Cooling of electrons via superconducting tunnel junctions and their arrays exhibiting nodal lines

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Abstract :

Cooling of electrons is an essential procedure for the modern electronics for the micro- and nanoelectronics used for quantum and mesoscopic science. The mK temperatures can be reached in commercial dilution refrigerators, however the lower temperatures are still hard to achieve. It is especially hard to reach lower electron temperatures, since dilution refrigerators cool phonons rather than electrons.
In this work, we consider a small electric current running from the bath of electrons through the setup (see Fig. 1 (a) from the blue part to the black part), where electrons have to have higher entropy, and thus remove heat from the bath, emitting it behind the setup (red part).
For the setup, we suggest to use a superconducting tunnel junction with a π phase difference and a usual insulator or a ferroelectric in-between, and an array of such junctions with ferroelectric layers in-between (Fig.1 (b)-(c)). As these setups have nodal lines, they have a complex structure of entropy, where the density of states can be divergent or larger than for a free electron gas at a chemical potential level (see Fig. 2). We consider different types of setup, in order to suggest more working regimes, some of which are shown in Fig. 2.

References

[1] Linus Aliani and Viktoriia Kornich, arXiv:2511.08342 (2025)

Figures

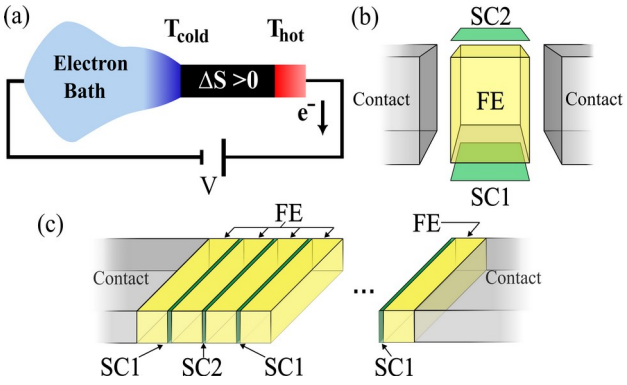

Figure 1: (a) The cooling scheme. The current flows from the electron bath (blue region) through the setup with a large entropy (black region) into the electric circuit. Electrons absorb heat from the bath because they need to increase their entropy. They emit this heat after the region with high entropy (red region). (b) Setup consisting of a tunnel junction with a ferroelectric layer in-between. (c) Setup consisting of an array of tunnel junctions with ferroelectric layers in-between.

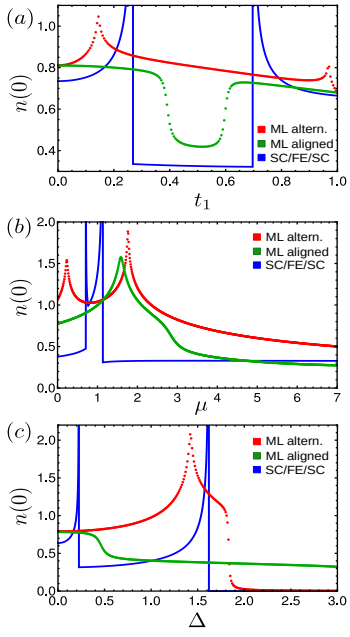

Figure 2: Density of states of a tunnel junction superconductor-ferroelectric-superconductor (blue lines) with the phase difference π, and of a multilayer structure of superconducting layers with alternating phases 0 and π and ferroelectric layers with aligned polarization (green dots), and with alternating polarization (red dots).