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Performance optimization of a total momentum filtered energy selective electron (ESE) heat engine with double resonances

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ABSTRACT

A model of an energy selective electron (ESE) heat engine with double resonances which filter electrons according to their total momentum is established in this paper. The optimal performance of the double resonance ESE heat engine is analyzed by using the theory of finite time thermodynamics (FTT). The performance of the double resonance ESE heat engine is compared with that of the single resonance device. It is shown that the double resonance device can generate more power but at the same time becomes less efficient. Performance comparisons are also performed between the total momentum filtered ESE heat engine in which the electrons are transmitted according to the total electron momentum in all the three dimensions and the conventional ESE heat engine where the electrons are filtered according to the momentum in the direction of transport only. It is found that the total momentum filtered ESE heat engine outperforms the conventionally filtered ESE heat engine on both power output and efficiency performance. Moreover, the effects of resonance width, energy spacing of two resonances and cold reservoir temperature on the performance of the total momentum filtered double resonance heat engine are analyzed in detail by numerical calculations. In practical operation of the double resonance ESE heat engine, the values of resonance width, energy spacing and cold reservoir temperature should be small in order for the device to obtain higher efficiency.

1. Introduction

In recent years, the study of microscopic energy conversion systems, such as Brownian motors [1–6], and quantum ratchets [7–10] has attracted considerable interests due to their importance in developing miniaturized devices which help to utilize energy resources at the microscopic scale. The electron engine is also a typical microscopic energy conversion system. The model of an energy selective electron (ESE) heat engine in one dimensional (1D) system was first proposed by Humphrey et al. [11] as a reversible quantum Brownian heat engine for electrons. Later, Humphrey [12] extensively explored the theoretical model of ESE heat engine and analyzed its power and efficiency performance. The ESE heat engine utilizes a temperature difference between two electron reservoirs to transport high energy electrons against an electrochemical potential gradient. In particular, in the electron system, an energy filter is applied in the direction of electron transport between the two electron reservoirs to freely transmit electrons in a specified energy range and block the transport of all others. Such an energy filter can be realized by the resonance in a quantum dot [11,13] or a superlattice [14,15]. Humphrey [12] showed that the ESE engine system can also work as a refrigerator if the energy level of the transmitted electrons are located in certain ranges; the ESE engine can operate reversibly and attain the Carnot efficiency (or coefficient of performance (COP)) if the energy level is suited to a specific value where the Fermi distributions in the hot and cold electron reservoirs are equal.

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