Superconducting multi-stage thermionic cooler for quantum technology

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Refrigeration is an important pillar of quantum technology: due to the low energy of most fundamental quantum excitations, several practical implementations outright require temperature scales well below 1 K. For quantum electronics, this is typically achieved with expensive dilution refrigerators, where a massive inner sample space is cooled down to few hundredths of degrees above absolute zero over the course of tens of hours. Phonon-engineered thermionic coolers give a promise of a solid state technology that enables cooling from pulse tube compatible temperatures 2.5 – 3 K to sub-100 mK, removing the need of dilution cooling. This reduces infrastructure and cost requirements of operating quantum devices and would be a game-changer, for example, in spaceborne applications.

The full cooling range between 3 K and sub-100 mK is realized by cascading multiple cooler stages together with 3D integration techniques. Each stage consists of highly transparent and low leakage semiconductor-superconductor (Sm-S) tunnel-junctions, which also provide phonon isolation and mechanical support. Optima-l operation point in temperature depends on the superconducting energy gap, i.e., critical temperature of the superconductor. To cover the full temperature range, a set of materials is required, e.g. Nb, V, Al, Ti for 3 K to sub-100 mK. We have demonstrated high quality silicon-vanadium tunnel-junctions, cooled a suspended silicon chip down to 40% below the bath temperature, and demonstrated high thermal isolation between 3D-integrated chips enabling the cooling operation.