# Thermoelectric properties of nanomaterials and quantum systems

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In this tutorial we will first have a look at the basics of thermoelectricity and understand the quest for topical research on thermoelectric phenomena at the nanoscale. This includes the design of nanomaterials for energy efficient applications as well as the future solid state quantum electronics. Then I will review our recent studies: Emphasis lies on identification of electron and phonon contributions and the influence of surface effects. First, a state-of-the-art combination of the full structural, chemical, and temperature-dependent thermoelectric characterization is demonstrated for individual single crystalline nanowires (NWs) [1-4]. It proves essential to conclude on surface effects for thermoelectric nanomaterials. Second, for high purity single-crystalline monovalent metal NWs (Ag) [6] which are of interest for transparent and flexible electronics, the heat and charge transfer processes are coupled (Wiedemann-Franz relation). We demonstrate the temperature dependence of the Lorenz number $L(T)$. It is determined by the material's purity and to be independent of surface scattering. We observe the transition from diffusive transport to quasiballistic one-dimensional transport in a single metallic NW. Third, we review investigations of thermal non-equilibrium in various implementations of low-dimensional electron systems hosted in semiconductor heterostructures (GaAs/AlGaAs). Quasi-one-dimensional waveguide networks [7,8] are formed as quantum wire rings. Thermal non-equilibrium is realized by heating currents and the charge carrier temperature is determined directly by noise thermometry. The voltage-noise is measured with respect to bath temperatures, heating currents, thermal gradients and electric fields. Therefrom, we determine and discuss electron-energy loss rates, electron-phonon interaction and heat transport processes.

Acknowledgements: This work has been financially supported by the German Science Foundation within the priority programme SPP1386 "Nanostructured Thermoelectrics". We gratefully acknowledge scientific collaborations with K. Nielsch, P. Woias, M. Kroener, A. Mogilatenko, M. Albrecht, D. Wallacher, M. Ramsteiner, K. Rademann, D. Reuter, A. D. Wieck, S. Buchholz, C. Kreisbeck and T. Kramer.

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