

## HL 46: Transport properties II

Time: Thursday 15:00–17:00

Location: ER 325

HL 46.1 Thu 15:00 ER 325

**Monitoring Cation Exchange in Individual Semiconductor Nanowires via Transistor Characterization** — •DANIEL LENGLE<sup>1,2</sup>, MAXIMILIAN SCHWARZ<sup>1</sup>, ALF MEWS<sup>1,2</sup>, and AUGUST DORN<sup>3</sup> — <sup>1</sup>Institute of Physical Chemistry, University of Hamburg, 20146 Hamburg, Germany — <sup>2</sup>The Hamburg Center for Ultrafast Imaging, 22761 Hamburg, Germany — <sup>3</sup>Innovationszentrum Niedersachsen, 30159 Hannover, Germany

The properties of nanostructures are largely determined by their material composition and their geometry. Chemical cation-exchange reactions allow for a controlled change of the elemental composition within a nanostructure while its geometry is preserved. However, controlling the exchange at the single particle level is challenging. Here, we investigate the successive cation-exchange with silver on individual semiconducting nanowires. For this purpose, nanowire field-effect transistors are fabricated via optical lithography. Then the cation exchange is performed by submerging the device in a silver-nitrate solution. By precisely timing the duration in the solution, the reaction progress and thus the exchange degree can be controlled. Transport measurements reveal a change in conductivity, charge carrier concentration, and mobility with progressing cation exchange. The approach presented here shows an efficient way to monitor the transport properties of individual nanostructures with a minimum of interference in the reaction. Nanowires with carefully adjusted elemental composition, and thus adjusted optoelectronic properties, could find a way into electrical devices such as sensors, transistors or batteries.

HL 46.2 Thu 15:15 ER 325

**Direct Observation of Hole Drift and Diffusion in Contacted Nanowires Under Local Illumination** — •MORITZ WEHRMEISTER, DANIEL LENGLE, CARLO HÖHMANN, CHRISTIAN STRELOW, ALF MEWS, and TOBIAS KIPP — Institute of Physical Chemistry, University of Hamburg, Hamburg, Germany

Kelvin probe force microscopy (KPFM) is a method for measuring the surface potential. Being based on atomic force microscopy, KPFM enables investigating nanostructures, such as nanowires and nanosheets. Combining optical, electrical, and KPFM measurements in one setup enables advanced investigations of the charge-carrier separation in these materials and the properties of semiconductor-metal interfaces. We investigate individual electrically contacted CdS nanowires, by combining scanning photocurrent mapping (SPCM) and KPFM. The charge-carrier mobility information of SPCM extended by KPFM maps gives a more complete picture of the path and hurdles, the charge carriers take inside the nanodevice in operando. We show that upon local optical excitation, differences in charge-carrier mobilities of electrons and holes lead to an imbalance in the surface potential. At the point of illumination, positive charges accumulate, due to their lower mobility. KPFM reveals this imbalance and how it influences the potential drop along the biased CdS nanowire. Furthermore, performing KPFM while optically exciting the probed sample position monitors the excess of positive charge carriers for each position of the illuminated nanowire. A decrease of this excess shows how holes drift and diffuse into the contacts, where they contribute to the measured photocurrent.

HL 46.3 Thu 15:30 ER 325

**Simulation of Charge-Carrier Transport in Cadmium Sulfide Nanowires** — •CARLO HÖHMANN, MORITZ WEHRMEISTER, DANIEL LENGLE, ALF MEWS, and TOBIAS KIPP — Physikalisches Chemie, Hamburg, Deutschland

Theoretical simulations form the backbone of experiments and help to confirm physical models, find material properties, and also provide more detail in results such as spatial resolution. Here we report on a numerical finite element simulation of single electrically contacted cadmium sulphide (CdS) nanowires using COMSOL Multiphysics software. The focus of the simulation is on the surface potential, the band alignment and the current-voltage behavior. The results are compared with experimental results obtained by local photocurrent microscopy and Kelvin probe force microscopy on single wet-chemically synthesized CdS nanowires. This comparison gives us a better understanding of the underlying physics and provides material parameters that are difficult to obtain by experiments alone.

We show that simulations based on the drift-diffusion approach in-

cluding trap-assisted charge-carrier recombination at the surface, local photo excitation and ohmic metal contacts on the surface, is able to provide comparable results and new insights, for example, into the type of recombination or the exact location of the electrons and holes. We can also see how the system behaves under extreme conditions, such as high applied voltages or temperatures.

HL 46.4 Thu 15:45 ER 325

**Counter-Ion Size Effect on the Thermoelectric Properties of Doped Carbon Nanotubes Network** — •ADITYA DASH<sup>1</sup>, ANGUS HAWKEY<sup>2</sup>, DOROTHEA SCHEUNEMANN<sup>1</sup>, JANA ZAUMSEIL<sup>2</sup>, and MARTIJN KEMERINK<sup>1</sup> — <sup>1</sup>Institute for Molecular Systems Engineering and Advanced Materials, Heidelberg University, Im Neuenheimer Feld 225, 69120 Heidelberg, Germany — <sup>2</sup>Institute for Physical Chemistry, Universität Heidelberg, D-69120 Heidelberg, Germany

Doping is a proven technique to improve the thermoelectric properties of semiconducting single-walled carbon nanotube networks, which are promising for the conversion of waste heat to electricity. For this, understanding the counter-ion size effect is crucial, as Coulombic interactions between the ions and the free charge carriers cause scattering and trapping. Here, we propose a random resistor network model that accounts for the formation of Coulombic traps at low doping levels, and the formation of an impurity band at high doping levels. As such, it accounts for the increasing overlap of the Coulombic potentials due to dopant ions. The model semi-quantitatively reproduces our experiments that demonstrate that larger counter-ions enhance conductivity and maximize the power factor before a saturation sets in. Moreover, the conductivity dependence on ionic size is stronger at low temperatures. Overall, the employed model may guide the counter-ion selection to improve thermoelectric efficiency, depending on the interplay between the achievable doping level, ion size and the energetic disorder in the network.

15 min. break

HL 46.5 Thu 16:15 ER 325

**Universal Theory of Hall Transport in Organic Semiconductors** — •MICHEL PANHANS and FRANK ORTMANN — TUM School of Natural Sciences, Technische Universität München, 85748 Garching b. München, Germany

The investigation of Hall transport is a key experimental method to understand transport mechanisms in organic semiconductors (OSCs). Despite many experimental observations of the Hall effect in OSCs, theoretical descriptions usually fail to understand these experiments.

This lack in the theoretical description motivated our recent study, where we develop a universal theory to understand the Hall effect in OSCs and beyond. Our new approach embeds previous theoretical descriptions covering different aspects of Hall transport ranging from semi-classical band-transport approaches, via topological descriptions utilizing geometrical concepts such as the Berry curvature to disorder driven transport scenarios.

Using rubrene as a showcase, we discuss the range of validity of different Hall-transport regimes and finally compare our results for the temperature-dependent Hall mobility to the experiment. The determination of the Hall mobility allows us to quantify the number of charge carriers that are responsive to the magnetic field. These results can be used to classify the charge transport in rubrene in terms of band-like and hopping transport at different temperatures.

HL 46.6 Thu 16:30 ER 325

**Hall field-induced resistance oscillations in two-dimensional Lorentz gases** — •FREDERIK BARTELS, JOHANNES STROBEL, MIHAI CERCEZ, and THOMAS HEINZEL — Condensed Matter Physics Laboratory, Heinrich Heine University, Düsseldorf, Germany

Two-dimensional electronic systems in non-equilibrium exhibit some exciting phenomena. One phenomenon are Hall field-induced resistance oscillations (HIROs), which can be recognized in the magnetoresistance of a highly mobile sample. Applying a direct current ( $x$ -direction) generates a tilt of the Landau levels due to the additional Hall field ( $y$ -direction). Tunneling to a higher Landau level is therefore possible, whereby the maximum probability depends on the shift in the  $y$ -direction. From theoretical considerations, a HIRO maximum arises

due to backscattering, because this leads to the maximum shift (by  $2R_c$ ) in the  $y$ -direction for a single scattering event. We have investigated HIROs as a function of the obstacle density in two-dimensional Lorentz gases. A monotonous increase of the HIRO period with increasing density of the designed obstacles is observed. At large current densities, the HIROs deviate even qualitatively from the theoretical expectations. In addition, we determined the quantum scattering time  $\tau_q$  and the backscattering time  $\tau_\pi$  using the HIROs. The quantum scattering times from the HIROs are significantly larger than the quantum scattering time that can be determined from the Shubnikov-de Haas oscillations in the equilibrium.

HL 46.7 Thu 16:45 ER 325

**Identifying different electronic transport mechanisms in nanoporous inorganic C12A7 using Hall measurements and electron paramagnetic resonance spectroscopy** — •JULIUS K. DINTER<sup>1</sup>, JUREK LANGE<sup>1,2</sup>, DETLEV M. HOFMANN<sup>1,2</sup>, J. FABIÁN PLAZA FERNÁNDEZ<sup>3</sup>, ANGEL POST<sup>3</sup>, SANGAM CHATTERJEE<sup>1,2</sup>, MATTHIAS T. ELM<sup>1,2,4</sup>, and PETER J. KLAR<sup>1,2</sup> — <sup>1</sup>Center for Ma-

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$[\text{Ca}_{24}\text{Al}_{28}\text{O}_{64}]^{4+}(2\text{O}^{2-})$  is a nanoporous compound, whose properties are strongly determined by its degree of reduction. It consists of a positively charged cage and additional oxygen ions  $\text{O}^{2-}$ , which ensure charge neutrality and can move almost freely between them. A transition from insulating behavior to metallic behavior occurs when replacing the  $\text{O}^{2-}$  ions in the cages by electrons, finally generating the electride  $[\text{Ca}_{24}\text{Al}_{28}\text{O}_{64}]^{4+}$ . However, a complete understanding of the charge transport mechanisms of the system and their variation with the degree of reduction is far from complete. Here, we present the characterization of a series of  $[\text{Ca}_{24}\text{Al}_{28}\text{O}_{64}]^{4+}(2\text{O}^{2-})_{(1-x)}(4e^-)_x$  with different  $x$  using Hall-measurements and electron paramagnetic resonance spectroscopy in a high temperature range. Three different transport mechanisms are identified which dominate at different temperatures.