Proximity Effect in Superconducting-Ferromagnetic (SF) Granular Structures

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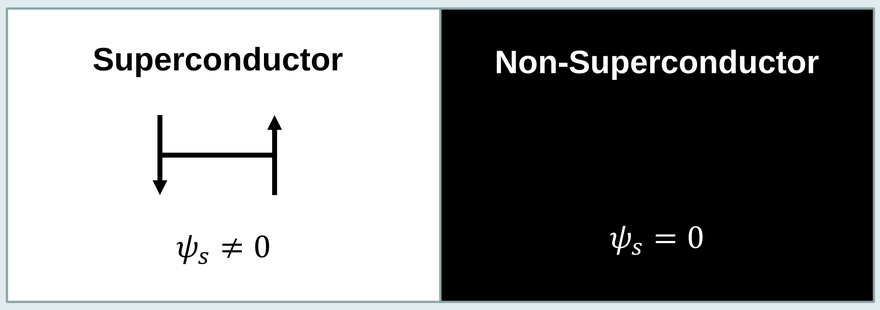
ABSTRACT

This past decade has seen increasing interest in systems which give rise to interactions between superconductors and ferromagnets, owing to experimental progress. In this study, we examined the proximity effect between Pb, a type II superconductor and Ni, a ferromagnet, in granular structures. We measured the critical temperature of the samples, along with the critical magnetic field, and compared our experimental data with relevant theories developed for multilayers. Non-monotonic behavior of the critical temperature as a function of the relative volume concentration of Ni per sample was demonstrated by our measurements.

PROXIMITY EFFECT IN SF SYSTEMS



- Material properties decay over a typical coherence length
- Coherence length in the *dirty limit* ($l < \xi_a$):
  - $\xi_a = \sqrt{\frac{\hbar D_a}{2\pi k_B T_{cs}}}$
- "Cooper Limit": Typical size of each material $d_a \ll \xi_a$
  - Simplifies terms for T_c

T_c OF SF MULTILAYER SYSTEM - THEORY

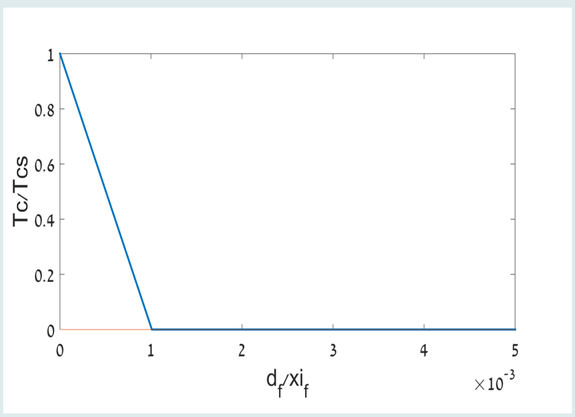


Fig. 1. **SF Bilayer:** Monotonic decay of T_c as a function of $\frac{d_f}{\xi_f}$. Calculated according to linearized Usadel equation, simplified for a thin S layer [1]. Note: For Ni/Pb system, superconductivity is suppressed for F layers ~ 0.01Å

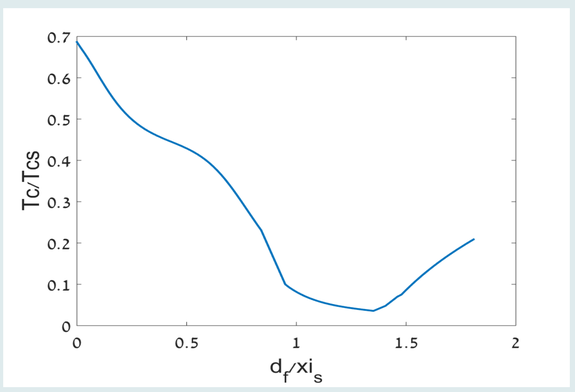


Fig. 2. **F/S/F Trilayer:** Example of re-entrant behavior of T_c as a function of $\frac{d_f}{\xi_s}$. Calculated according to linearized Usadel equation [2], including Cooper pair triplet component.

Future work: Calculation for F/S/F/S/F Pentalayer

T_c OF SF MULTILAYER SYSTEM - EXPERIMENT

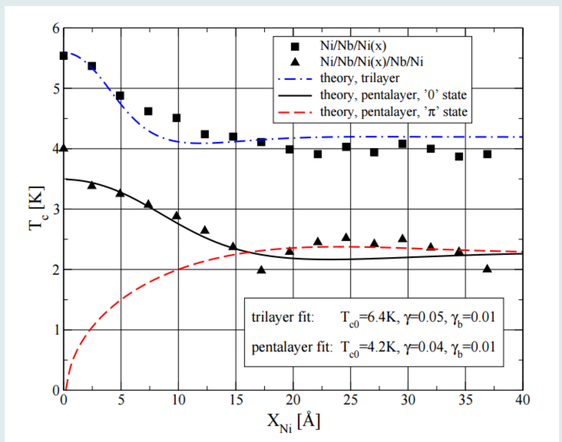


Fig. 3. (From [3]) Critical temperature as a function of Ni thickness for a trilayer Ni/Nb/Ni and pentalayer Ni/Nb/Ni/Nb/Ni; exhibits re-entrant superconductivity; data fit to linearized Usadel equation, with spin triplet component.

SAMPLE FABRICATION

- 500Å thick granular samples w/ varying Ni/Pb ratios, achieved by "co-sputtering" technique.
- Standard "lift-off" photolithography with typical Hall Bar mask.

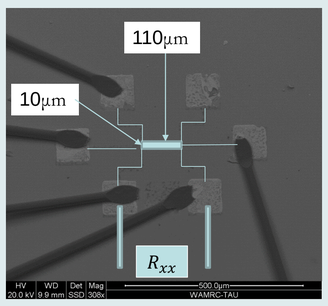


Fig. 4: ESEM micrograph of a typical sample

T_c OF SF GRANULAR SYSTEM - EXPERIMENT

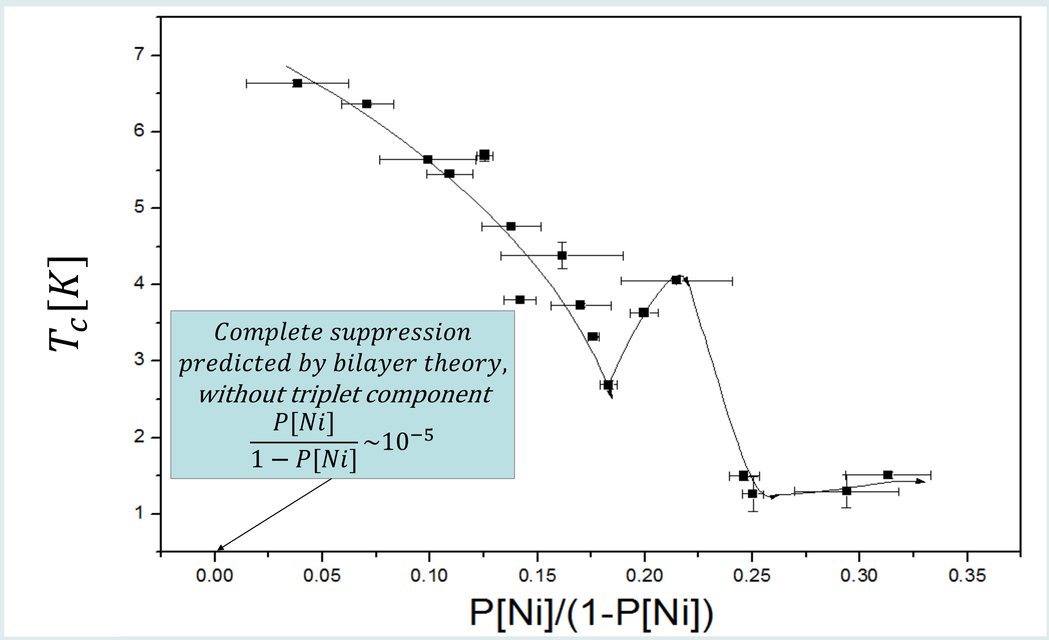


Fig. 5: Critical temperature as a function of relative volume concentration of Ni in granular SF structures; exhibits non-monotonic behavior.

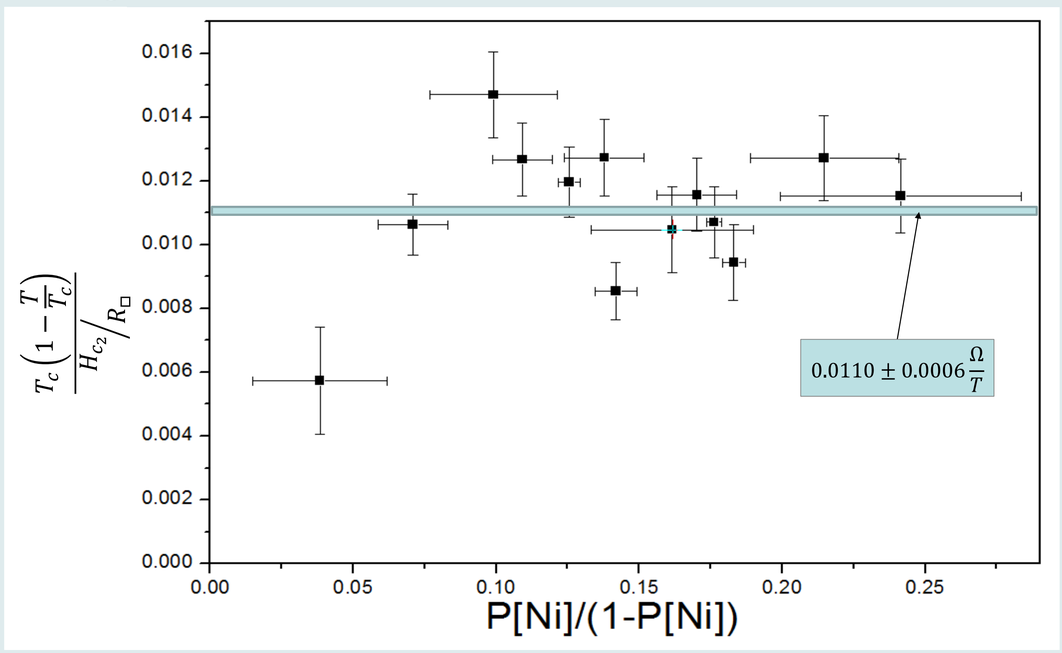


Fig. 6: Comparison of data to Ginzburg-Landau theory. Function should be constant in the Cooper limit.

SUMMARY

- ✓ We observed non-monotonic behavior of T_c dependent on SF grain concentration ratio.
- ✓ This behavior cannot be explained by theory developed for bilayer structures without invoking triplet component.
- ✓ Data complies with Ginzburg-Landau theory at Cooper limit.

REFERENCES:

[1] Y. V. Fominov et al. Phys. Rev. B **66**, 014507 (2002).

[2] T. Lofwander et al. Phys. Rev. B **75**, 014512 (2007).

[3] V. Shelukhin et al. Phys. Rev. B **73**, 174506 (2006).

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