Novel results obtained by modeling of dynamic processes in superconductors

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HTS 2022 Modelling, Nancy, France

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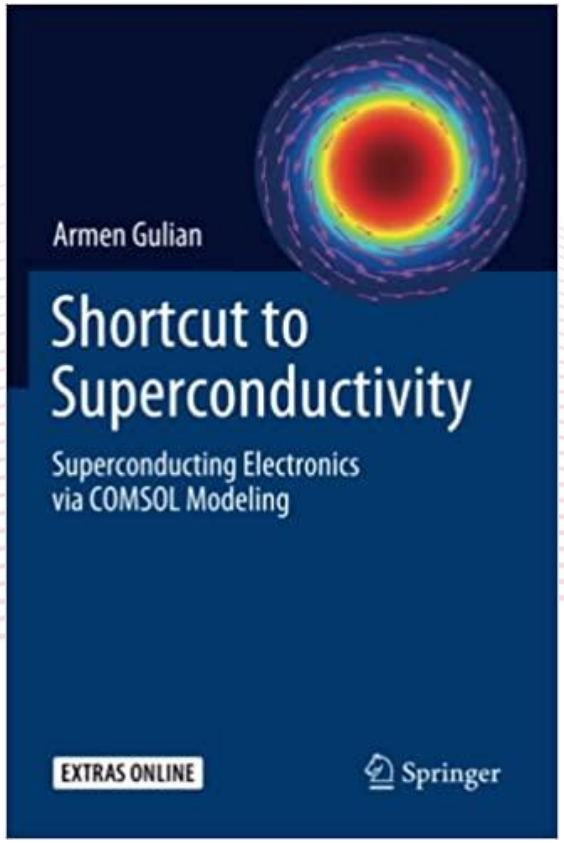
Overview:

- TDGL Modelling in COMSOL Multiphysics®
- Previous Related Modelling Work
  - Magnetic Flux Violation in SC Nano-rings
  - Gravitational Wave Detector (GEFEST)
- Coupled Electron-Phonon Dynamics
  - Phase Slip Centers (PSCs)
- **Main Topic:**
  Cryocooling based on Phase Slip Centers
  - **Negative Phonon Flux**
  - **Cooling Mechanism**



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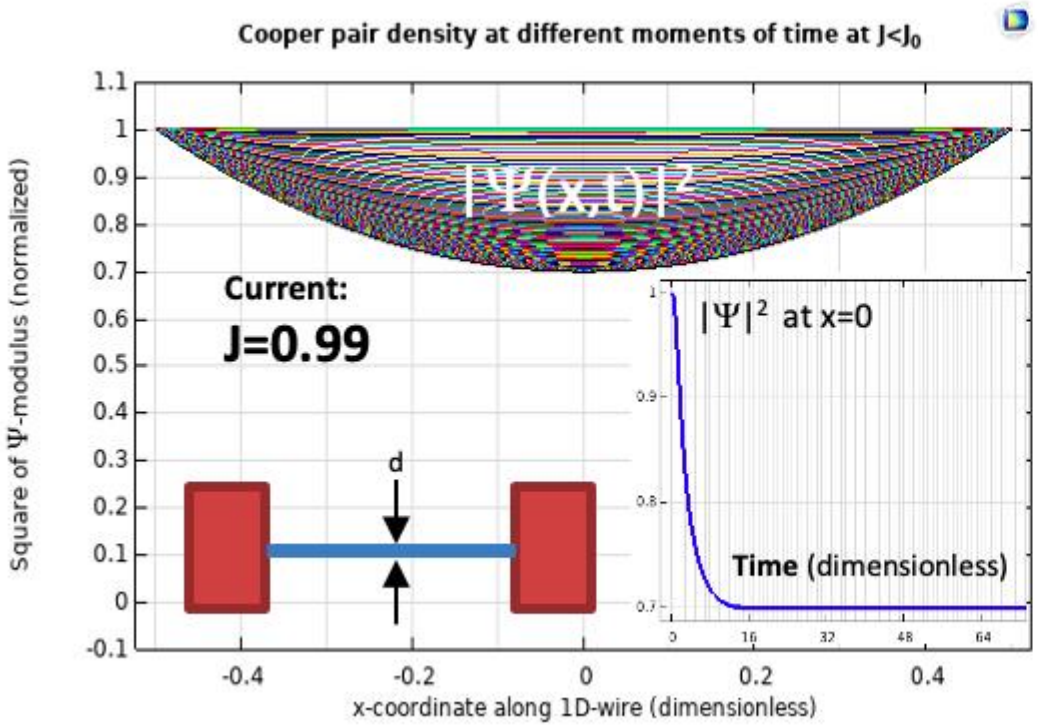
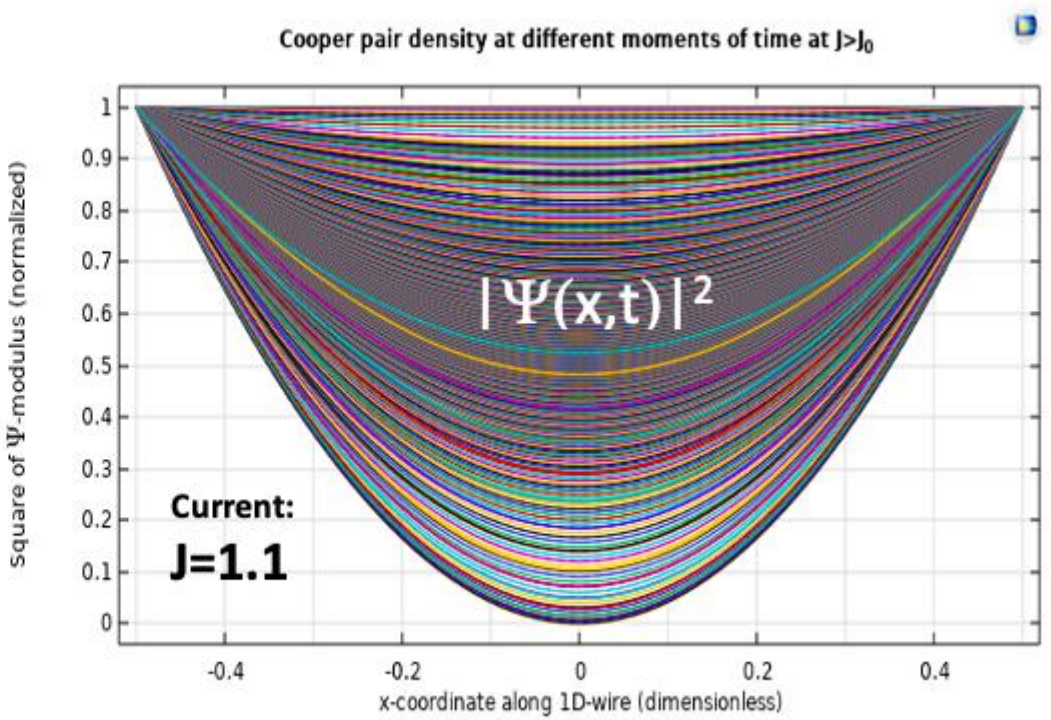
Time-Dependent Ginzburg-Landau Equations for PSCs

- Dimensionless and Gauge Invariant
- DC-Biased 1-D Wire Model





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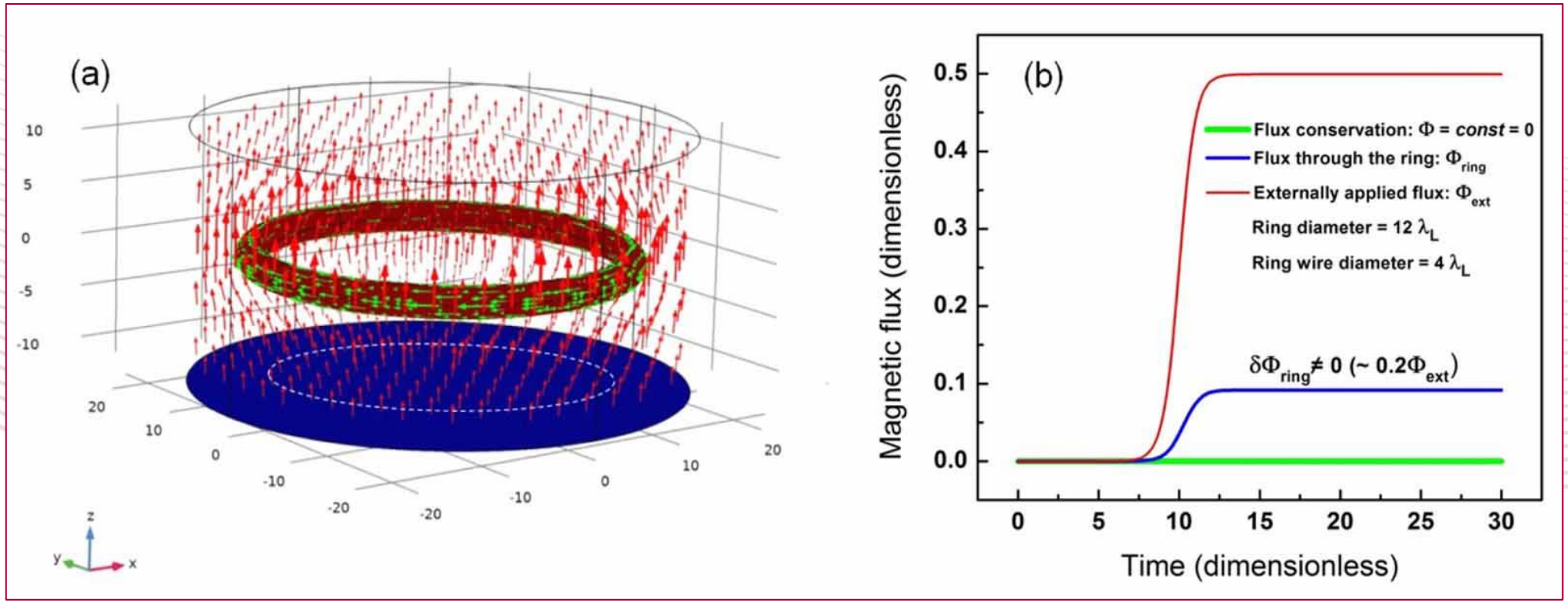
Published Results from 3-D Modelling

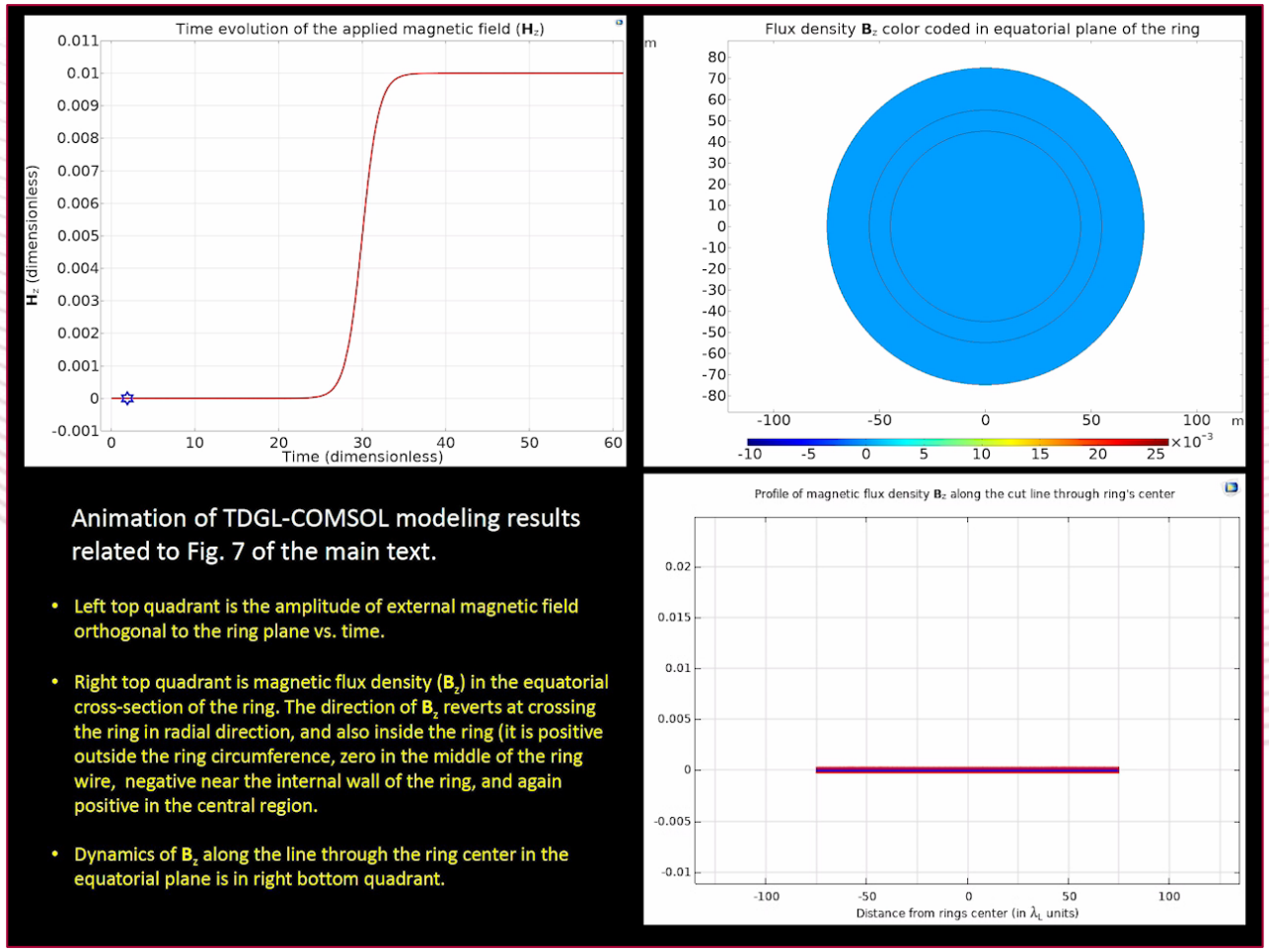
Magnetic Flux Violation



I. Mowgood et al, “Violation of magnetic flux conversation by superconducting nanorings,” Supercond. Sci.&Technol., vol. 34, no. 4, February 2022, Art no. 045006

Published Results from 3-D Modelling

Magnetic Flux Violation



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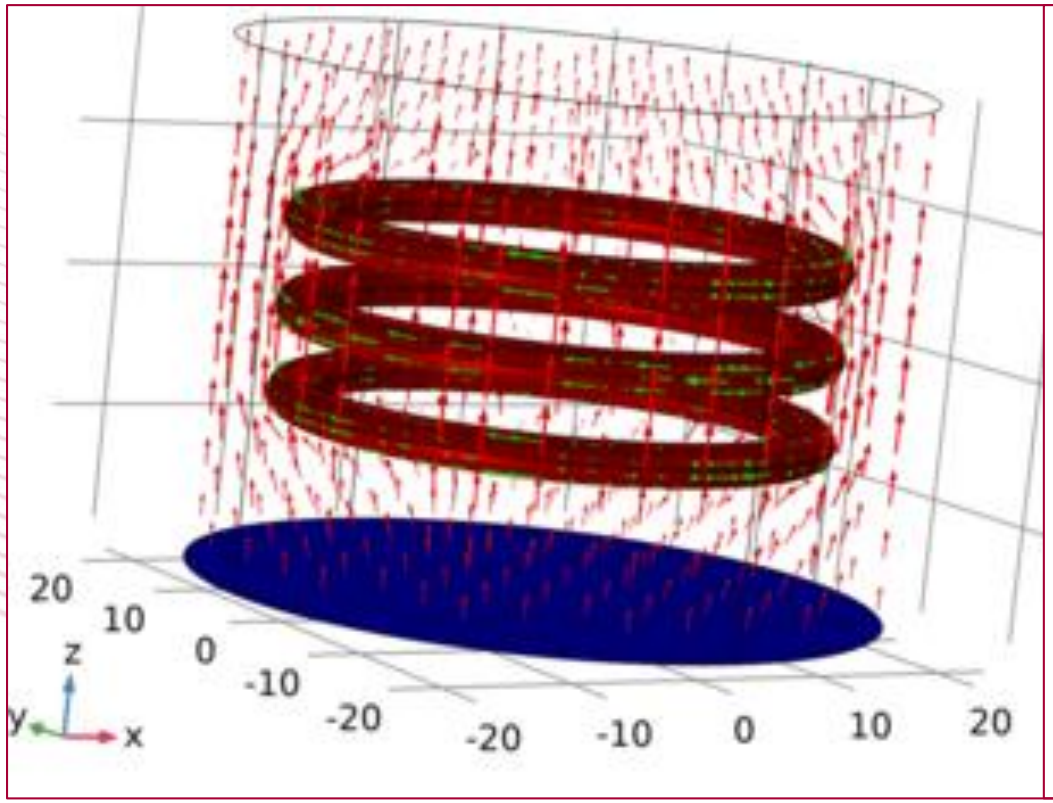
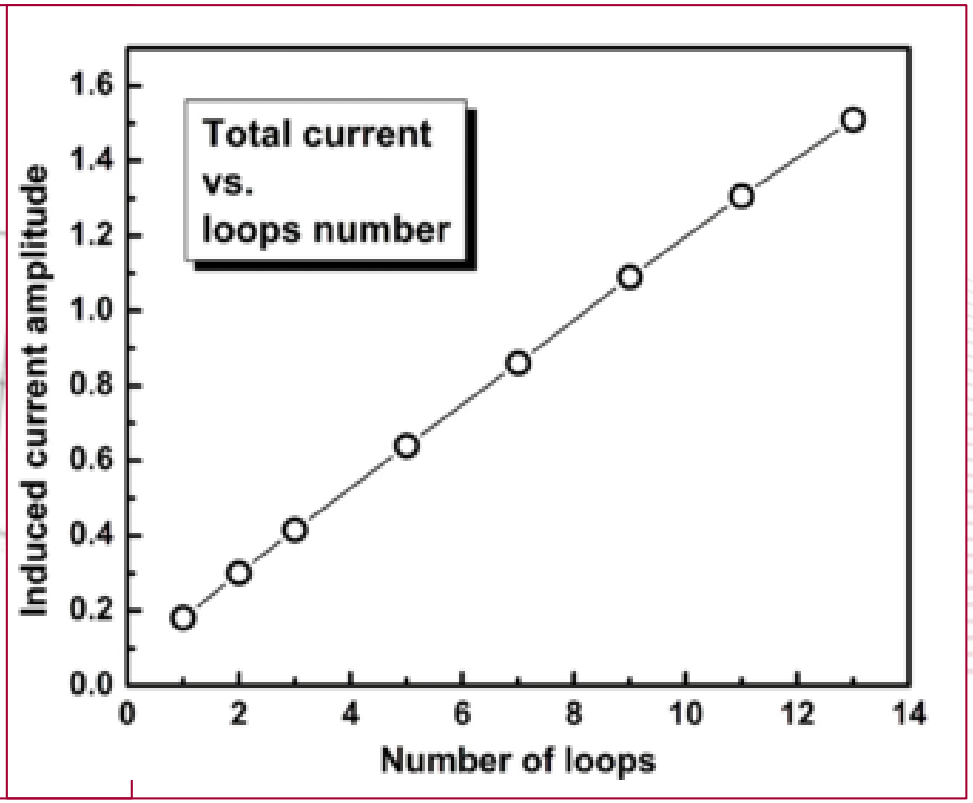
Published Results from 3-D Modelling

Gravitational Wave Detector





Gulian et al., "Gravitational wave sensors based on superconducting transducers," Phys. Rev. Res., vol. 3, November 2021, Art no. 043098, doi: 10.1103/PhysRevResearch.3.043098.

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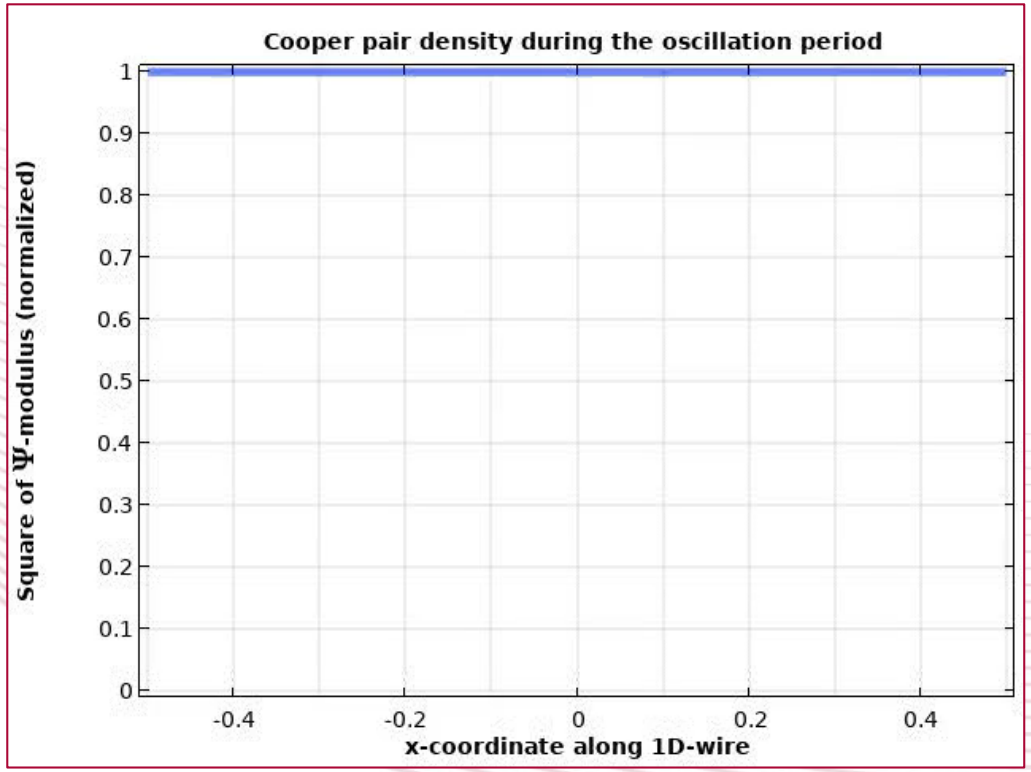
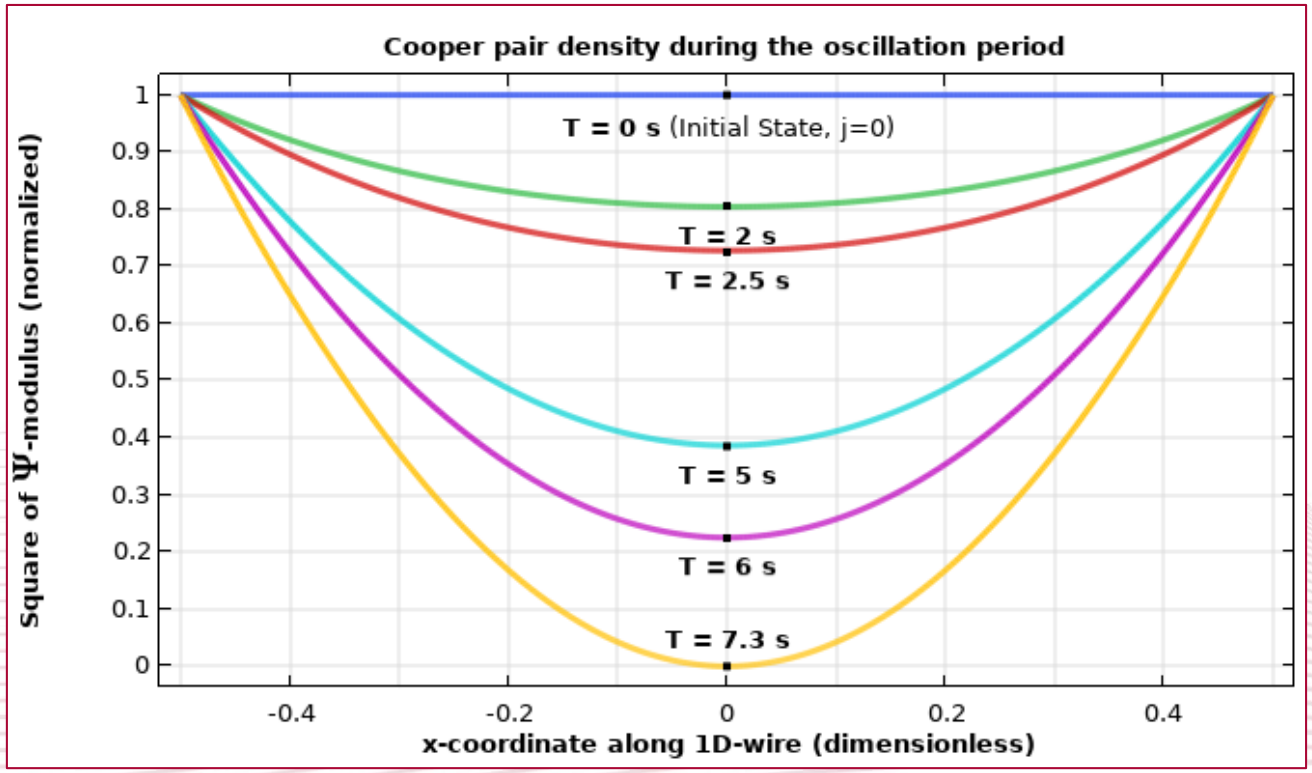
Coupled Electron-Phonon Dynamics of PSCs





- Non-Equilibrium Oscillatory Behavior
  - Current density **j** > critical current j_0
  - Cooper-pair density (CPD)

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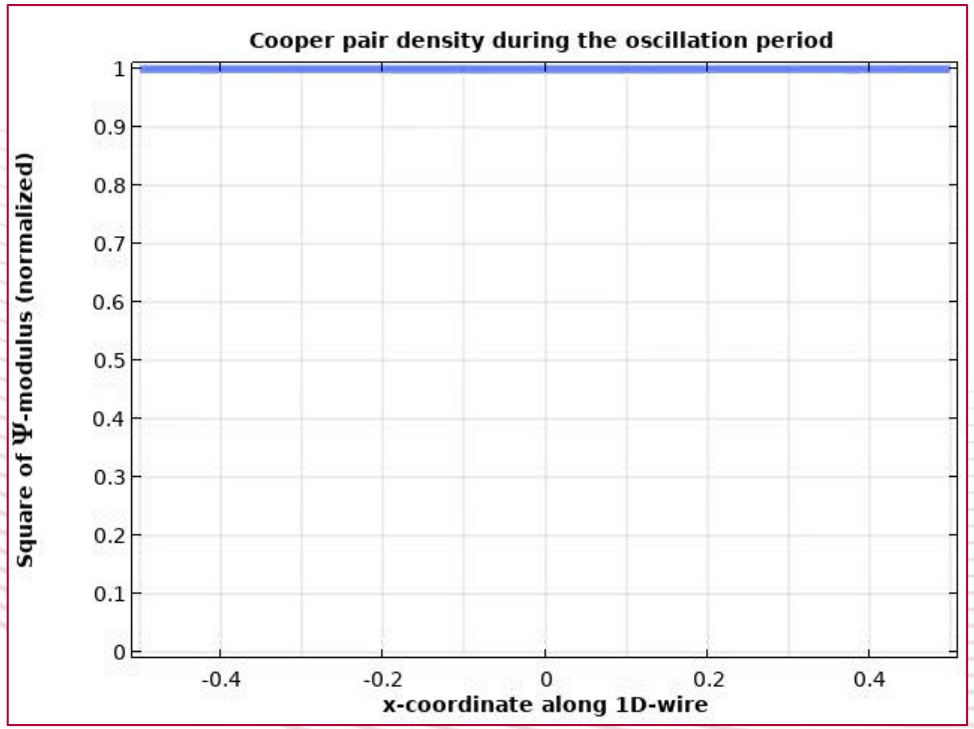
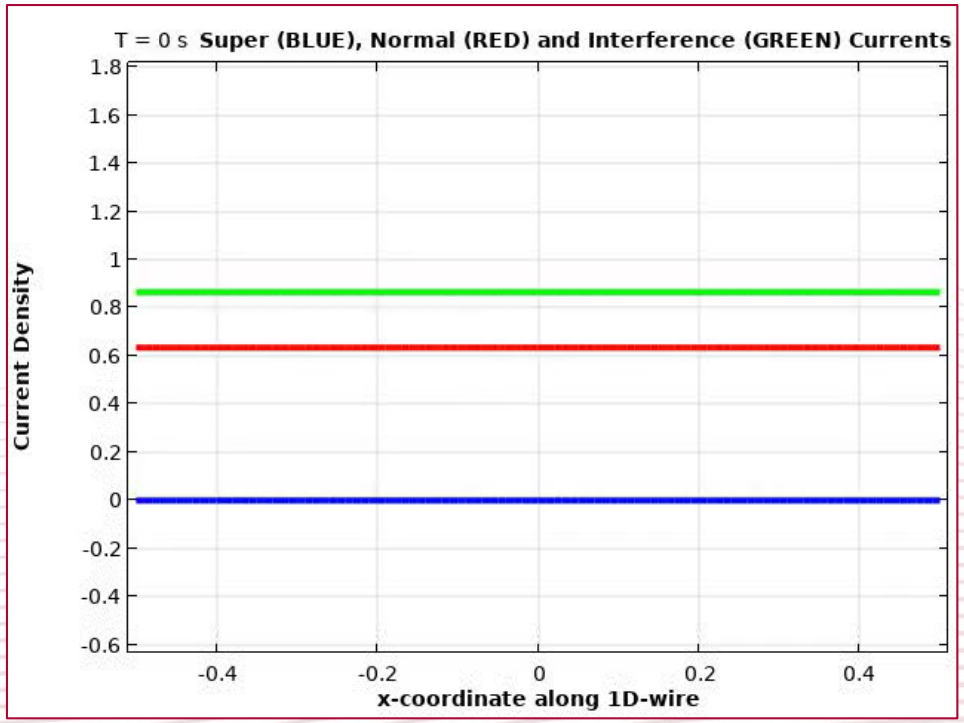
Coupled Electron-Phonon Dynamics of PSCs





- Non-Equilibrium Oscillatory Behavior
  - Current density **j** > critical current j_0
  - Normal current j_n, supercurrent j_s and interference current j_{int}

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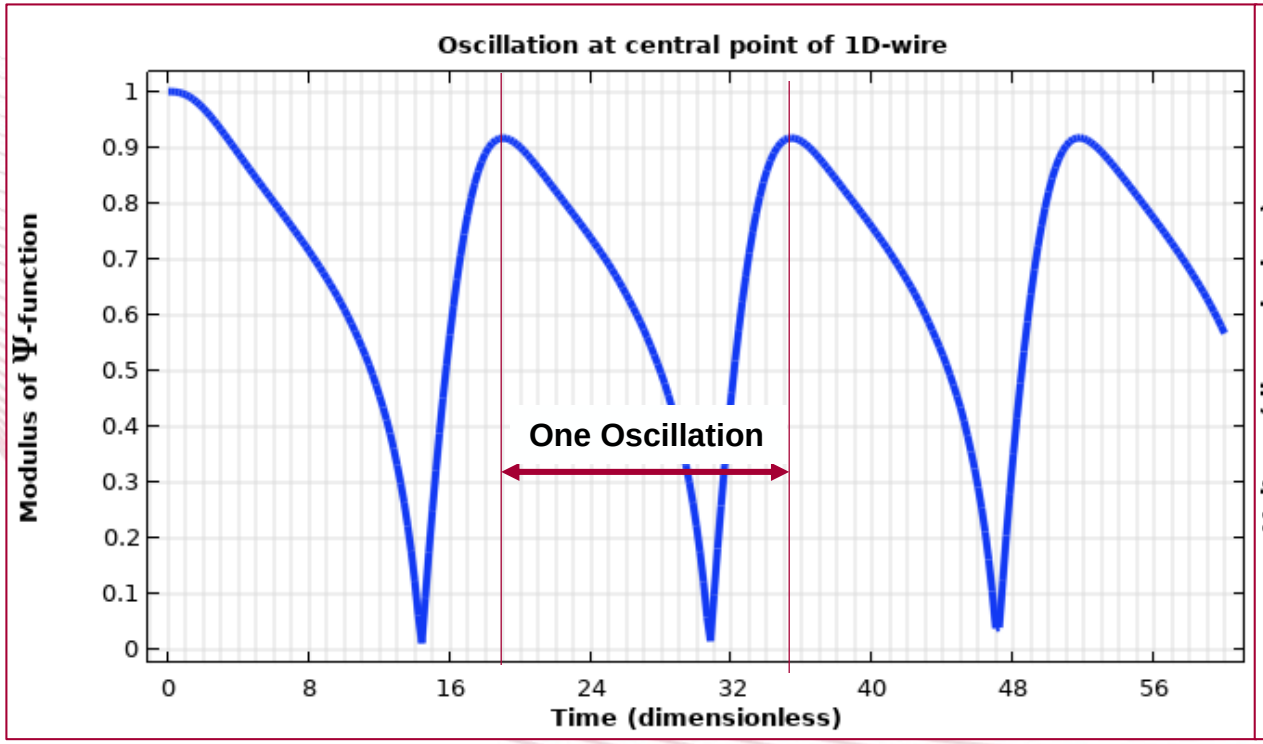
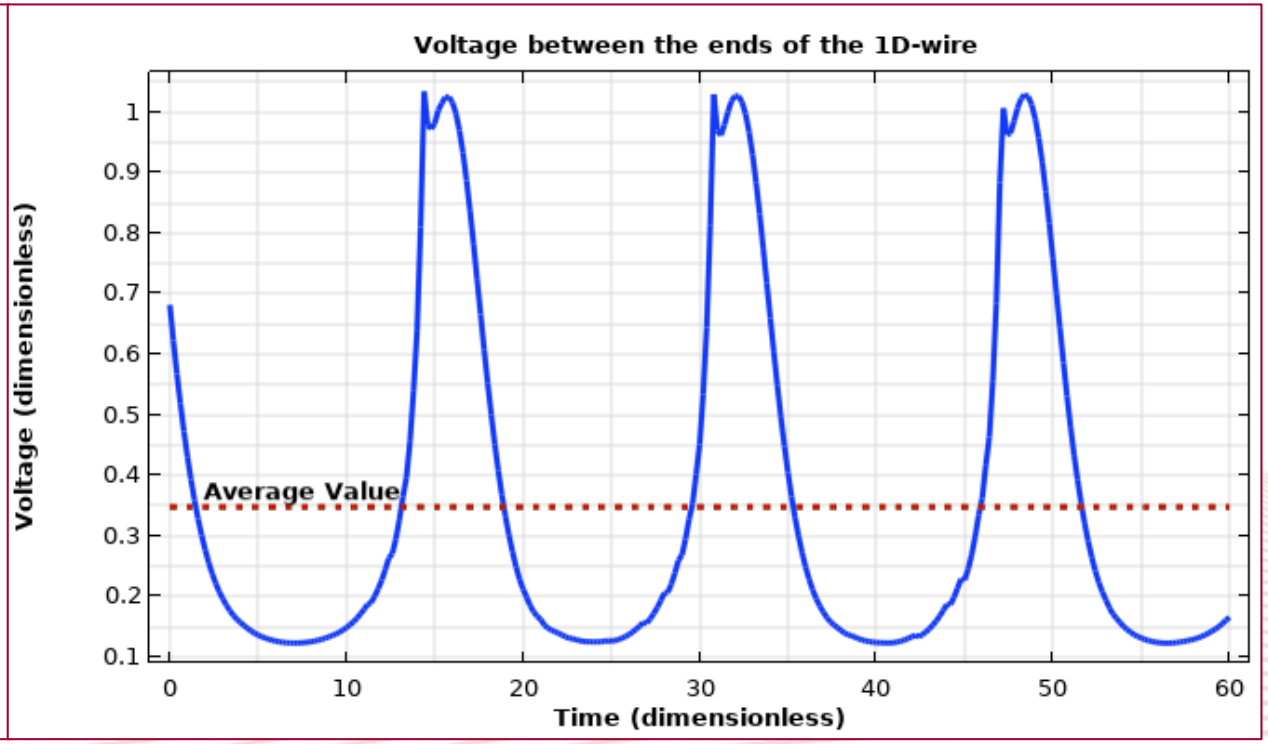
Coupled Electron-Phonon Dynamics of PSCs





- Time dependency of Voltage
  - Average voltage is non-zero

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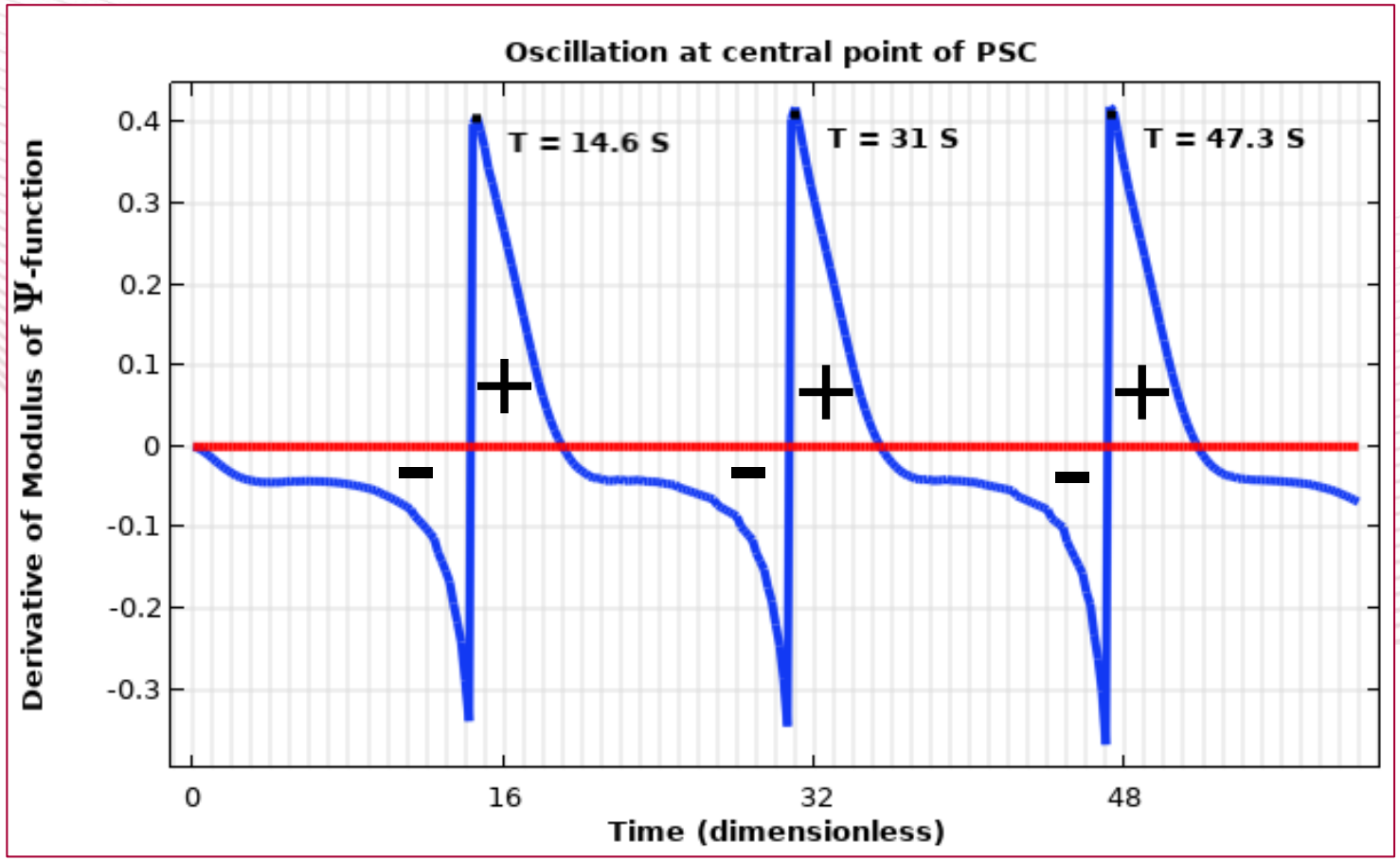
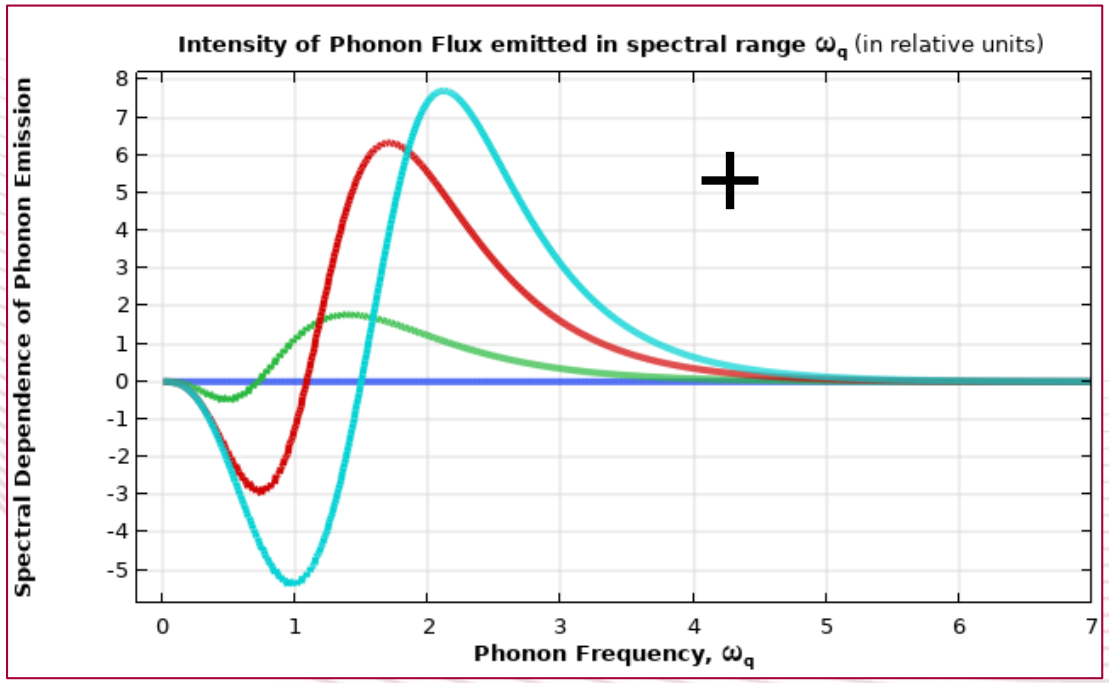
Coupled Electron-Phonon Dynamics of PSCs

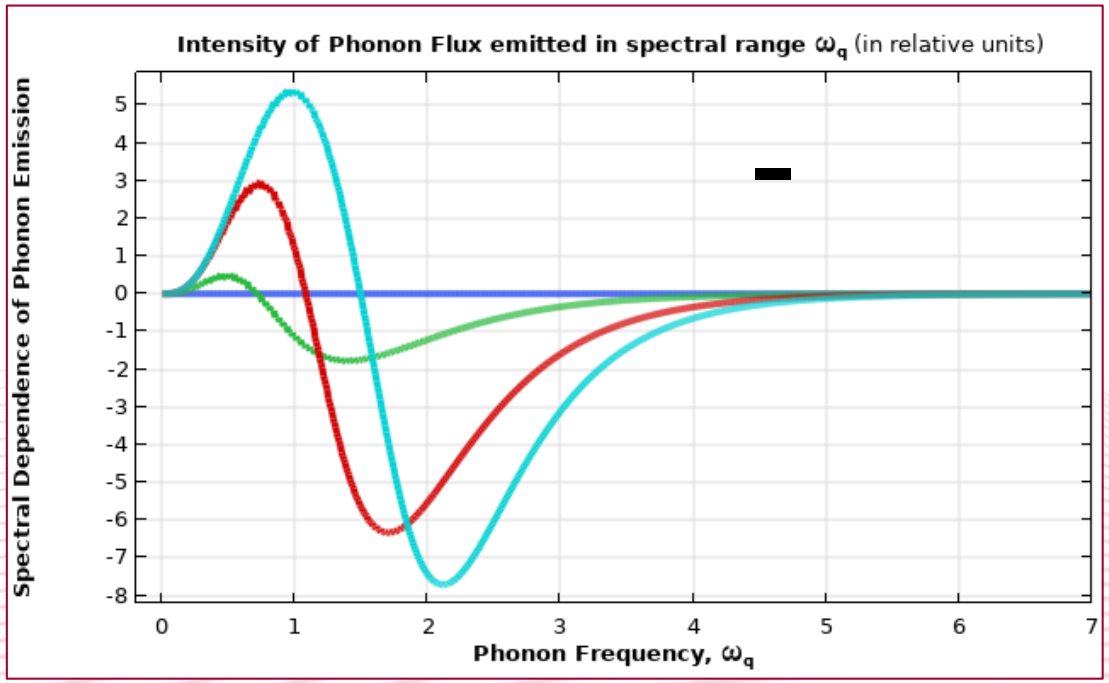
Evolution of $\frac{\partial|\Psi|}{\partial t} \propto dn \propto dN_{\omega_q}$



Sign of phonon emission fluxes is time dependent.

Cryocooling from Phase Slip Centers





- Phonon Fluxes
  - Periodically change of sign
  - Emission when $\delta(n_{\varepsilon}+n_{-\varepsilon})>0$
  - Absorption when $\delta(n_{\varepsilon}+n_{-\varepsilon})<0$
- Positive phonon flux > Negative phonon flux
  - External DC dissipates power due to PSC caused resistive state
  - Time-average resistance is non-zero

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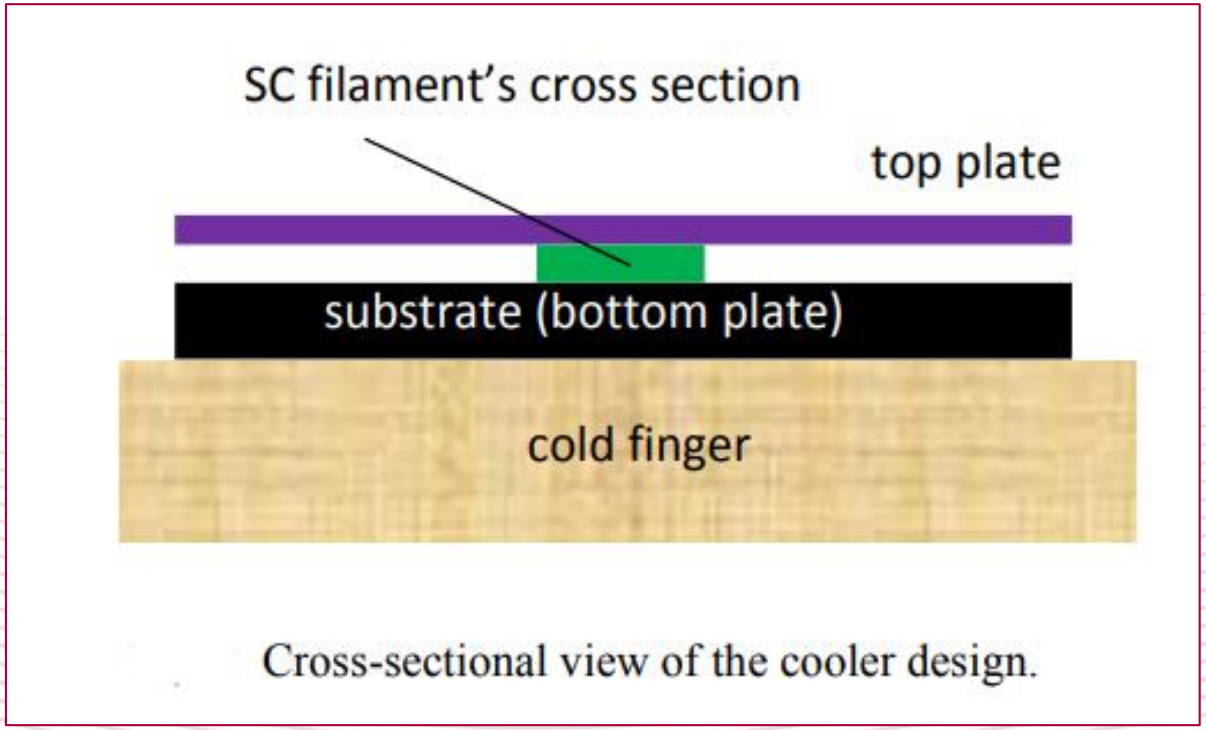
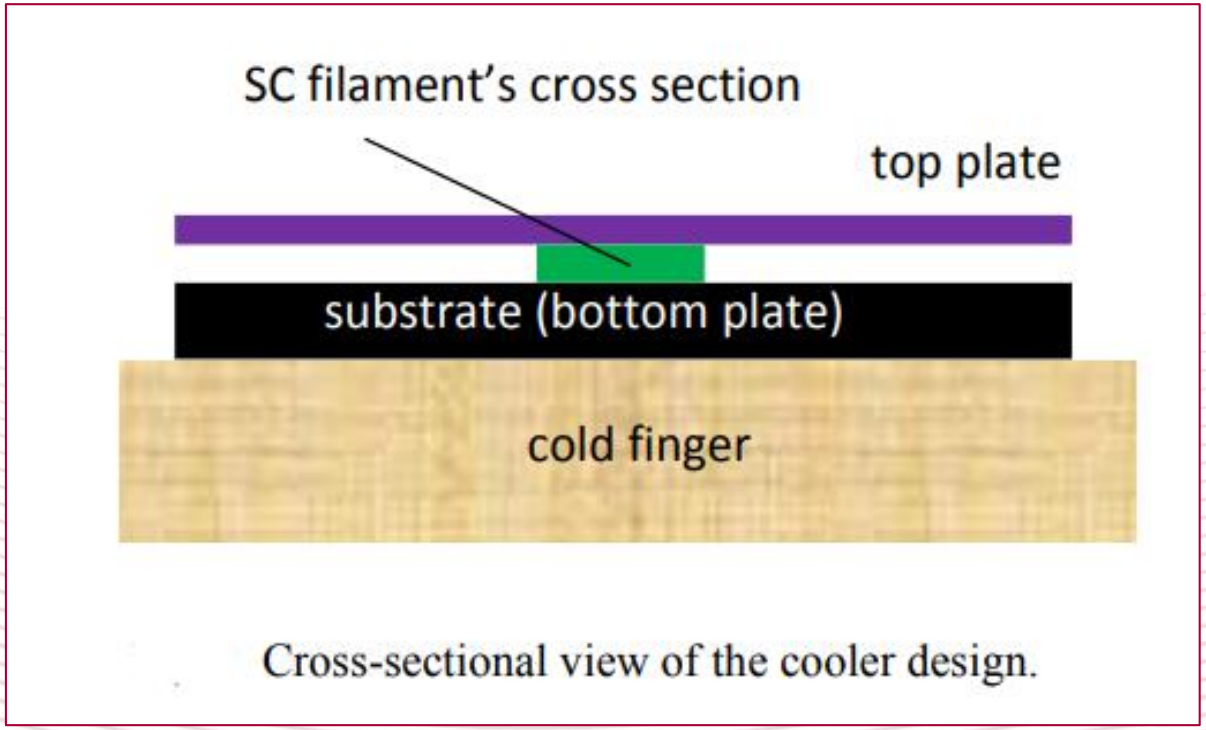
Cryocooling from Phase Slip Centers



Cross-sectional view of the cooler design.

- Cooler Design Concept
  - 1-D wire deposited onto substrate with higher acoustic density ρu
    - ρ: mechanical density and u: phonon propagation speed
  - Phonons emitted by substate without total internal reflection

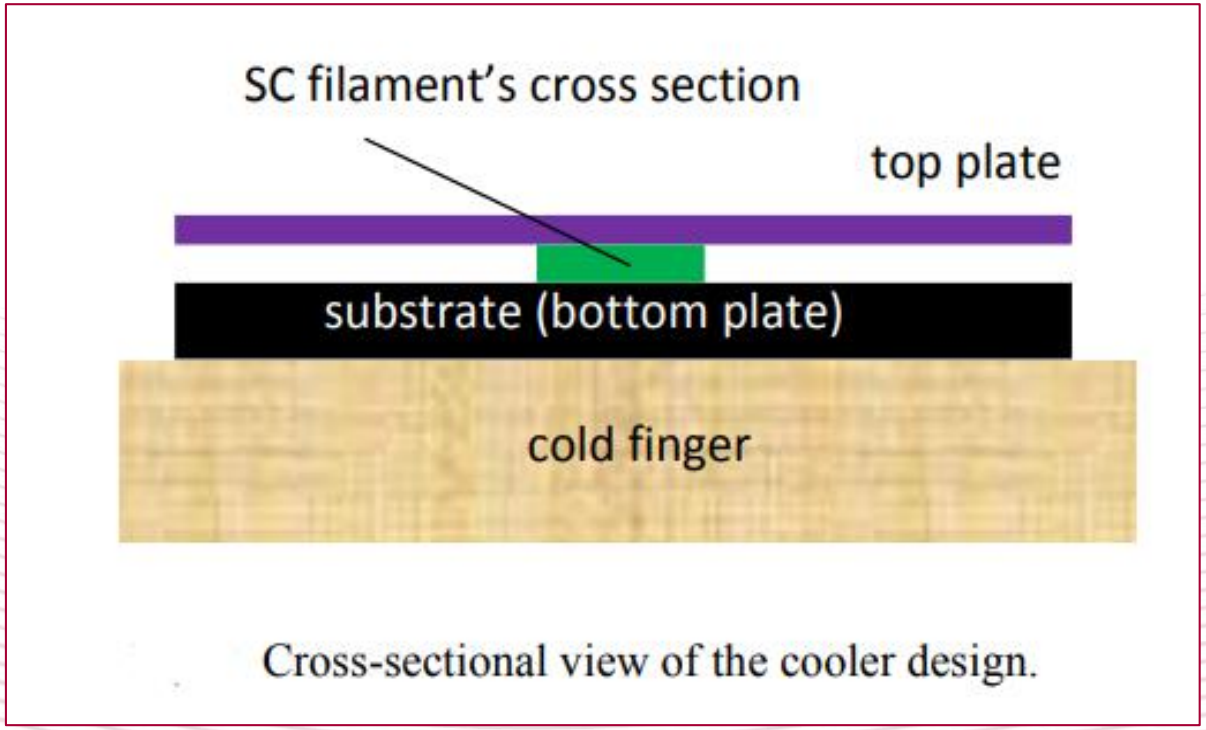
Cryocooling from Phase Slip Centers



Cross-sectional view of the cooler design.

- Cooler Design Concept
  - Top plate fused onto of 1-D wire with lower acoustic density ρu
  - Kapitza resistance occurs
    - Total internal reflection partially restricts wire's phonon emission

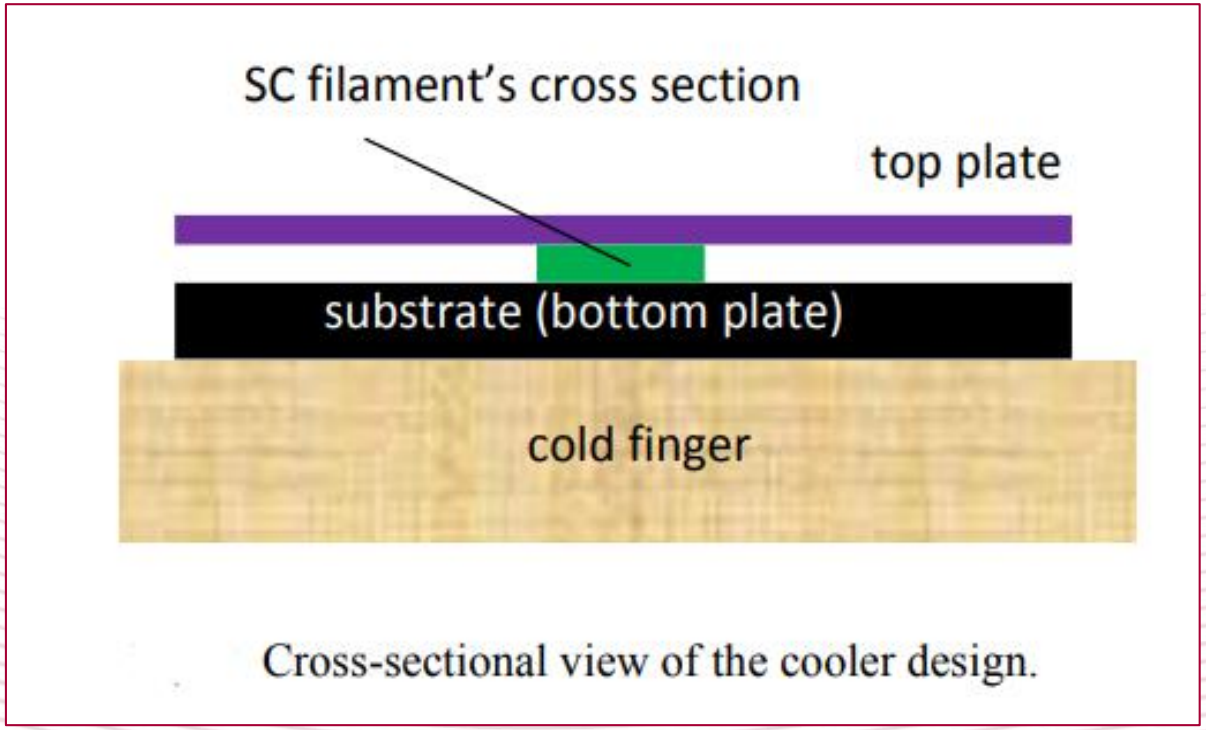
Cryocooling from Phase Slip Centers



Cross-sectional view of the cooler design.

- Cooler Design Concept
  - Wire in phonon-absorption state
  - Thermal phonons from acoustically less dense top plate will propagate into wire without restriction.
  - Thermal phonons from the acoustically denser substrate suffers total internal reflection.

Cryocooling from Phase Slip Centers



Cross-sectional view of the cooler design.

- Further work
  - Explore parameters of the system that allow greater outflow of phonons from top plate versus inflow.
  - Resulting cooling of top-plate and substrate remains at cold finger temperature.

Novel results obtained by modeling of dynamic processes in superconductors

Thank you. Questions?

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