CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

LPEM - CNRS - ESPCI

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ESPCI

Long range proximity effect in High Tc Josephson NanoJunctions : a quantitative study

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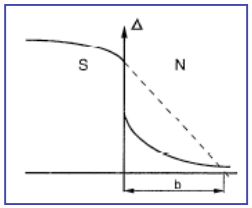
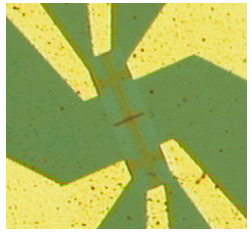
Outline

Proximity effect in Superconductors



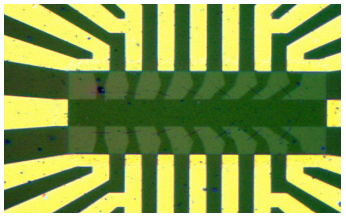
HTSc Josephson nano-Junctions



Quasi-classical approach of the proximity effect

$$\frac{\hbar D(x)}{2}\frac{\partial^2\theta_n}{\partial x^2} - \omega_n \sin\theta_n + \Delta(x)\cos\theta_n - \Gamma_{AB}(x)\sin\theta_n\cos\theta_n = 0$$

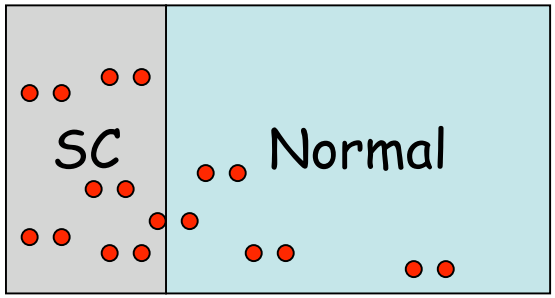
Comparison with experimental results

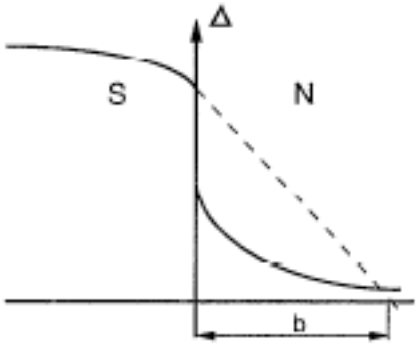


Conclusions

Proximity effect in Superconductors

- Physics : propagation of superconducting correlations





$$\psi_N(x) \approx \psi_N(0^+) e^{-\frac{x}{\xi_N}}$$

$$\xi_N = \sqrt{\frac{\hbar D}{2\pi k_B T}}$$

De Gennes : Rev Mod Physics 1964

Diffusive case

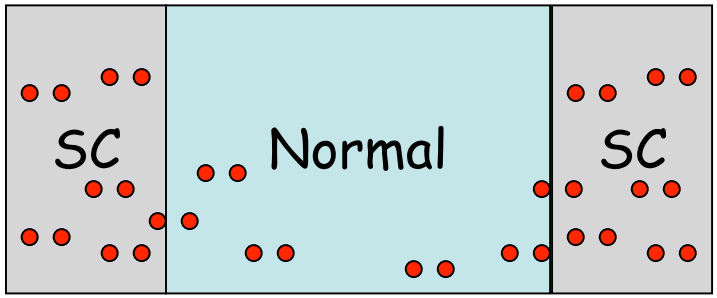
- Physics : mesoscopic superconductor/normal metal systems

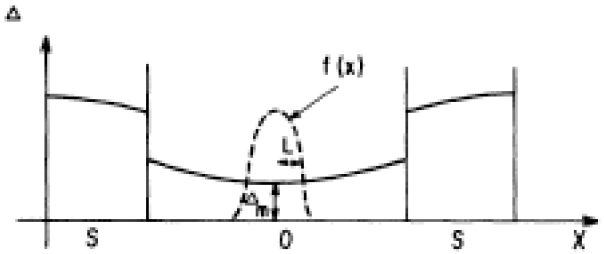
- Physics : local probe of the DOS in Sc/N Nanostructures

- Applications : normal to SC current conversion and Josephson Junctions

Proximity effect based Josephson Junctions

- Phase coherence through normal metal : Josephson coupling





$$\xi_N = \sqrt{\frac{\hbar D}{2\pi k_B T}}$$

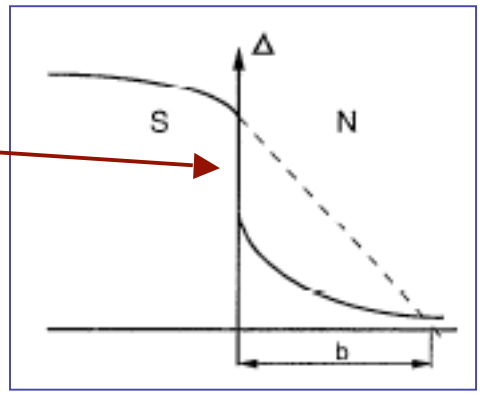
$$I_c = I_0 \left(1 - \frac{T}{T_c}\right)^2 \frac{l/\xi_N}{\sinh(l/\xi_N)}$$

Diffusive case

- Strength of the coupling

  Low interface resistance

  Fermi Velocities match



Proximity effect with HTSc Superconductors ?

- Experimental evidences ???

  YES : Josephson Junctions with HTSc material

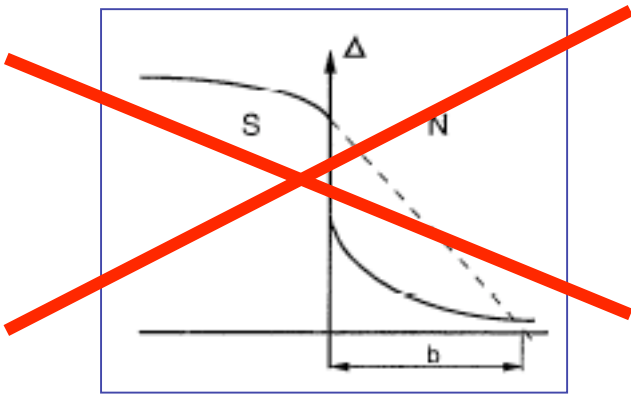
  BUT : Weak control of the systems …

- Major difficulties :

  HTSc / Normal metal : poor Fermi Velocity match

  HTSc / Normal metal : poor interface -> high resistance

  Anisotropy !

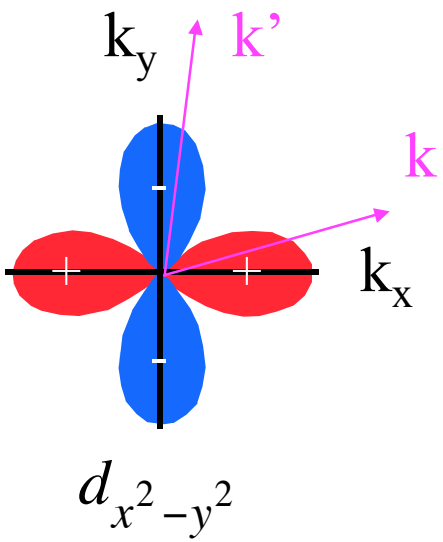


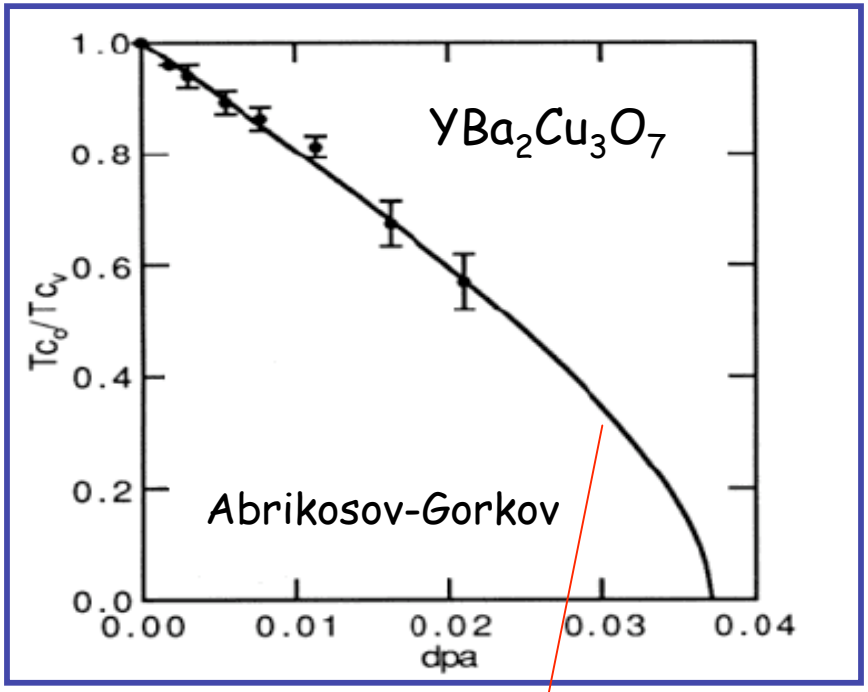
- Idea ?

Create new HTSc S/N/S junctions with « no interface »

Disorder in High Tc Superconductors

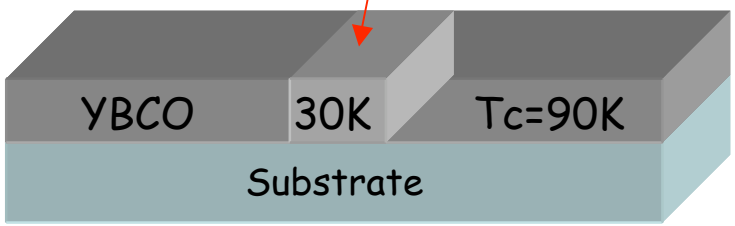
➢ Defect in d_{x2-y2} superconductor ➡ depairing





➢ Local control of the disorder

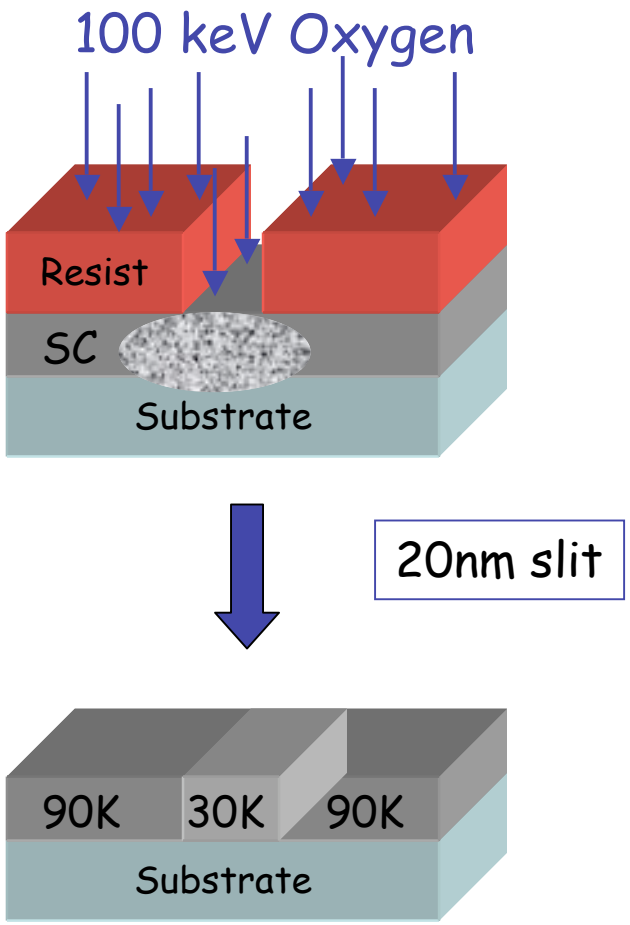
➢ Nanoscale engineering (ξ_N)

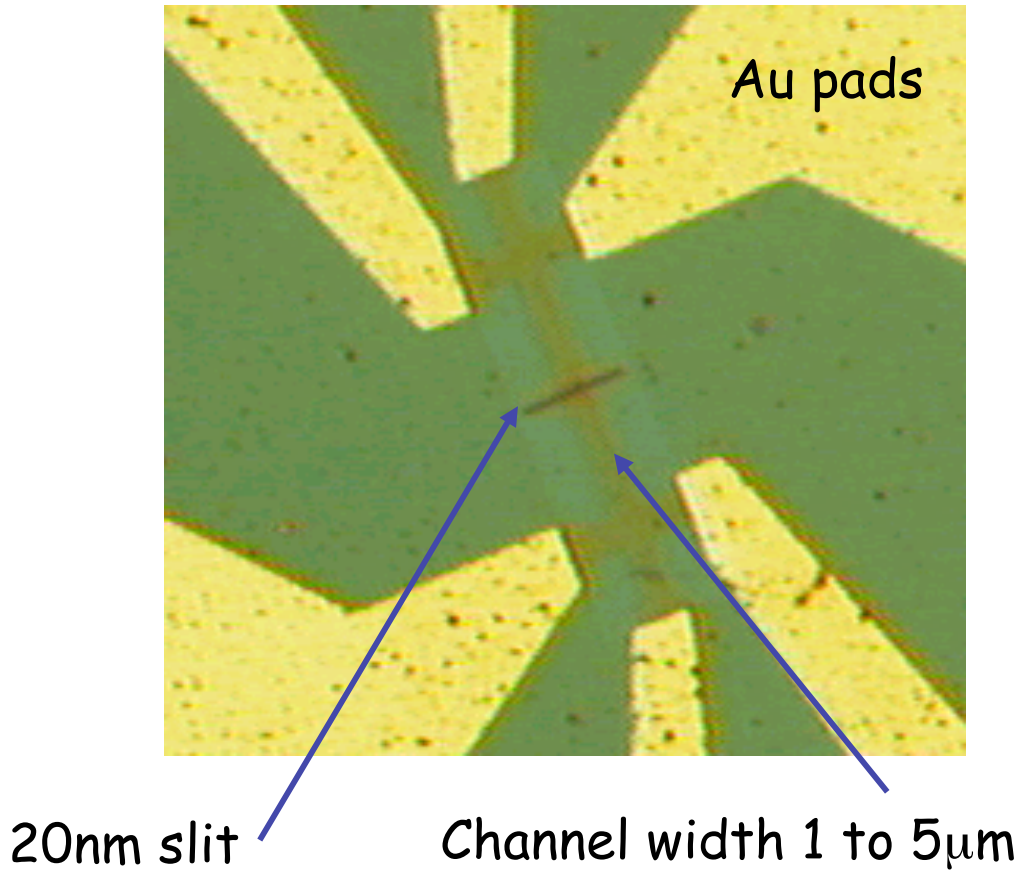


30K<T<90K Super/Normal/Super Josephson junction

Making HTSc Josephson NanoJunctions (YBCO)

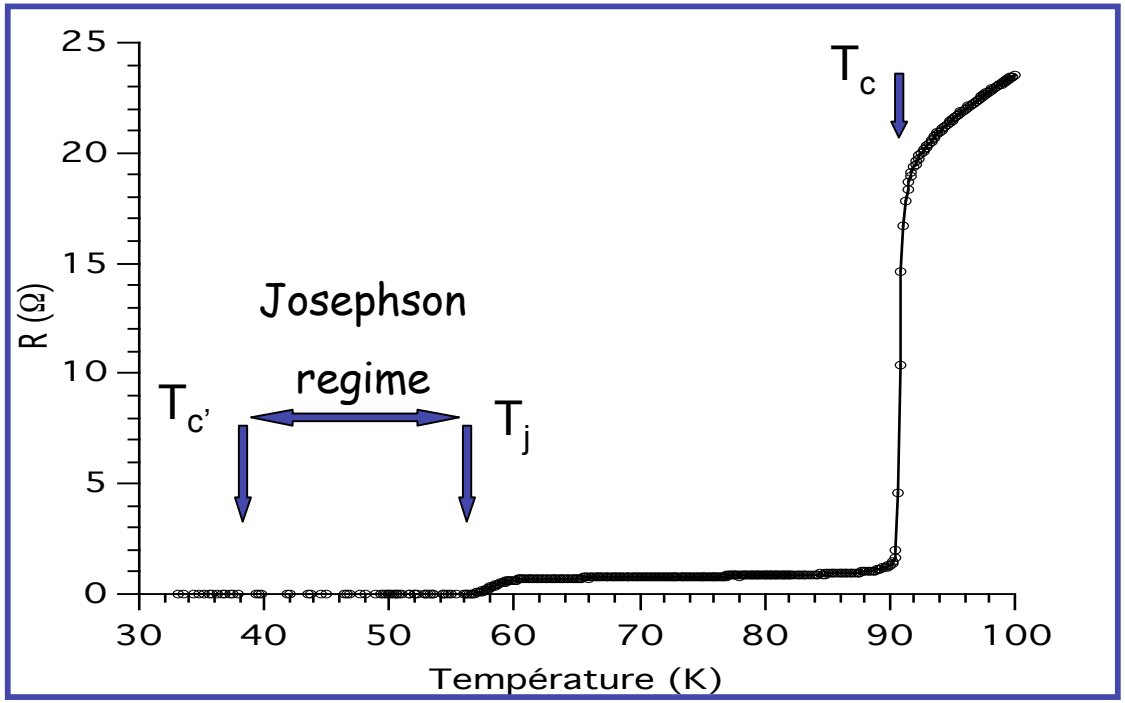
- Controled defect concentration through ion irradiation
- Irradiation through a resist mask

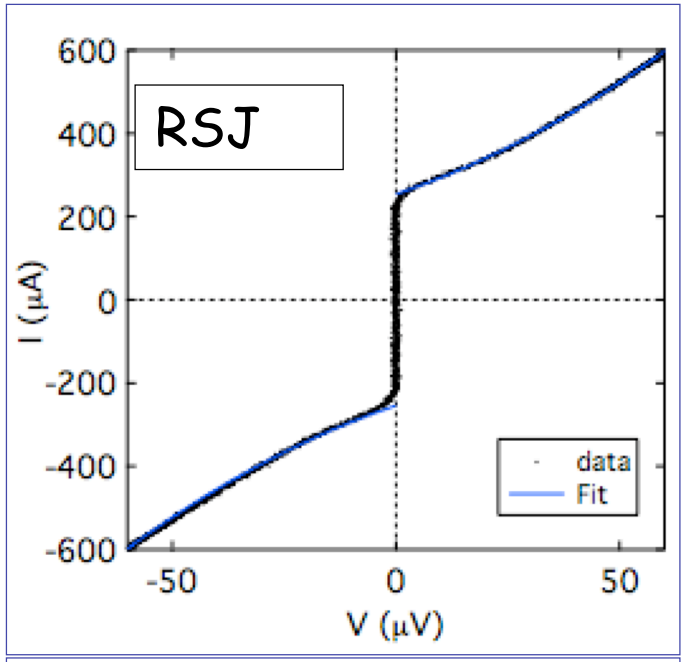


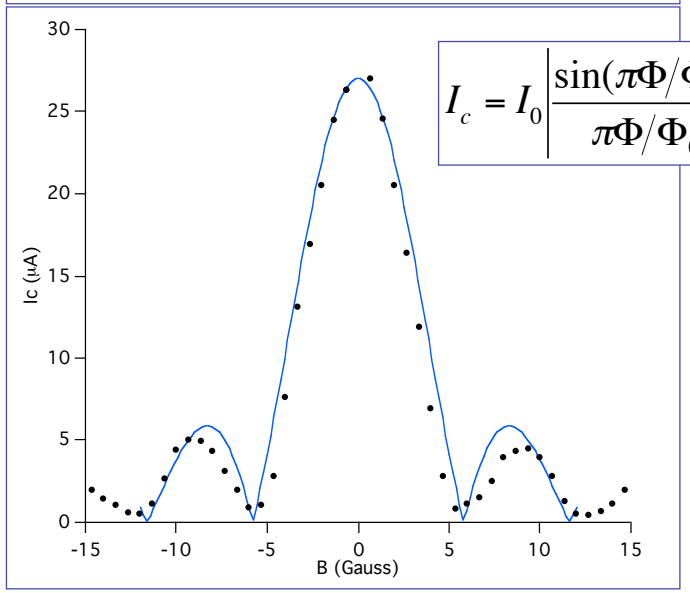


Josephson Junctions characteristics

➢ Reproducible Josephson Junctions

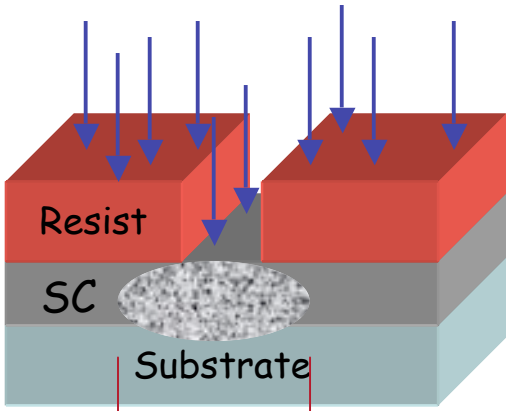






$$I_c = I_0 \left| \frac{\sin(\pi\Phi/\Phi_0)}{\pi\Phi/\Phi_0} \right|$$

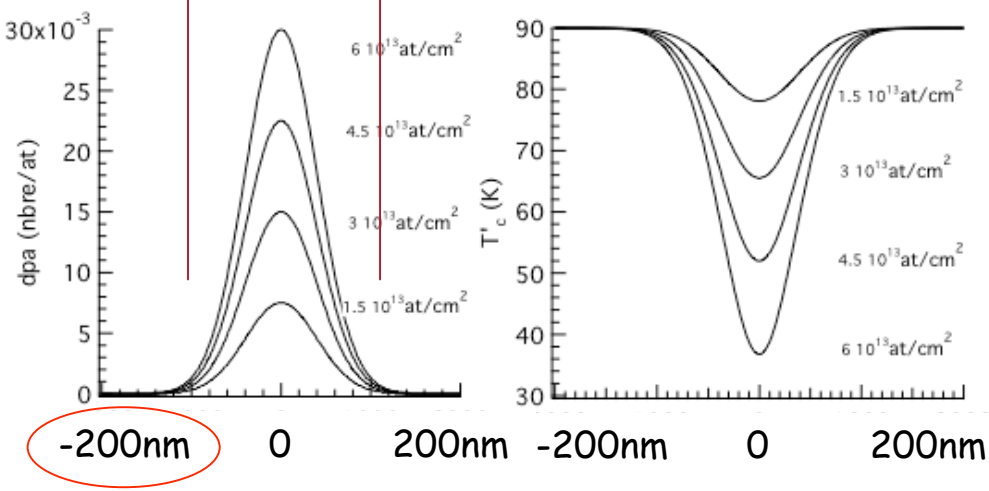
Modeling the junction



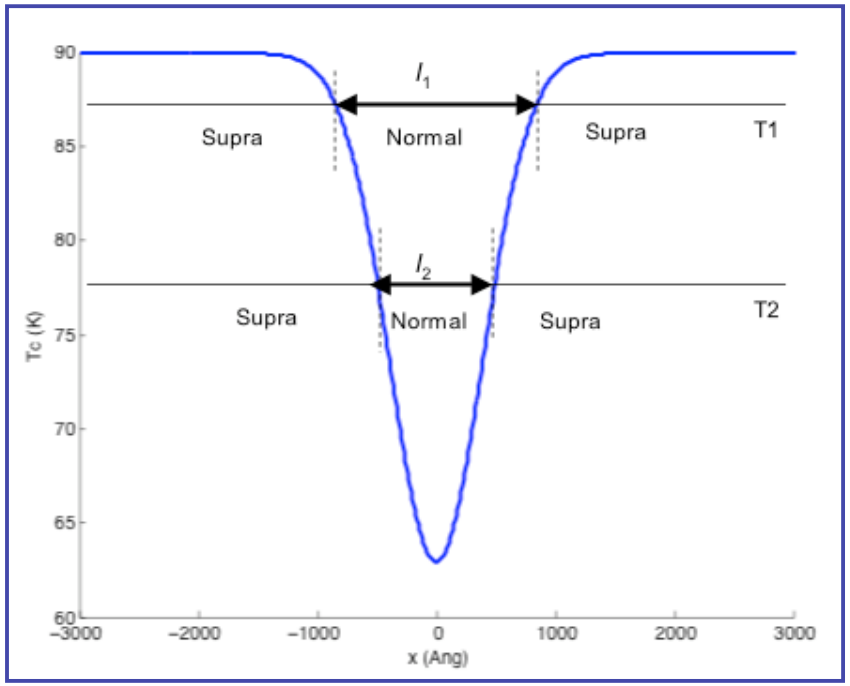
- « Ideal proximity system »
- Perfect Fermi velocities match
- No interface
- Long range Proximity Effect

SRIM simulations

σ = 40 nm



Defect density Corresponding Tc



Quasi-classical approach of the proximity effect

➢ Usadel equations parametrized in θ

$G=\cos\theta$ Quasiparticles

$F=\sin\theta$ Pairs

Homogeneous SC

Depairing Γ_{AB}

$$\frac{\hbar D(x)}{2}\frac{\partial^2\theta_n}{\partial x^2} - \omega_n \sin\theta_n + \Delta(x)\cos\theta_n - \Gamma_{AB}(x)\sin\theta_n\cos\theta_n = 0$$

$\omega_n = \pi k_B T(2n+1)$ Matsubara frequencies

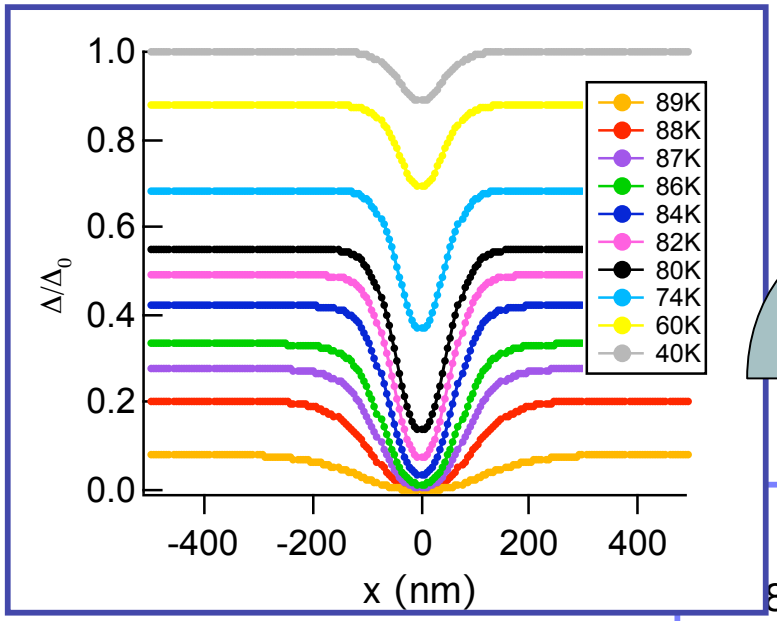
Limits conditions $\tan\theta_N = \dfrac{\Delta}{\omega_N}$

➢ Self-consistant gap equation

$$\Delta(x) = \lambda_S 2\pi K_B T \sum_{\omega_n} \sin\theta_n$$

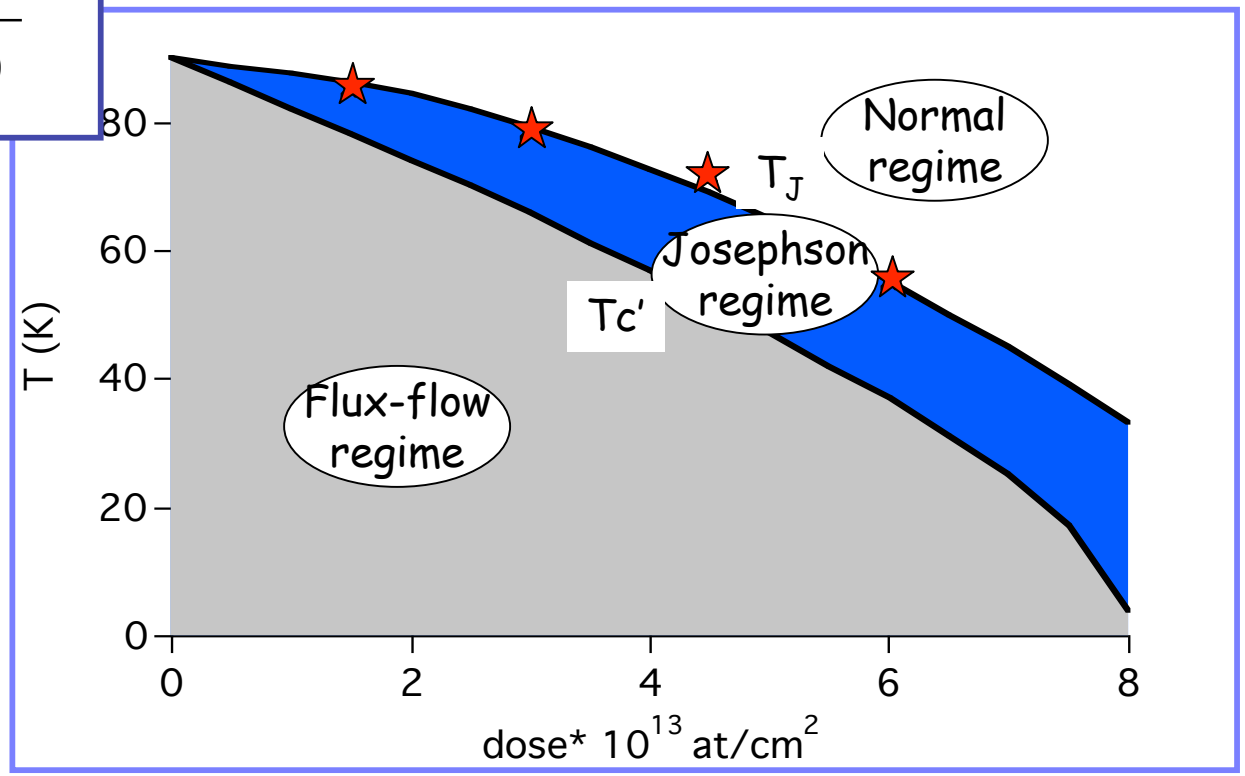
$\Delta(x)$ profil along the junction

Quantitative agreement with experiments …

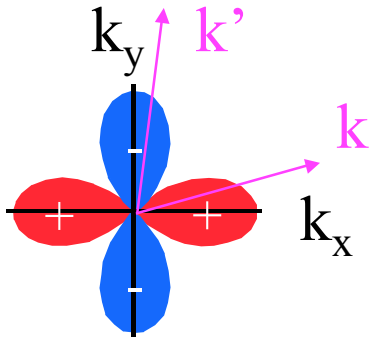


Pair potential profile

Actual coupling temperature

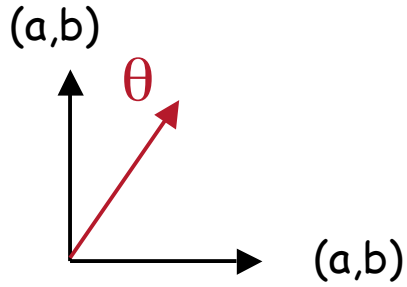


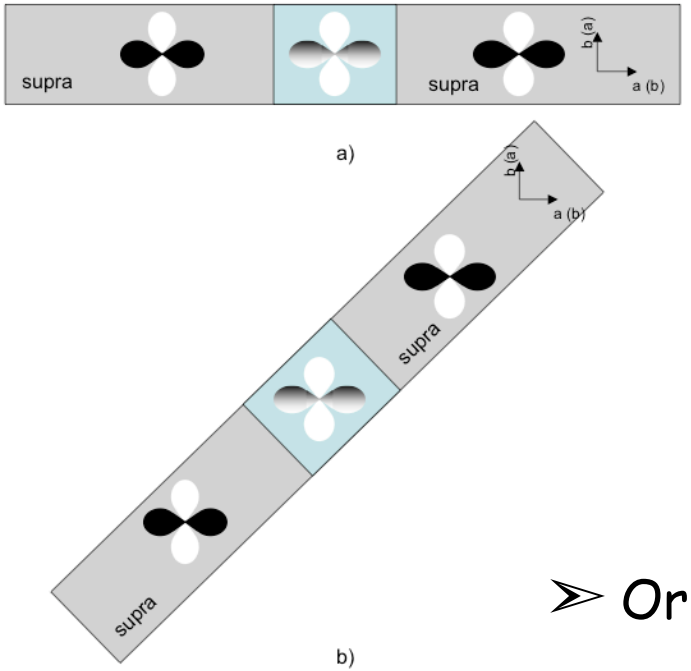
Order parameter anisotropy ?

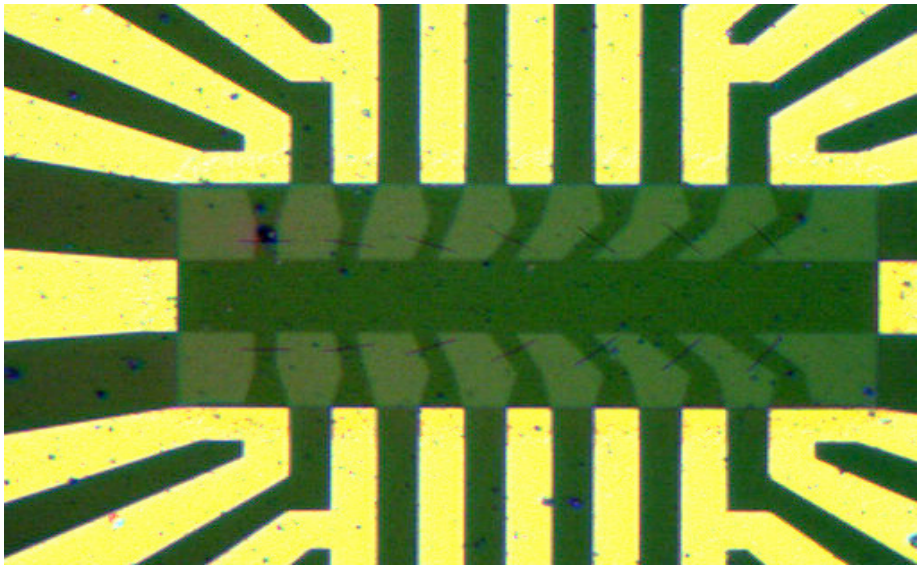


$d_{x^2-y^2}$

➢ D-wave order parameter

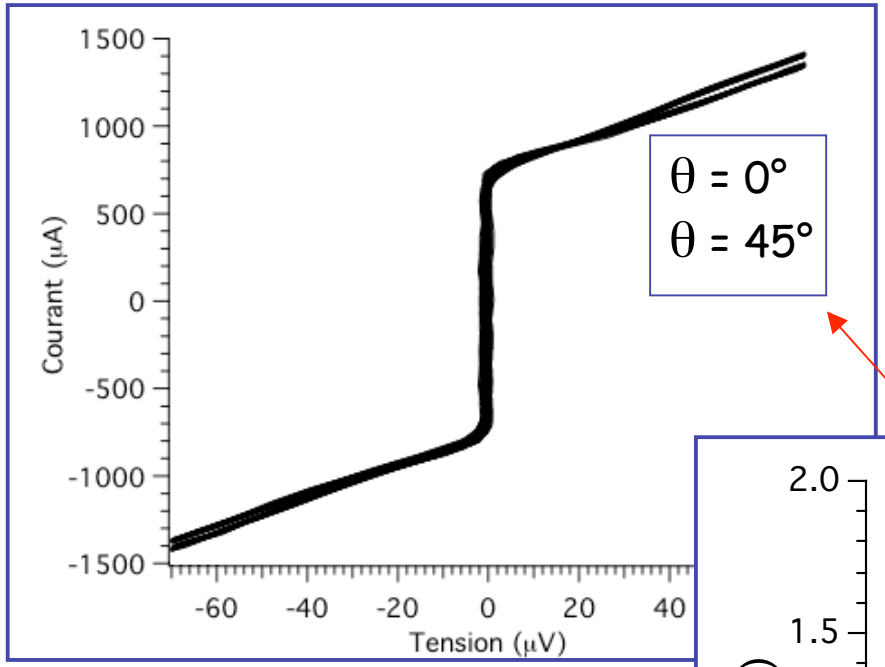




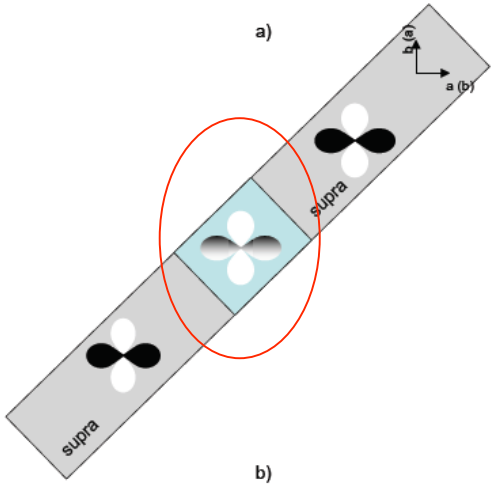


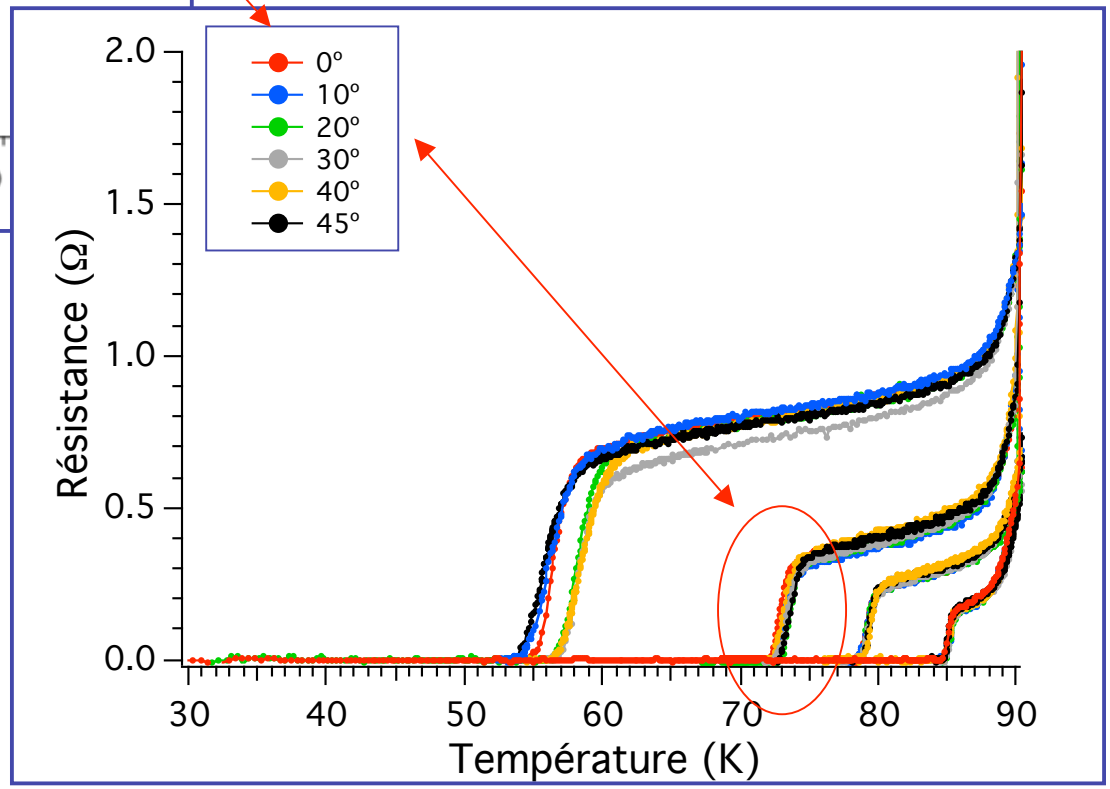
➢ Orientations θ = 0 °,10 °,20 °,30 °,40 °,45°

Order parameter anisotropy ?



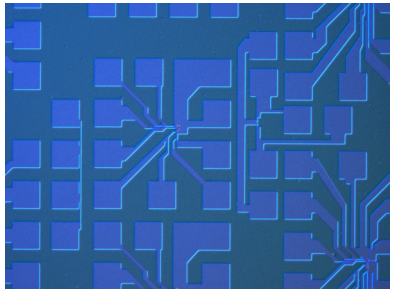
- No effect !!
- Diffusion ?
- 2d order parameter ?
- Anisotropic pairing !





Conclusions

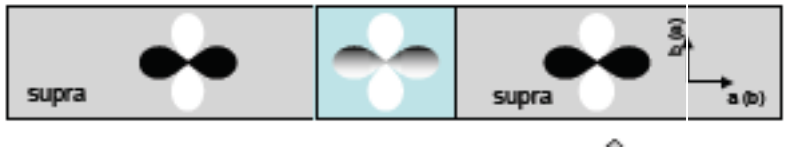
- Proximity effect : probe of superconducting correlations
- Reproducible High Tc Josephson NanoJunctions



- Superconducting electronics (SNS)
- Ideal proximity system

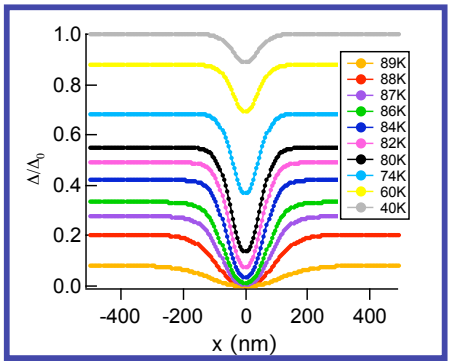
  High transparency barrier

  Long range SC correlations (GIANT !)
- Quasiclassical approach



  Diffusive equations (Usadel)

  Quantitative agreement : calculation of T_J



- Future work

  Local study of $\Delta(x)$ by STM

  Calculation Ic(T)

  Anisotropic pairing in narrow channels