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Optical manipulation of parallel thermoelectric effect in a nanoscale three-terminal junction

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We propose a hybrid thermoelectric system based on extending two-terminal thermoelectric structure to three-terminal one where a quantum dot is coupled to a normal-metal lead and two ferromagnetic electrodes with noncollinear magnetic moments, the thermoelectric properties of this parallel thermoelectric system which is subject to a continuous polarized light are theoretically investigated. Within the nonequilibrium Green's function theory, analytical expressions for thermoelectric coefficients are derived at length, which provides a powerful tool for further numerical calculations of thermoelectric properties. Some interesting thermoelectric features are reported and elucidated. We find that the polarized light can induce the Fano-like resonance in the spectrum of the electrical conductance and the thermal conductance, the thermopower and the charge figure of merit may be enhanced near the Fano-like resonance. Our results show that the polarized light and the increase of magnetic polarization are favor of achieving the better thermoelectric performance which indicates the strong violation of the Wiedemann–Franz law, especially, a significant enhancement of the spin thermal efficiency (spin figure of merit) can be obtained. We also analyze the dependence of thermoelectric features on the noncollinearity, it is found that the configuration of two ferromagnetic leads and the polarized light can jointly determine the thermoelectric features of this system, and the parallel configuration is best for obtaining the enhancement of spin figure of merit. Moreover, the polarized light can be favor of obtaining the lager spin thermoelectric efficiency at relatively high temperature. Therefore, the parallel thermoelectric structure may be used as a

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high-efficiency spin thermoelectric conversion device under certain circumstances.

1. Introduction

In recent years, there has been an increasing interest in thermoelectric properties of solid-state materials, especially in the case of nanostructures, which stems from the development of the 'green' energy sources to sustain the future prosperity of mankind [1–6]. As a matter of fact, the most established Seebeck effect in which an electromotive force is induced by a temperature gradient has been known for two centuries [7]. The energy conversion efficiency of a thermoelectric system is determined by the dimensionless figure of merit $ZT = G_e S^2 T/(\kappa_e + \kappa_{ph})$, where G_e is the electrical conductivity, S is the Seebeck coefficient (also known as thermopower), $\kappa_e(\kappa_{ph})$ is the electron (phonon) thermal conductivity, and T is the average operating temperature. But the highest value of ZT for conventional bulk materials is smaller than one, and it is difficult to enhance the ZT due to the constraint of the Wiedemann–Franz law. Besides, the thermopower is decreased as the charge conductance increases according to the Mott's relation. These largely affect the industrial applications of thermoelectric materials. The original theoretical works pointed out an enhancement of thermoelectric efficiency in materials of the reduced dimensionality, which suggests that the low-dimensional nanostructures are promising candidates for good thermoelectric systems owing to quantum confinement [8], this sparks intensive research activity in the field of thermoelectrics in quantum dots (QDs), nanowires, molecular junctions, granphene interface junctions, and other nanocomcomposite materials [9–15].

As far as we know, the thermoelectric properties of nanostructured materials are strongly influenced by quantum confinement, Coulomb interactions, and Kondo effects. These effects can cause the strong violation of the Wiedemann–Franz law, and the thermal conductance of nanoscale systems is very small, which is an advantage over the enhancement of the thermoelectric efficiency [16–21]. QDs with discrete energy spectra and tunable parameters in experiments have a Seebeck coefficient that is independent of the feature of materials, and an intrinsic, nanoscale standard for the Seebeck coefficient with use of a QD was created by Mani et al., which implies that QD systems are perfect candidates for better thermoelectric devices [22]. The thermopower in PbSe nanocrystal QD superlattices was experimentally examined, whose results exhibited a substantial thermopower enhancement of several hundred microvolts per Kelvin relative to bulk PbSe [23]. The thermoelectric study in strongly correlated QD nanostructures shows that the high thermoelectric efficiency can be obtained in the Kondo regime, this suggests that the violation of the Wiedemann–Franz (WF) law is the main mechanism for an enhancement of thermoelectric efficiency in nanoscale junctions [24]. Thermoelectric effects in an Aharonov–Bohm (AB) interferometer consisting of two laterally gated QDs have theoretically been studied, the Coulomb blockade effect and the quantum interference inducing the enhancement of ZT were uncovered [25,26]. Dubi discussed the spin analogs to the thermopower and the figure of merit in a QD connected to ferromagnetic electrodes, it was indicated that the thermospin figure of merit is relatively large [27]. Recently, the enhancement of thermoelectric efficiency in triple QDs due to the Dicke effect has been found [28]. A more comprehensive investigation of thermoelectric transport properties in QD systems has been shown that QDs are very attractive for potential applications in energy-conversion devices.

However, it is noticeable that early theoretical and experimental studies of thermoelectric effects were mainly focused on charge and heat currents in two-terminal thermoelectric nanodevices. Recently, thermoelectric transports in the multiterminal case have gained some achievements. In particular, some interesting results have been obtained in the three-terminal thermoelectric transport [29,30], a three-terminal thermoelectric device may be viewed as a very typical parallel thermoelectric system [31] where a thermal reservoir is kept at the high temperature and other two ones are held in general at their respective low temperatures. Thermopower in a three-terminal QD ring structure