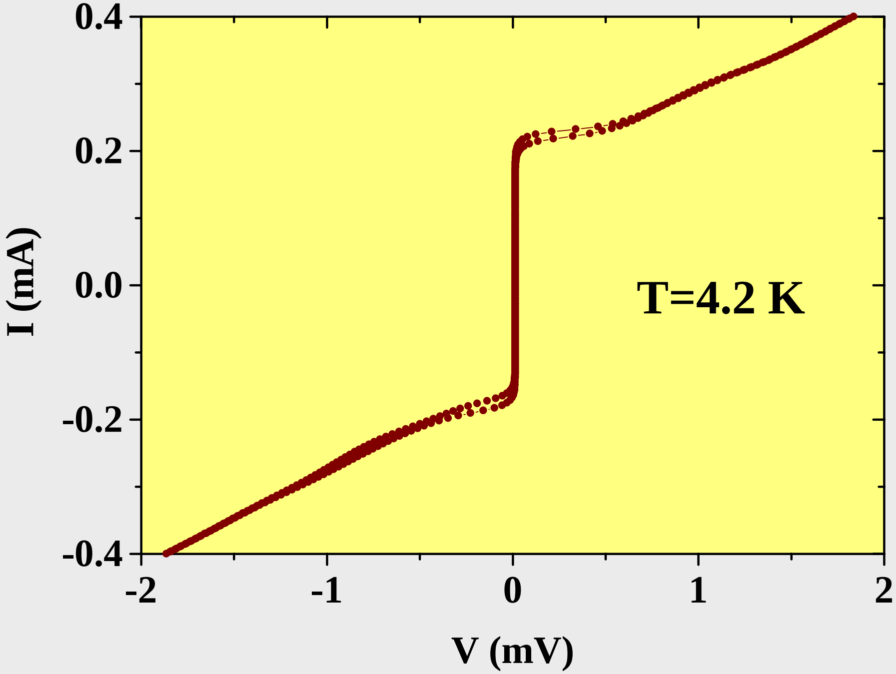


At any given temperature, the linear branch only appears in a well defined range of control current and reaches its maximum height (that we call I_{Max}) for a given value of I_{cr}.

The plot of I_{Max} vs. T is shown in the figure inset.

*The available dc power for a typical bias point on the linear branch (V = 1.5 mV and I = 0.3 mA) , is **W = 0.45 μW***

Evaluation of same characteristic parameters of the junction



$$\alpha = \frac{1}{I_c R_N}\left(\frac{J_c \Phi_o}{2\pi C}\right)^{\frac{1}{2}}$$

A relevant parameter in the fluxon dynamics is the damping coefficient α .

- *Evaluating $C = 80$ fF μm^{-2} from the voltage position ($V_1 = 0.9$ mV) of the first Fiske resonance, and assuming an effective penetration length $d \approx 2\lambda_L$, and $\lambda_L = 0.150$ nm , we get $\alpha = 0.6$.*
- *Estimating the Mc Cumber parameter β_c from the hysteresis of the IV characteristic, and using the relation $\alpha = (1/\beta_c)^{1/2}$ we get $\alpha = 0.7$*

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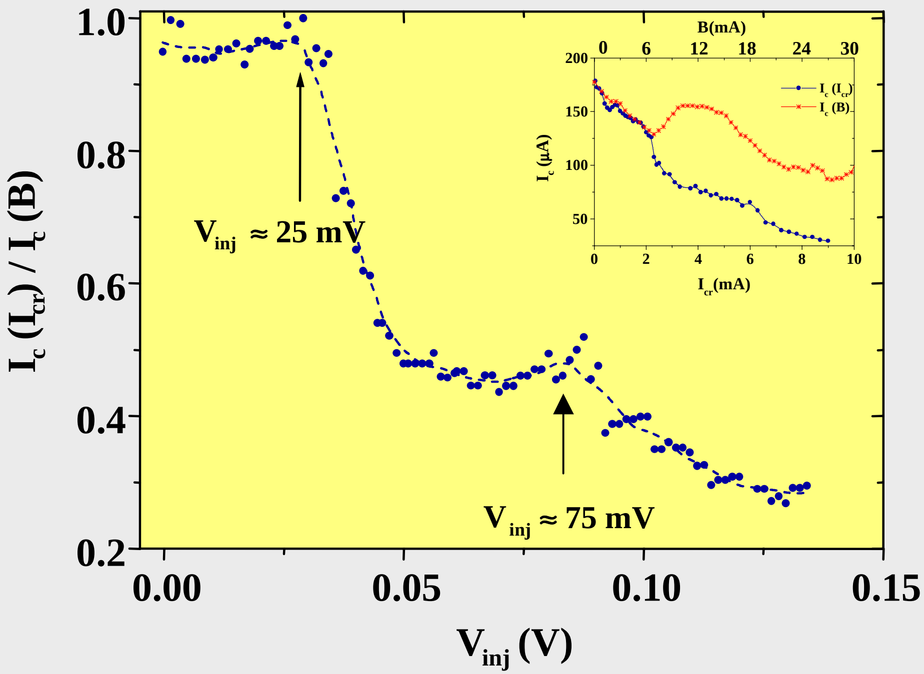
Non equilibrium effect induced by the current injection

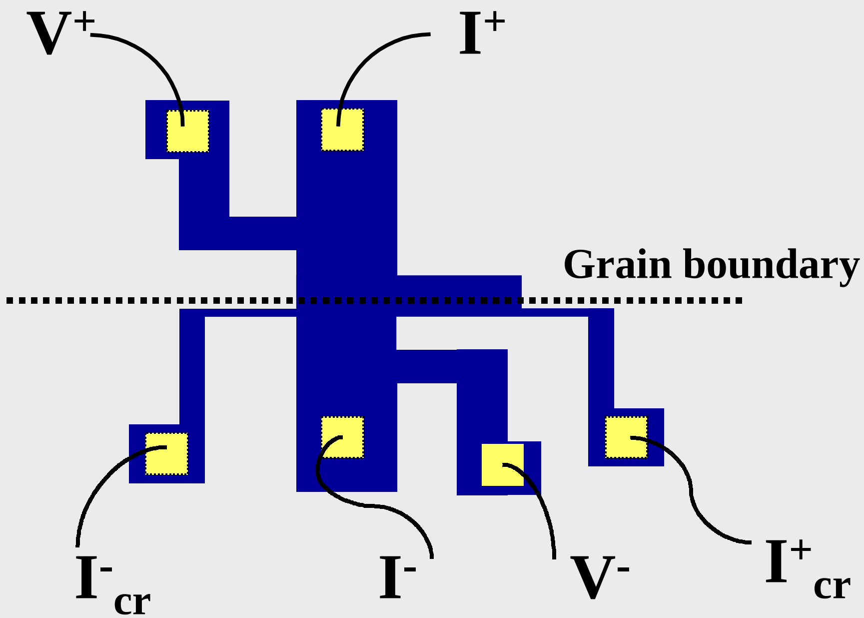


T = 4.2 K

Ratio between $I_c(I_{cr})$ and $I_c(B)$ (data in the inset) as a function of the voltage drop V_{inj} across a single Au/YBCO interface.

Two step reduction of the Josephson current are observed at $V_{inj} \approx$ 25 mV and $V_{inj} \approx$ 75 mV corresponding approximately to Δ and 3Δ.

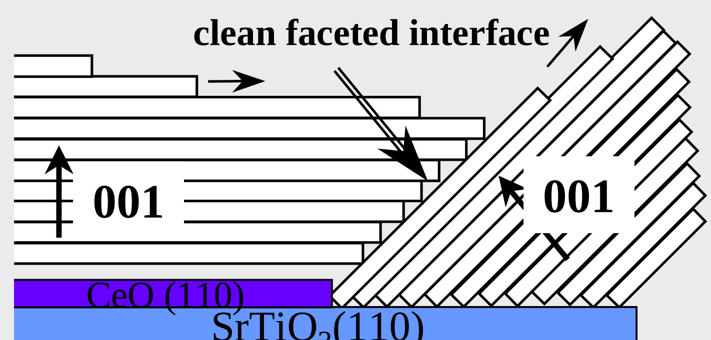
Flux flow in biepitaxial Josephson junctions



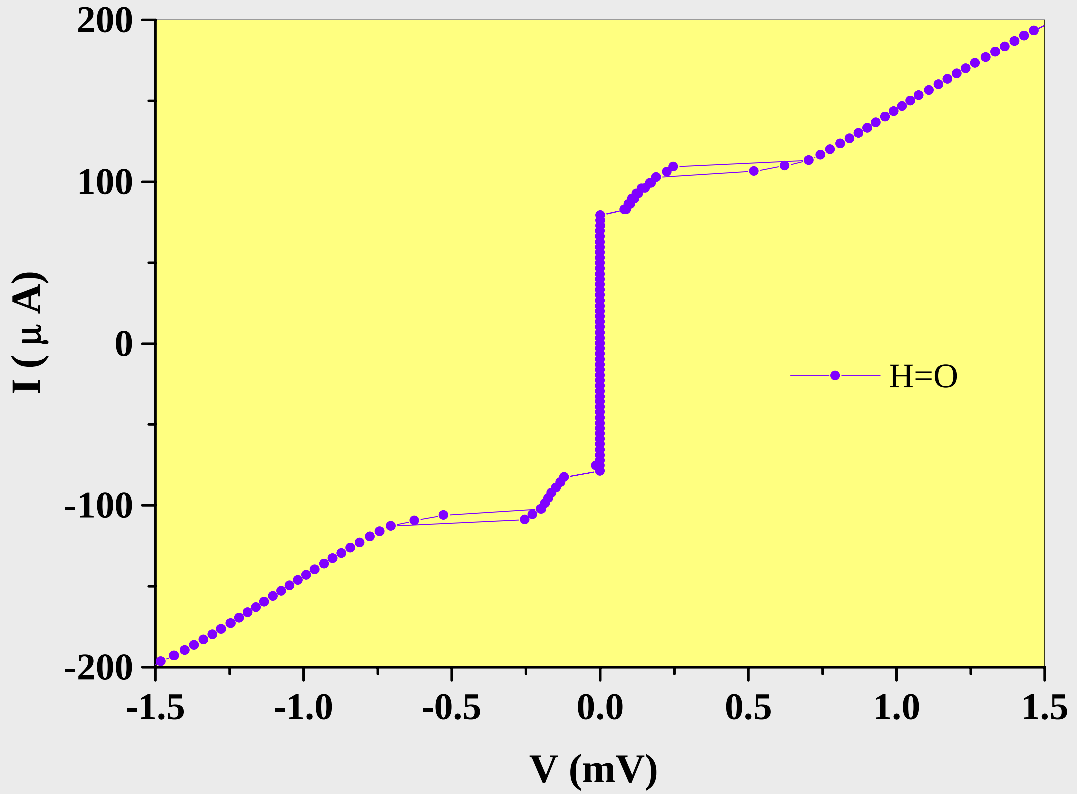
Layout of the device

Grain boundary structure

biepitaxial junctions



IV characteristic of a partially asymmetric biepitaxial junction



T = 4.2 K

The IV curve clearly exhibits symmetric linear branches at $I_{cr} = 0$

Conclusions

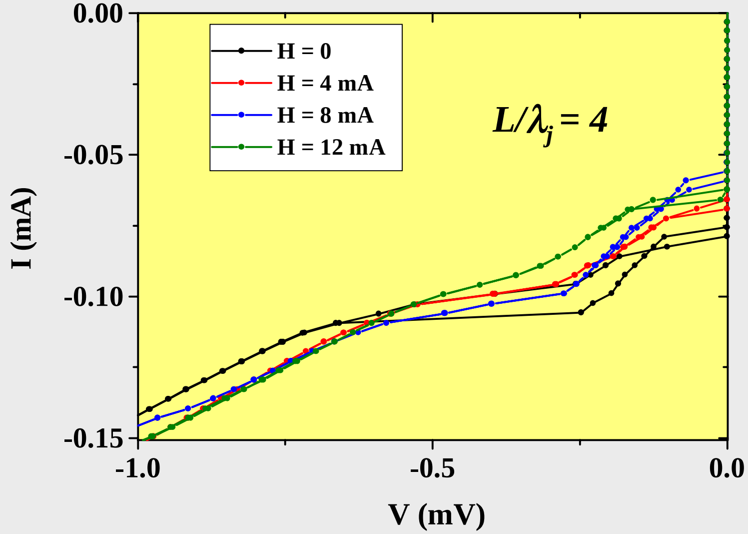
- *Linear branches have been detected in the IV characteristics of YBCO step edge Josephson junctions with a four terminal configuration. The phenomenology observed allows to connect the appearance of the linear branches with flux flow in long junctions. Moreover the fluxon nucleation is induced by non-equilibrium effects.*

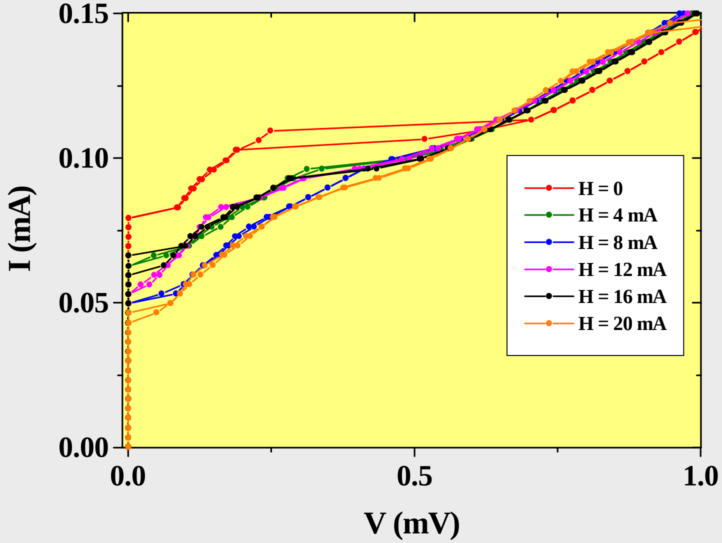
- *The large and stable voltage tunability of the bias point of the linear branches and the available power make the device interesting for the development of Josephson oscillators.*

- *Preliminary measurements on biepitaxial junctions have shown the appearance of linear branches. Their voltage position can modulate by applying an external magnetic field.*

IV characteristics at different magnetic fields

T = 4.2 K





junction with a symmetric bias

$L/\lambda_j = 4$

junction with a partially symmetric bias

$L/\lambda_j = 4$