Towards sub-mK Electron Temperatures Using Pomeranchuk Cooling in Twisted Bilayer Graphene

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Lowering the electron temperature in nano-electronic devices to sub-millikelvin levels promises to unveil novel physical phenomena in electron transport and enhance quantum device performance. On-chip cooling has posed a persistent challenge, however, with on-chip adiabatic magnetization currently being the sole viable method to reach temperatures below 1 mK [1].

Recently, electronic phases exhibiting high entropy at low temperatures have been discovered in magic-angle twisted bilayer graphene (ma-tBLG) [2,3], reminiscent of the Pomeranchuk effect in ^{3}He [4] due to competition with low-entropy phases. Here, we establish a framework to map out the phase diagram of these competing phases as a function of carrier density and temperature, aligning qualitatively with experimental observations.

Additionally, we explore the feasibility of implementing a heat cycle in ma-tBLG by leveraging its gate-tunability. By passing a current through a locally gated device, we aim to locally increase the entropy. The transition from low to high entropy extracts heat from the environment, and lowers the temperature. This heat is released when the charge carriers transition back to a low entropy phase. Our simulations demonstrate that a significant temperature gradient can be obtained (Fig. 1).

The Lorenz number, governing the heat-to-charge flow ratio, emerges as a critical parameter; a decrease in this number, typical in strongly correlated electron gases, markedly reduces the attainable lowest temperature [Fig. 1(a)]. Finally, we propose scaling up the cooling device with multiple cooling stages. Our simulations suggest that this approach, combined with a reduction of the Lorenz number, demonstrates the feasibility of achieving sub-mK electron temperatures.

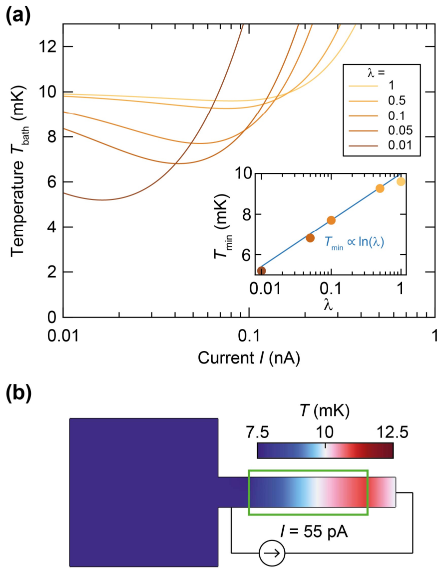

Fig.1. (a) Temperature as a function of current for a Pomeranchuk cooling device. The Lorenz number is scaled from the non-interacting case by the factor λ. (b) Simulated temperature over the device geometry with $\lambda = 0.1$. The large blue square is an isolated bath, the rectangular part on the right is the cooling device. A current is run through the rectangular part, and the section of device within the green rectangle is locally gated into a high-entropy phase.

References

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