The Electron Energy Spectrum and Thermionic Device Efficiency

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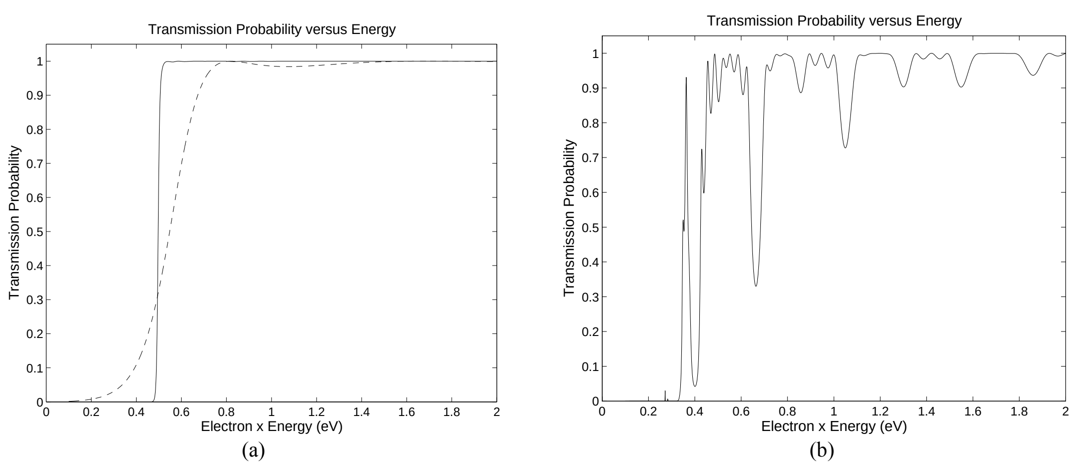
Abstract

Multilayer semiconductor-based thermionic devices, originally proposed by Mahan *et al.* [1], have received much attention over the past decade due to their potential for high-efficiency refrigeration and power generation. Recently, it has been suggested that in order to achieve maximum efficiency thermionic devices should allow transmission of electrons between the hot and cold reservoirs at a single energy only [2-3]. An electron energy spectrum that rises sharply is also desirable [3].

Here we analyse how the electronic efficiency of solid-state thermionic devices depends on the energy spectrum of electrons transmitted between the hot and cold reservoirs. Using the ballistic transport formalism we show that high efficiency may be achieved by designing a device so that the electron energy spectrum rises sharply. Calculations are performed on both single and multibarrier GaAs/AlGaAs and InGaAs/InAlAs systems with angular and rounded barriers respectively. Analysis reveals a wide barrier is desirable for single-barrier thermionic devices due to the associated sharpness in the electron energy spectrum. It is also shown that high electronic efficiency may be achieved in multibarrier thermionic devices consisting of thin barriers, which would give low efficiency when used on their own, though careful arrangement that produces a desirable electron energy spectrum.



(a) The transmission probabilities associated with 10-nm (dashed line) and 100-nm (solid line) InGaAs/InAlAs single barrier thermionic devices. The wider barrier has a sharper electron energy spectrum and relative efficiency/COP of 0.87/0.85 and the narrower barrier 0.33/0.28. (b) The transmission probability of a four-barrier GaAs/AlGaAs device with 10-nm barriers separated by 10 nm. The sharp peak produced through careful barrier positioning is desirable for high electronic efficiency giving a relative efficiency/COP of 0.75/0.75.

[1] G. D. Mahan, J. O. Sofo, and M. Bartkowiak, "Multilayer thermionic refrigerator and generator," *J. Appl. Phys.*, vol. 83, pp. 4683-4689, 1998.
[2] T. E. Humphrey, R. Newbury, R. P. Taylor, and H. Linke, "Reversible quantum Brownian heat engines for electrons," *Phys. Rev. Lett.*, vol. 89, pp. 116801-1-4, 2002.
[3] M. F. O'Dwyer, T. E. Humphrey, R. A. Lewis, C. Zhang, in preparation.