JOSEPHSON WEAK LINK BASED ON PROXIMITY EFFECT IN LONG BIMETALLIC THIN-FILM BRIDGE

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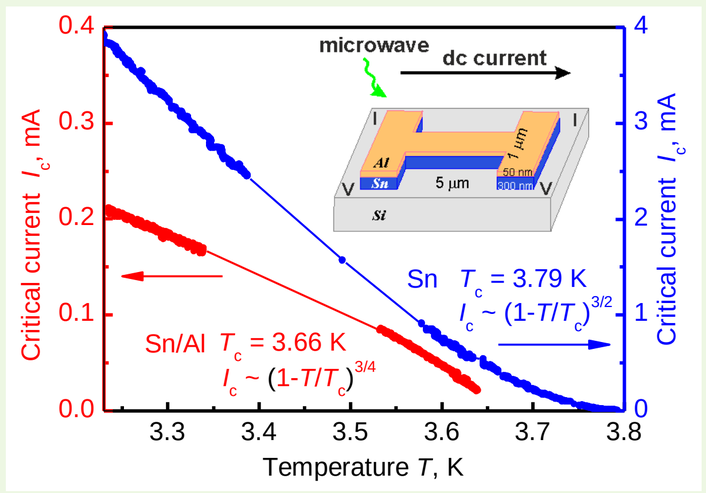
INTRODUCTION

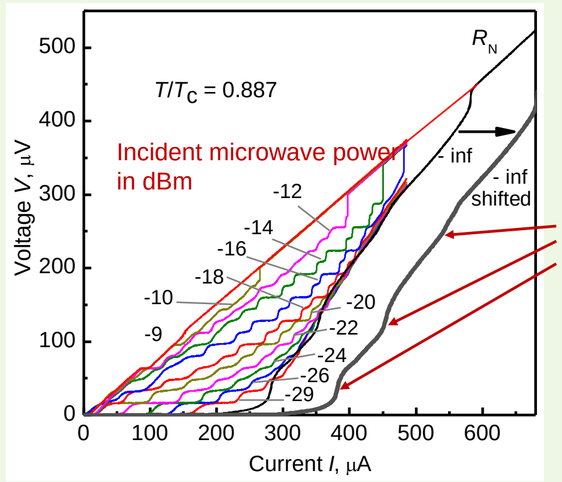
- **Tunnel Josephson junctions** have *current-phase relation* (***CPR)***, superconducting current I_s vs. order-parameter phase difference φ, which is simply sine: $\boldsymbol{I_s=I_c \sin\varphi}$ (I_c is max superconducting current). They are the best for superconducting electronics but need high-tec fabrication procedure.
- **Josephson weak links** (microbridges, SNS junctions, etc.), which are simpler in fabricarion, *show non-sine skewed CPR*, up to saw-tooth-like and even *hysteretic for long strips* with *phase-slip centers (PSC) inside*. The characteristics of superconducting devices using such weak links deteriorate.
- **The hallmark of sine CPR** is observing *Shapiro steps* under microwave irradiation. Due to mixing of Josephson radiation (non-stationary Josephson effect) and external irradiation with frequency $\boldsymbol{f}$ a smooth current-voltage characteristic (IVC) of the JJs becomes step-like, current steps appear at voltages $\boldsymbol{V_n=nhf/2e}$, while the height of *n*-th step ΔI_n oscillates as a Bessel function of *n*-th order with the microwave field amplitude ***U***: $\Delta I_n(U) = I_c\left|J_n\left(nU/V_n\right)\right|$
- **We found** that rather long superconducting (***Sn***) thin-film bridge (strip) covered with a thin normal layer (***Al***) behaves like a "good" Josephson weak link with CPR similar to sine.

S-N BI-METALLIC vs. SUPERCONDUCTING THIN FILM BRIDGES



After covering s/c thin film (Sn) by a normal metal (Al), critical current $I_c(T)$ and T_c are changed and dropped down.

I-V CURVES UNDER IRRADIATION (10 GHZ). SHAPIRO STEPS



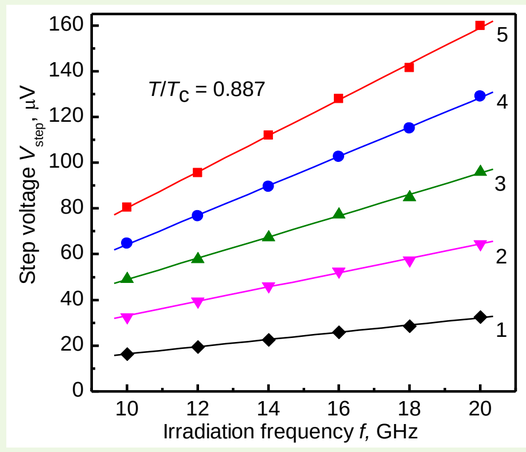
Only integer Shapiro steps, no fractional.

This means: → Unskewed, quasi-sine CPR

Up to 3 phase-slip centers enter the bridge.
No hysteresis.
Shapiro steps emerge even at voltages lower than that of the 1st PSC creation

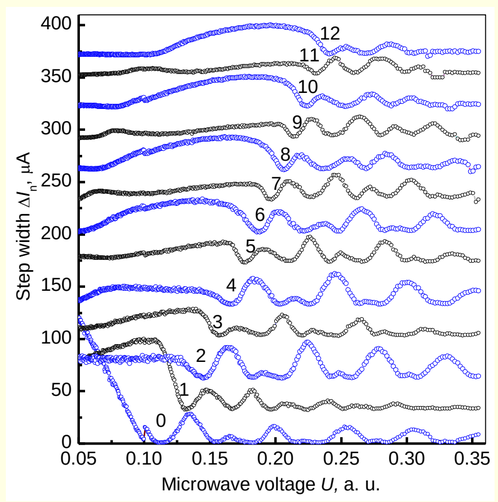
To compare, this behavior is unlike long superconducting bridges with PSCs which show non-oscillating Shapiro steps with subharmonics (non-sine CPR).

VOLTAGE POSITIONS OF 5 SHAPIRO STEPS



The voltage step multiple is 20% less than $\boldsymbol{V=hf/2e}$ since $\boldsymbol{V}$ is measured via normal pads and is determined by quasiparticle electrochemical potential difference while quasiparticle diffusion length exceeds the sample length.

12 SHAPIRO STEPS WIDTH VS. MW AMPLITUDE



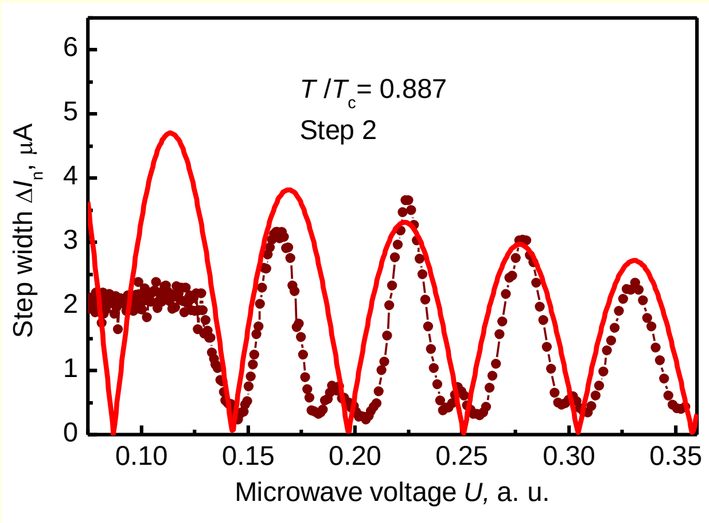
The even and odd steps exhibit anti-phase oscillations with microwave field amplitude.

Odd and even curves differ

- The large number of distinct steps,
- their oscillation with microwave amplitude and
- the absence of fractional steps

are signs that the ***CPR is close to sine or at least not significantly skewed***

2nd STEP WIDTH OSCILLATIONS



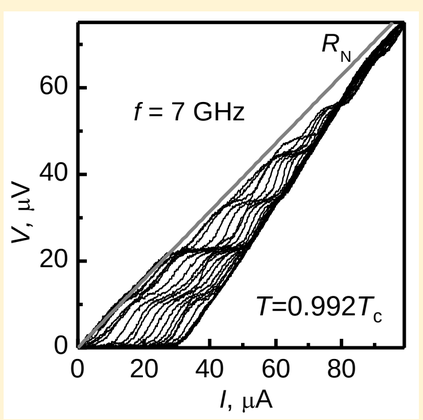
Additional set of small oscillations suggests two parallel ***competing 2π and 4π-periodic processes***.

Presumably, they may be due ***to Landau-Zener transitions*** at the anti-crossings between highly transparent 2π-periodic Andreev states, which can potentially induce ***4π-periodic behavior***.

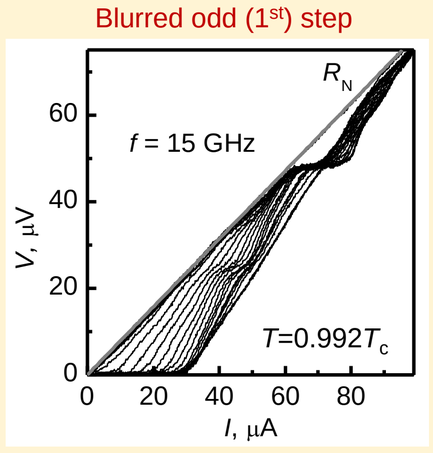
If this true, the relative contributions of 2π- and 4π-periodic processes must depend on the microwave frequency since the probability of LZ transitions is larger for faster movement along energy levels.

INTERPLAY BETWEEN LZ TRANSITIONS AND ENERGY RELAXATION TIME

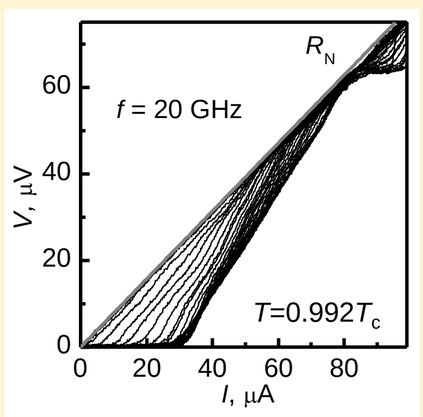
All-integer steps



Blurred odd (1st) step



Missing 1st step



ANDREEV LEVELS & LZ TRANSTIONS

MW frequency $\boldsymbol{f}$ is less / greater than energy relaxation time τ_ε

2π-periodic — Slow motion: $\boldsymbol{f < \tau_\varepsilon}$

2π-periodic + 4π-periodic — Intermediate: $\boldsymbol{f \sim \tau_\varepsilon}$

4π-periodic — Fast motion: $\boldsymbol{f > \tau_\varepsilon}$

For Sn, $\tau_\varepsilon = 3\cdot10^{-10}$ s

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Conclusion

- Covering a narrow superconducting tin strip with a normal metal thin film (aluminum) alters the properties of its resistive state governed by current-induced PSCs or PSLs.
- This bi-metallic long bridge demonstrates bright Josephson behavior with CPR close to sine.
- Its fabrication is much simpler than that of tunnel junctions making it beneficial for use in small-scale projects as a novel weak link in applications such as DC and RF SQUIDs.
- Deviation from ideal Bessel-like dependences of Shapiro step oscillations can be explained by two competing 2p and 4p-periodical processes due to Landau-Zener transitions between bound Andreev states and needs further study.

Literature

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