Modelling of Josephson Nanostructures and Intrinsic Josephson Junctions in HTS

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Outline

- Radiation effects
- Shunting and radiation
- Staircase structure of Shapiro steps
Radiation effects
IV-characteristics without irradiation (curve 1) under radiation with $A = 0.1$ (curve 2) $A = 0.5$ (curve 3).


Demonstration of changing of LPW wavelength with an increase of the amplitude of radiation.
Waves in the stack of coupled JJ

LPW wavelengths at $\nu = 2$

Filled squares - fundamental PR
Circles - radiation related PR

“Devil’s Staircases” and Continued Fractions in Josephson Junctions.
Devil’s Staircases in Josephson Junctions.

DS structure, $A=0.8$

DS structure, $A=0.9$
Continued Fractions in Josephson Junctions.

Continued fraction algorithm for SS subharmonics (underlined is value of n)

Fractal structure


A. M. Hriscu and Yu. V. Nazarov
PHYSICAL REVIEW LETTERS
PRL 110, 097002 (2013)
Josephson junctions detectors for Majorana fermions

We demonstrate that the current-voltage (I-V) characteristics of resistively and capacitively shunted Josephson junctions (RCSJs) hosting localized subgap Majorana states provide a phase-sensitive method for their detection. In addition, the RCSJs hosting Majorana bound states also display an additional sequence of steps in the devil’s staircase structure seen in their I-V characteristics; such a sequence of steps makes their I-V characteristics qualitatively distinct from that of their conventional counterparts.

Shunting of Josephson junctions
\[
\begin{align*}
\frac{\partial \varphi_l}{\partial \tau} &= V_l - \alpha(V_{l+1} + V_{l-1} - 2V_l) \\
\frac{\partial V_l}{\partial \tau} &= I - \sin \varphi_l - \beta \frac{\partial \varphi_l}{\partial \tau} - CU \\
\frac{\partial U}{\partial \tau} &= \frac{1}{LC} \left( \sum_{l=1}^{N} V_l - u_c \right) \\
\frac{\partial u_c}{\partial \tau} &= U
\end{align*}
\]

\[I \rightarrow I_c;\]
\[\text{time} \rightarrow \tau = \omega_p t, \quad \omega_p = \sqrt{\frac{2eI_c}{C_j \hbar}};\]
volatges \(V_l, u_c \rightarrow V_0 = \frac{\hbar \omega_p}{2e};\)
\[C \rightarrow C_j;\]
\[L \rightarrow (C_j \omega_p^2)^{-1};\]
\[\beta = \frac{1}{R_j \sqrt{\frac{\hbar}{2eI_c C_j}}} = \frac{1}{\sqrt{\beta_c}}.\]
Resonance circuit branches

\[ \omega_{rc} = \sqrt{1 + \frac{NC}{LC}} \]

- Variation of amplitude dependence of SS width in IV-characteristics of single JJ
Variation of amplitude dependence of SS width in resonance region

\[ \Delta I = 2|J_n(Z)|, \quad Z = \frac{A}{\omega_R \sqrt{\beta^2 + \omega_R^2}} \]

- EPL, 110, 47001 (2015)
Resonance conditions

- EPL, 110, 47001 (2015)
We calculate the necessary capacitance of the shunt at a given inductance \( L = 50 \text{ pH} \) using the typical parameters for BSCCO:

- \( S = 1 \mu m^2 \),
- \( d_I = 12 \times 10^{-10} \text{m} \),
- \( \varepsilon = 25 \),
- \( \beta = 0.1 \),
- \( \alpha = 0.1 \),
- \( \omega_p = 0.5 \text{ THz} \).

At these parameters, the capacitance of the Josephson junction is \( C_J = 0.2 \text{ pF} \).

At real inductance \( L = 50 \text{ pH} \), the dimensionless inductance is \( L = 2.5 \). Consequently, the shunting capacitance \( C_{\text{sh}} = 0.04 \text{ pF} \) is sufficient for the observation of the \( rc \) branch at \( LC = 0.5 \).

* Presented by A. Ustinov and E. Ilichev
Experimental results of Klushin A., Institute of Microstructures, Nizhnii Novgorod, Russia
Features of rc-branch

The rc-branch AB in IV-characteristics and I-dependence of the superconducting current (sweep along 01ODEAEBCDEF0)

The IV-characteristic and I_s(I) dependence (sweeping along 01OBCDEBCEF0)

The rc-branch at different resonance frequency and dissipation parameter

Resonance frequency dependence of the maximal superconducting current

Independence of the rc-branch end point from shunt parameters at fixed resonance frequency

Charge density waves
Charge Density Waves

LPW $\rightarrow$ CDW,  CDW $\rightarrow$ CDW

Breathing Charge Density Waves in Intrinsic Josephson Junctions

The effect of external electromagnetic radiation on the system of coupled Josephson junctions in the CDW state is completely different from the case of single JJ. It causes the appearance of the set of the Shapiro steps in the IV-characteristics of JJ of the stack related to the voltage distribution among JJs. However, usual harmonics and subharmonics of radiation frequency are observed in the total IV-characteristics of the stack.

Staircase structure of Shapiro step

Different states of the stack, $A=0.05$,

What is Shapiro step? How to measure its width?

Position of the SS for intrinsic JJ does not correspond to the frequency of the external radiation (‘broken SS’)

Conclusions

- We have demonstrated a series of novel effects in intrinsic Josephson junction in HTSC, particularly:
  - Variation of longitudinal plasma wavelength with an increase of the amplitude of radiation
  - The algorithm for the appearance and detection of subharmonics with increasing radiation amplitude is proposed.
  - Variation of amplitude dependence of SS width in resonance region
  - Position of the SS for intrinsic JJ does not correspond to the frequency of the external radiation (‘broken SS’)
  - Breathing charge density waves
Thank you for your attention!

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