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CRYOGENIC COOLING BY LIGHT EMISSION FROM SEMICONDUCTORS

Abstract

There is a critical need for novel small-footprint and lightweight cryogenic containment solutions that will enable long-term storage and transportation of, for instance, lunar material samples back to Earth. We explore the possibility of a simple active cooling system combining existing thermal-container technology with a semiconductor light-emitting diode (LED) for refrigeration.

The wall-plug efficiency (WPE) of LEDs, i.e., the electrical-to-optical power conversion ratio, has increased steadily towards the level where almost all the electrical energy supplied to the semiconductor material is turned into extractable photons. Recently, initial evidence that the extracted optical power from an LED can be, counterintuitively, greater than the electrical input power has also been reported. This above-unity WPE is possible because LEDs are thermodynamic machines that can draw energy (heat) from the semiconductor crystal lattice. The result is a refrigeration effect referred to as electroluminescent cooling, which originates from enhancing the spontaneous emission far beyond its thermal value. When the amount of thermal energy extracted through the enhanced spontaneous emission exceeds the parasitic heating caused by the non-radiative relaxation processes and other heat-generating non-idealities, cooling by light emission becomes feasible.

In this work, we present a concept for a cryogenic cooling solution based on a vacuum flask incorporating high-efficiency light-emitting cooling devices with an above-unity WPE. The temperature difference between the inside and the outside of the flask is maintained solely because of the refrigeration effect from the externally-powered LED. With device parameters within the reach of present technologies, our LEDs have a cooling efficiency of around 3 % when the inside and outside of the flask are kept at -150 °C and room temperature, respectively. With further optimisation, we hypothesise that this cooling process can reach a performance level that is inaccessible for current technologies, such as thermoelectric coolers (TECs).