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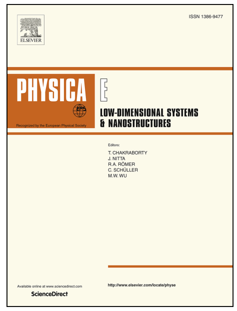

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Thermoelectric and thermal transport properties of graphene under strong magnetic field

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Abstract

We investigate theoretically the thermoelectric and thermal transport properties of graphene under strong magnetic field in the presence of short-range scatterers. The numerical results are in good agreement with available experimental data for all thermoelectric quantities except for the Seebeck coefficient near zero chemical potential. This anomaly is attributed to the overestimation of the longitudinal resistivity. Furthermore, we find an anomalous oscillation in the transverse thermal conductivity at the lowest Landau level and double peaks in the longitudinal thermal conductivity at higher Landau levels, which are expected to be observed in future experiments on high mobility graphene samples. An important finding of our work is that the thermoelectric figure of merit ZT can be as high as 2.4 for a magnetic field under which the chemical potential is pinned to the $|n| = 1$ Landau level. This finding can greatly advance the thermoelectric application of graphene.

Keywords: graphene, thermoelectric transport, thermal transport
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1. Introduction

Since the experimental discovery of graphene in 2004 [1], researching its novel properties has reveled many potential applications in electronics and photonics, but in a less extent in its thermoelectrics properties. The electrical and thermal transport properties of graphene can be influenced strongly by the external conditions, such as the bias, sample geometry, and the impurity scatterings[2–5]. Especially, the electrical transport under magnetic field shows a large amount of novel features, such as the half integer quantum Hall effect[2, 6], metal to insulator transition on the zeroth Landau level [7] correlated with additional quantum Hall states due to the split of valley and spin degeneracies above $10T$ magnetic field[8–14].

Thermoelectric transport properties have been revealed to be powerful tools in the study of intrinsic transport mechanisms in metals and semiconductors, providing complement to the inadequacy of conductivity measurements. Recently, a number of experiments have been carried out to investigate the thermoelectric properties of graphene. The expected change of sign of the thermopower is confirmed experimentally when the majority carriers change from electrons to holes in the absence of magnetic field[15–21]. When the magnetic field is lower than 10T and still strong enough to quantize the system, the Seebeck coefficient is found to has a sign anomaly in the lowest Landau level (LL)[15, 17–19]. Several theories have been put forward to explain these thermoelectric transport properties of graphene[22–28]. However, many observed thermoelectric properties remained to be explained. Recent experimental and theoretical work have shown several different strategies to improve the figure of merit ZT [29–44]. For graphene under a perpendicular magnetic field, the confinement of electron motion in cyclotron orbital effectively reduce the dimensionality of the electronic states and an enhanced figure of merit is expected.

In this Letter, we present a numerical study of the thermoelectric and thermal transport properties of graphene with short-range scattering impurities under strong magnetic field. Our result of the chemical potential dependence of many thermoelectric properties is in very good agreement with experimental observations. The single adjust parameter is the product of impurity potential strength and concentration. The only remaining anomaly is the Seebeck coefficient near zero chemical potential. Moreover, our study of the longitudinal and transverse thermal conductivities which are not measured in previous experiments may motivate further experimental investigations on the physical origin of the anomaly at the lowest LL. The large values of the thermoelectric figure of merit ZT at $|n| = 1$ Landau level suggest the potential application of graphene in thermoelectric devices.

2. Formalism

Based on the nearest-neighbor tight-binding model with the $\mathbf{k} \cdot \mathbf{p}$ method or with the effective-mass approximation[45–47], a graphene system with short-range impurity are described by

$$H = v_F(\tau_0 \otimes \sigma_x \pi_x + \tau_z \otimes \sigma_y \pi_y) + U(\mathbf{r}), \qquad (1)$$

on the basis $\Psi = \left(\psi_{AK}, \quad \psi_{BK}, \quad \psi_{AK'}, \quad -\psi_{BK'}\right)^T$, where T stands for transpose, $\boldsymbol{\pi} = \mathbf{p} + e\mathbf{A}$ is the mechanical momen-

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