TT 1: Tutorial: Thermoelectricity – Fundamental Aspects, Materials, Applications (joint session TT/TUT/MA)

Thermoelectric effects have been discussed for several decades and have found widespread applications. Characteristic physical quantities are the efficiency, the figure of merit, ZT, and the power factor. In particular, increasing ZT has been the issue for many years. In recent developments, the focus has been on "unconventional" thermoelectric phenomena and materials: these include, in particular, transverse thermoelectric effects where the generated charge current is perpendicular to the temperature gradient, as can be observed, e.g., when applying a magnetic field (ordinary and anomalous Nernst effect). Transverse thermoelectricity can be found even without a magnetic field, e.g., in goniopolar materials (which have n- and p-type parts of the Fermi surface at the same time). – The Tutorial, jointly organized by the divisions MA and TT, will cover the basic physics of thermoelectricity, as well as discuss the question which materials are most useful for which applications, respectively. Attending the Tutorial thus will allow the non-experts in the field to fully appreciate the related presentations in the conference.

Organizers: Ulrich Eckern (University of Augsburg), Claudia Felser (MPI CPS Dresden), Anke Weidenkaff (TU Darmstadt & Fraunhofer IWKS)

Time: Sunday 16:00–18:10 Location: H 1058

Tutorial TT 1.1 Sun 16:00 H 1058

Transport properties of thermoelectric materials — •Maria Ibáñez — Institute of Science and Technology (ISTA), Klosterneuburg, Austria

Thermoelectricity is the phenomenon of converting heat directly into electricity and vice versa. As energy harvesters, thermoelectric devices can be used to partially recover large quantities of the waste heat to reduce our primary energy production or to run low-power devices, especially those that require autonomy, such as sensors and transmitters in remote or difficult-to-access locations. Furthermore, its reversible nature allows thermoelectric devices to be operated as precise coolers for small-scale temperature control. Such localized cooling is crucial in infrared detectors, microelectronics, and optoelectronics, among others, where space is limited, and heat dissipation is localized. This lecture will provide a comprehensive introduction to thermoelectricity. We will begin by giving a brief history of thermoelectrics, a description of the phenomenon, and its potential applications. Later on, we will introduce the fundamental principles of thermoelectricity, emphasizing the importance of material properties, in particular, those related to electronic and thermal transport. We will present the thermoelectric figure of merit and its significance as a metric for evaluating thermoelectric efficiency. ZT components, including electrical conductivity, Seebeck coefficient, and thermal conductivity, and their interplay in determining the overall performance will be deeply evaluated, and the different strategies to maximize performance will be presented using, as examples, traditional thermoelectric materials.

5 min. break

Tutorial TT 1.2 Sun 16:45 H 1058

Thermoelectricity: basic concepts, and applications to nanoscale heat engines — •Karol I. Wysokiński — Institute of Physics, M. Curie-Sklodowska University, Lublin, Poland

Thermoelectric power generators directly convert heat into electricity. These solid-state heat engines have no moving parts and are extremely reliable. Their performance is characterized by efficiency and power output, both of which depend on a single parameter called the thermoelectric figure of merit ZT, of which they are monotonically increasing functions. The dimensionless parameter ZT depends on the materials' transport coefficients: conductivity, thermal conductivity, Seebeck coefficient, and operating temperature. However, due to the coupling between conductivity and thermal conductivity quantified by the Wiedemann-Franz ratio obeyed by standard materials, the quest to increase ZT is a challenge for contemporary materials physics. Novel materials and structures have been proposed to overcome these difficulties on the way to achieve efficient waste heat harvesters with possible applications at large and small scales.

During the lecture, the above main ideas in the theory of thermoelectricity will be discussed, and their application in the nanoscale illustrated by the analysis of the devices consisting of a single or two quantum dots, tunnel coupled to two or more external electrodes. The electrodes may be simple metals, ferromagnets, or superconductors. The steady-state transport characteristics of the devices will be analysed. Special attention will be paid to the role of interactions between the carriers, and the non-linear effects prevalent in such structures.

5 min. break

Tutorial TT 1.3 Sun 17:30 H 1058

Novel thermoelectric materials: synthesis, characterization and application — •Wenjie Xie — Institute of Materials Science, Technical University of Darmstadt, Darmstadt, Germany — Fraunhofer IWKS, Alzenau, Germany

Thermoelectricity offers a direct and highly efficient approach for converting heat into electricity, relying on two key factors: Carnot efficiency and the materials-dependent property, ZT. Over the past two decades, significant progress has been made in pursuing high ZT thermoelectric materials, culminating in a bulk ZT surpassing 3. In this presentation, we offer a comprehensive review of the development of novel thermoelectric materials, categorized according to their application temperature ranges: low/room, medium, and high temperatures.

Within each temperature range, we will focus on the synthesis and characterization of one or two exemplary materials. For instance, the discussion will delve into materials such as Bi_2Te_3 for room temperature applications, SnSe/PbTe for medium temperature regimes, and the utilization of half-Heusler and oxide materials for high-temperature scenarios. Furthermore, the sustainable aspects of thermoelectric material synthesis will be explored.

Last, we will discuss the practical application of thermoelectric materials, examining their usage in real-world scenarios. The discussion will mainly focus on Bi_2Te_3, half-Heusler, and oxides, providing a comprehensive overview of the current landscape and future potential in the realm of thermoelectric cooling and power generation.