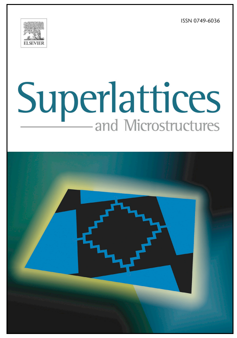
Accepted Manuscript



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PII: S0749-6036(15)30171-3

DOI: 10.1016/j.spmi.2015.08.029

Reference: YSPMI 3959

To appear in: *Superlattices and Microstructures*

Received Date: 24 July 2015

Accepted Date: 24 August 2015

Thermoelectric Effects in Electron Chiral Tunneling in Metallic Carbon Nanotubes

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(Dated: July 17, 2015)

Thermoelectric effects in a metallic single-wall carbon nanotube in the presence of long-range electrostatic and pseudomagnetic potentials (produced by strain) are considered. It is shown that for strong scattering potentials (chiral tunneling) a pronounced energy "gap" appears in the energy dependence of electron transmission coefficient. This results in strong violation of Wiedemann-Franz law and in a peak-like behavior of thermopower as a function of chemical potential. The electronic figure-of-merit (ZT) is calculated and shown to be sensitive at low temperatures to nanotube chirality. By tuning chemical potential, ZT can reach high values ($ZT \simeq 5$) that makes specially engineered nanotube-based thermocouple to be a promising nano-device with a high thermoelectric performance.

PACS numbers: 74.25.fg, 73.23.Ad
Keywords: single-walled carbon nanotube, chiral tunneling, thermopower, figure-of-merit

I. INTRODUCTION

One of the most challenging problems in physics of thermoelectric phenomena is the search for new materials with a high figure-of-merit, $ZT > 1$ (see e.g. Ref.[1]). It was theoretically predicted[2] that low-dimensional nanostructures (and, in particular, semiconducting quantum wires[3]) are promising systems to be engineered as solid state material with enhanced thermoelectric performance.

Metallic single-wall carbon nanotubes (SWNTs) are known to be excellent 1D conductors and they could be good candidates for high-ZT materials. However, ballistic transport of charge carriers at low temperatures in impurity-free metallic SWNT (see, e.g. Ref.[4]) and Luttinger liquid properties of electron scattering on impurities (strong enhancement of electron backscattering at low temperatures[5]) makes them poor thermoelectrics. Indeed, in an impurity-free metallic SWNT thermopower (S) is determined by the effects of electronic band curvature and the Seebeck effect is weak due to electron-hole symmetry. In the presence of local defects (impurities) Luttinger liquid effects strongly suppress electric conductivity at low temperatures while thermal transport supported by electrically neutral plasmons and spinons is weakly influenced by charged impurities[6,7]. According to the definition of figure-of-merit $ZT = GS^2/(K_e + K_l)$ (where G is the electric conductance, $K_{e,l}$ is the electron (lattice) thermal conductance), weak conductivity and small thermopower make a system to be a poor thermoelectrics. At first glance, fundamental thermoelectric properties of individual metallic SWNT are not in favour of its high thermoelectric performance.

In this paper we suggest a new theoretical approach which overcomes above mentioned problems. To make metallic SWNT a high-ZT material it is reasonable to consider only forward scattering processes, which are not renormalized by interaction, and to use Dirac nature of charged quasiparticles in carbon nanotubes to get enhanced thermoelectric performance induced by intra-valley electron scattering by long-range defects.

Intra-valley Dirac electron scattering induced by pseudomagnetic potentials was predicted to occur in elastically deformed nanotubes[9]. The interplay of strain-induced pseudomagnetic field and electrostatic deformation potential results in specific phenomena called chiral tunneling[11,12]. It is characterized by oscillatory dependence of electron transmission probability on the strength of scattering potentials, nanotube chiral angle, and electron energy. Minima and maxima of transmission coefficient are explained by the effects of resonant chiral tunneling.

We have shown that a specific feature of pronounced chiral tunneling through a finite-range potential is the appearance of "energy gap" (extended dip in the energy dependence) in the transmission coefficient. This "semiconducting-like" property allows one to strongly enhance thermopower and electronic figure-of-merit by tuning the chemical potential to the dip boundaries. In general, thermoelectric effects at chiral tunneling have properties which strongly differ from the ones known for the scattering on purely electrostatic potential. The temperature dependence of electric conductance was shown to be a non-monotonic function with the minimum at temperature of the order of "gap" energy scale. Anomalous temperature behavior is predicted also for thermal conductance. However the anomalous features in temperature dependence of electric and heat conductances occur at slightly different temperatures that is manifested in strong violation of Wiedemann-Franz law. In particular at low temperatures the Lorentz ratio $L_0(T) = K(T)/TG(T)$ and the Seebeck coefficient have peak-like