# O 29: Metallic nanowires on semiconductor surfaces

Time: Tuesday 10:30–13:15 Location: MA 144

O 29.1 Tue 10:30 MA 144

**Lattice dynamics of one-dimensional In chains on Si(111) upon ultrafast optical excitation** — Tim Frigge, Bernd Hafke, Tobias Witte, Boris Krenzer, and •Michael Horn-von Hoegen — Fakultät für Physik und CENIDE, Universität Duisburg-Essen, 47057 Duisburg, Germany

The Indium induced (4x1) reconstruction on Si(111) is the prototype for 1D atomic wires at surfaces. At 130 K a metal-insulator transition to the (8x2) ground state takes place. A Peierls-like distortion causes periodicity doubling, opening of a band gap, and formation of a CDW. The non-equilibrium structural dynamics is studied by ultrafast RHEED with a fs-laser system in pump probe setup at temporal resolution better than 300 fs. Upon photo excitation the (8x2) ground state is driven in 350 fs to the (4x1) excited state as observed through the transient spot intensity changes. The transition is described in an accelerated displacive excitation scenario which relies on transient changes in the potential energy surface. The strong coupling between substrate and adsorbate is responsible for the sub-picosecond structural response by dephasing and damping the characteristic phonons in 1/4th of their oscillation period. Transient heating of the In atoms from 30 K to 80 K occurs delayed on a time scale of 2.2 ps. Thus the phase transition is driven by electronic entropy and not thermally.

O 29.2 Tue 10:45 MA 144

**Infrared Spectroscopic Investigations of Charge Transfer in Quasi-1D Au-Induced Superstructures on Vicinal Silicon Surfaces** — •Michael Tzschoppe, Christian Huck, Fabian Hötzel, and Annemarie Pucci — Kirchhoff Institute for Physics, Heidelberg University, Germany

Thermal evaporation of Au on vicinal silicon (*e.g.* Si(553)) under ultrahigh vacuum (UHV) conditions leads to atomic chain growth preferably along the step edges. During the experiments, the quality of the silicon surface, as well as the defined preparation of the atomic chains, are proven by reflective high energy electron diffraction (RHEED) measurements. We studied the plasmonic excitations of the metallic quasi-one-dimensional chains in the mid-infrared spectral region by Fourier transform infrared (FTIR) spectroscopy. By applying a model for excitations at low energies,[1] we are able to describe the spectrum and therefore to extract the one-dimensional free charge carrier concentration. In this talk, we will present how the free charge carrier concentration can be modified by doping the superstructures with organic molecules. For doping with $C_{70}$, the molecular adsorption leads to an increase of the plasmonic signal which can be attributed to an uptake of electrons by the $C_{70}$ molecules adsorbed on the surface.

[1] Hötzel *et al.* Nano Lett. 15, 4155-4160 (2015)

O 29.3 Tue 11:00 MA 144

**Light-induced phase transition in one-dimensional Indium wires** — •Mariana Chavez-Cervantes, Razvan Krause, Sven Aeschlimann, and Isabella Gierz — Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany

Strong Fermi surface nesting in one-dimensional wires drives Peierls transitions where a periodic lattice distortion opens up a band gap at the Fermi level. The In/Si(111)-(4x1) surface consists of quasi-one-dimensional indium wires which are metallic at high temperatures and become insulating below Tc˜100K via a complex three-band Peierls transition assisted by interband charge transfer [1]. We study the light-induced insulator-to-metal phase transition using time- and angle-resolved photoemission spectroscopy (tr-ARPES), complementing recent investigations of the underlying lattice dynamics [2-3]. We observe closing of the band gap on a timescale (˜500fs) that is a fraction of the amplitude mode period. The recovery time of the insulating state is found to be strongly fluence dependent with trapping in a metastable (4x1) phase at high fluences. We discuss the subtle role of the chemical potential [4] for both the temperature- and the light-induced phase transition.

[1]P. C. Snijders et al., Rev. Mod. Phys. 82, 307(2010)
[2]S. Wall et al., PRL 109,186101 (2012)
[3]T. Frigge et al., Nature 544, 207 (2017)
[4]E. Jeckelmann et al., Phys. Rev. B 93, 241407(R) (2016)

O 29.4 Tue 11:15 MA 144

**Understanding solitonic excitations in the charge density wave ordered ground state of the In/Si(111) nanowire array from phonon theory** — •Samad Razzaq[1], Stefan Wippermann[1], Tae-Hwan Kim[2], and Han-Woong Yeom[2] — [1]Max-Planck-Institut für Eisenforschung GmbH — [2]IBS Center for Artificial Low Dimensional Electronic Systems , University of Pohang

The Si(111)-(4x1)/(8x2)In atomic wire array is an extremely popular model system for one-dimensional electronic systems. It features a reversible temperature-induced metal-insulator transition into a charge density wave (CDW) ordered ground state. Solitonic excitations of the CDW and associated topological edge states are presently the focus of increasing attention. We carried out a combined *ab initio* and scanning tunneling microscopy (STM) study of solitonic phase defects in the In/Si(111) atomic wire array. We show how the solitonic CDW excitations can be modeled in terms of collective excitations of particular phonon modes. In conjunction with STM measurements, this phonon expansion approach allows us for the first time to determine the atomistic structure of the solitonic excitations. Due to the topological properties of the solitons and a strongly non-linear phonon-phonon coupling, these solitons interact in a deterministic way and are suitable for information processing. Financial support from the German Research Foundation (DFG), grant no. FOR1700 is gratefully acknowledged.

O 29.5 Tue 11:30 MA 144

**Chiral topological solitons in the Si(111)-(8x2)In atomic wire array** — Samad Razzaq[1], Tae-Hwan Kim[2], Han Woong Yeom[2], and •Stefan Wippermann[1] — [1]Max-Planck-Institut für Eisenforschung — [2]Pohang University

The Si(111)-(8x2)In atomic wire array is a prototypical system featuring a one-dimensional charge density wave (CDW) formed at low temperature at the surface. As a consequence of CDW formation, the (8x2) phase exhibits a band inversion in the surface band structure. This system is therefore a candidate for a 1D topological insulator. Recent experimental findings indicate that the associated topological edge states take the form of chiral topological solitons. At present, these results, the associated concepts and their applicability with respect to atomic wires are intensely debated. In this talk we review the fundamental ideas behind the topological solitons in this system. We discuss how to understand the nature of the solitons and their interactions within phonon theory from first principles and provide some recent atomistic insights. Financial support from the German Research Foundation (DFG), grant no. FOR1700 is gratefully acknowledged.

O 29.6 Tue 11:45 MA 144

**Quasi-ballistic transport through surface states of Ge(001)-c(4x2) demonstrated by two-probe STM measurements and multi-terminal fist-principles simulations** — •Pedro Brandimarte[1], Marek Kolmer[2], Hiroyo Kawai[3], Thomas Frederiksen[1,4], Aran García-Lekue[1,4], Nicolas Lorente[5], Mads Engelund[5], Rafal Zuzak[2], Szymon Godlewski[2], Christian Joachim[6], Marek Szymonski[2], and Daniel Sánchez-Portal[1,5] — [1]DIPC, Spain — [2]NANOSAM-UNIWERSYTET JAGIELLO, Poland — [3]IMRE, Singapore — [4]IKERBASQUE, Spain — [5]CFM CSIC-UPV/EHU, Spain — [6]CNRS, France

Dangling-bond (DB) dimer wires on both Si and Ge(001):H substrates were predicted to be robust against electron doping and capable of sustaining ballistic transport [1]. The ability to fabricate high-quality DB-dimer wires on Ge(001):H was demonstrated and their transport properties were measured in atomic level using a two-probe scanning tunneling microscope (STM) setup [2].

We present a joint theoretical and experimental study of the electronic transport through DB-dimer wires on bare Ge(001) surfaces. First-principles calculations (DFT+NEGF [3]) of a four-terminal setup were carried out to simulate the two-tip experiment. Our results confirm the capability of the DB-dimer wires to sustain quasi-ballistic transport, and opens the possibility to their use as interconnects for atomic-scale devices fabricated on these surfaces.

[1] M.Engelund *et al.* JPCC **120**, 20303 (2016). [2] M.Kolmer *et al.* JPCM **29**, 444004 (2017). [3] N.Papior *et al.* CPC **212**, 8 (2017).

O 29.7 Tue 12:00 MA 144

**Investigation of the phase transition in Si(553)-Au** — •Frederik Edler[1,2], Ilio Miccoli[2], Herbert Pfnür[2], and Christoph Tegenkamp[1,2] — [1]Institut für Festkörperphysik, Technische Universität Hannover, 09126 Chemnitz — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover

Atomic wires are prototype 1D systems for studying fundamental aspects, e.g. charge density waves or dimensional crossover from a Fermi to a Luttinger liquid behavior. Recently, the Si(553)-Au system revealed a lot of attention because of their quasi-1D metallic structures with pronounced magnetic order, mimicking a quantum spin liquid [1]. However, up to now the phase transition of this system is not completely understood. By means of LEED and 4-tip STM, we investigated the surface structure and transport properties of Si(553)-Au as a function of temperature. LEED revealed an structural transition at $T_C$=100 K, i.e. the ×3 periodicity along the wires vanishes. In contrast, upon cooling the resistance increases at 120 K across the wires sharply by 2-3 and along the wires by one order of magnitude in transport experiments. By systematic variation of the intrinsic doping levels for the Si-substrates we were able to disentangle space-charge layer from surface state contributions. The latter transport channel indeed showed a metal insulator transition at 65 K. However, we clearly rule out a metal insulator transition which is associated to the phase transition of the ×3 reconstruction.

[1] B. Hafke et al., Phys. Rev. B. **94** (2016) p. 161403

O 29.8 Tue 12:15 MA 144

**Control of plasmonic excitations in atomic arrays by adsorbates** — •Zamin Mamiyev, Timo Lichtenstein, Christoph Tegenkamp, and Herbert Pfnür — Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Germany

Self-assembled atomic wires on vicinal Si surfaces serve the possibility to investigate fundamental properties of low-dimensional metallic systems. Electronic properties of such ultimate wires are strongly correlated with local structural motifs such as atomic arrangements, terrace width as well as inter- and intrawire distances. Therefore, the electronic correlation on such metallic wires is possible without direct contact with the atomic chains by the proximity effects. In this work modification of plasmonic excitations on Au-Si(hhk) surfaces by $O_2$ and $H_2$ adsorption has been studied via EELS-LEED with high resolution in energy and momentum. While the plasmon energy decreases by atomic hydrogen on Au-Si(553), gap opening is observed on Au-Si(557). Theoretical results show that hydrogen adsorption on Si step edges transfers charges to the metallic chains and increases band filling of Au-induced bands on Si(553), resulting in a metal-insulator transition. However, oxygen affects plasmon dispersion only on Au-Si(557), probably due to its higher chemical reactivity. Oxygen adsorption on Au-Si(557) is consistent with calculations that show that oxidation of adatom rows decreases the plasmon frequency. On the other hand, the excess amount of adsorbates induces disorder and finite propagation lengths.

O 29.9 Tue 12:30 MA 144

**On the diffraction pattern analysis of bundled rare-earth silicide nanowires on Si(001)** — Frederic Timmer, Jascha Bahlmann, and •Wollschläger Joachim — Fachbereich Physik, Universität Osnabrück, Osnabrück, Germany

Silicides of trivalent rare earth elemensts form nanowires (NW) on Si(001) surfaces caused by strain effects due to the different crystal structures of Si substrate and silide [1]. After intial growth of 2D wetting layers, single NWs are formed first while NW bundles appear during later stages. Since the structure of the NWs are not correlated, streaks emerge in diffraction pattern. The streaks, however, show some substructure after formation of NW bundles. Here, we report on the analysis of this structure based on the binary surface technique to obtain detailed information on the width distribution of single NWs and bundles of NWs as well as the distribution of bundle distances [2]. We apply our analysis on diffraction pattern from $DySi_2$ NWs recorded by SPA-LEED and compare the results with previous STM studies [3,4].

[1] M. Dähne, M. Wanka, J. Phys.: Condens. Matter 25 (2013) 014012.
[2] F. Timmer et al., J. Phys.: Condens. Matter 29 (2017) 435304.
[3] B.Z. Liu, J. Nogami, J. Appl. Phys. 93 (2003) 593.
[4] S. Appelfeller et al., Surf. Sci. 641 (2015) 180.

O 29.10 Tue 12:45 MA 144

**A new atomic structure model for rare earth silicide nanowires on Si(001)** — •Stephan Appelfeller[1], Jonas Heggemann[2,3], Tore Niermann[2], Michael Lehmann[2], and Mario Dähne[1] — [1]Institut für Festköperphysik, Technische Universität Berlin, Germany — [2]Institut für Optik und Atomare Physik, Technische Universität Berlin, Germany — [3]Fachbereich Physik, Universität Osnabrück, Germany

Rare earth silicide nanowires on Si(001) are well known since 20 years. Soon after their discovery, their formation was explained by an atomic structure based on anisotropically strained hexagonal rare earth disilicide [1]. This univeral structure model was confirmed by scanning tunneling microscopy, with which only the surface of the nanowires is accessable.

Here, high-resolution transmission electron microscopy was utilized to analyze the cross-sections of Tb silicide nanowires with atomic resolution. For this purpose, the nanowires were passivated by an amorphous Si layer, which does not influence their inner structure [2]. As expected, hexagonal structural motives are found, but their orientation contradicts the accepted structure model of the nanowires. Thus, a new atomic structure model was developed based on these data as well as previous findings by scanning tunneling microscopy and low energy electron diffraction.

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[1] Y. Chen *et. al*, Appl. Phys. Lett. **76**, 4004 (2000).
[2] S. Appelfeller *et. al*, Appl. Phys. Lett. **108**, 013109 (2016).

O 29.11 Tue 13:00 MA 144

**Optical characterization of rare-earth silicide nanostructures on vicinal Si(001)** — •Sandhya Chandola[1], Eugen Speiser[1], Norbert Esser[1], Stephan Appelfeller[2], Martin Franz[2], and Mario Dähne[2] — [1]Leibniz-Institut für Analytische Wissenschaften ISAS e.V., Berlin, Germany — [2]Institut für Festkörperphysik, Technische Universität, Berlin, Germany

Rare-earth metals can interact strongly with Si(001) surfaces to form different types of silicide nanostructures such as wetting layers, nanowires as well as bundles of nanowires. Reflectance anisotropy spectroscopy (RAS) is used to monitor optically the growth evolution of Tb and Dy silicide nanostructures on vicinal Si(001) surfaces while STM is used to analyze their structural properties so as to directly relate the spectral signatures in RAS to the structural features. It is shown that the optical signatures of the different types of silicide nanostructures can be distinguished quite clearly with RAS due to their distinctive electronic properties associated with the structural units as observed with STM.