TT 28: FS: Time-Resolved Spectroscopy in Correlated Electron Systems: Experiment and Theory

Time: Thursday 9:30–13:00 Location: H18

Topical Talk TT 28.1 Thu 9:30 H18

Angle- and time-resolved photoelectron spectroscopy of charge density wave materials — •Uwe Bovensiepen — University Duisburg-Essen, Faculty of Physics, Duisburg, Germany

In charge density wave (CDW) materials a band gap opens at sufficiently low temperatures because the system gains energy by forming a new periodic arrangement of the ion cores, which modulates the electron charge density. As shown femtosecond time- and angle-resolved photoelectron spectroscopy (trARPES) monitors the phonon mode that couples to electrons at the Fermi level, which is a direct example of electron-phonon coupling. To achieve this the material is pumped by an IR femtosecond laser pulse ($h\nu = 1.5eV$). The response to this excitation is probed by a delayed UV laser pulse ($h\nu = 6.0eV$). The latter pulse generates photoelectrons which are analyzed regarding parallel momentum and kinetic energy. The tritelluride $TbTe_3$ responds by electron-hole pair excitation and two distinct coherent phonon modes that result in periodic variations of the respective photoemission lines at the phonon frequency. One of them presents a pronounced momentum dependent dynamics and is responsible for closing (and opening) of the band gap. Hence it represents the amplitude mode of the CDW. In the dichalcogenide $1T$ -TaS_2 the amplitude mode is also excited, however, it does not couple strongly to the band gap. Accordingly, electronic correlations might contribute to the gap formation. This is confirmed by a considerably faster and shortlived closing of the gap.

Experiments have been performed at the Freie Universität Berlin.

Invited Talk TT 28.2 Thu 10:00 H18

Many Body Theory for Time-Resolved Pump/Probe Photoemission and its Solution via Nonequilibrium Dynamical Mean-Field Theory — •James Freericks — Georgetown University, Washington, DC, USA

In this talk, I will present the exact many-body formalism for time-resolved pump/probe photoemission spectroscopy (PES). By using the sudden approximation and neglecting the energy and momentum dependence of matrix elements, one can reduce the PES response to a relative time Fourier transform of the (nonequilibrium) lesser Green's function in the presence of the pump and modulated by the probe envelope. We will apply this theory to a system that cannot be described by a quasiequilibrium approach with a time-dependent effective temperature: namely, the response of the system to a large dc electric field which generates damped Bloch oscillations in the system as it evolves to a nonequilibrium steady state. We will describe the interplay between the probe width and the ability to see temporal oscillations or sharp features in the spectra.

Recent references include: J. K. Freericks, H. R. Krishnamurthy and Th. Pruschke, Phys. Rev. Lett. **102**, 136401 (2009); J. K. Freericks, H. R. Krishnamurthy, Yizhi Ge, A. Y. Liu, and Th. Pruschke, phys. stat. sol. b **246**, 948 (2009); and B. Moritz, T. P. Devereaux, and J. K. Freericks, arXiv:0908.1807.

TT 28.3 Thu 10:30 H18

Electron-phonon interaction in 122-iron pnictides investigated by femtosecond time-resolved ARPES. — •Rocío Cortés[1], L. Rettig[1], S. Thirupathaiah[2], U. Bovensiepen[1,3], M. Wolf[1], H. A. Dürr[2], P. Gegenwart[4], T. Wolf[5], and J. Fink[2,6] — [1]Freie Universität Berlin, D-14195 Berlin — [2]Helmholtz-Zentrum Berlin, D-12489 Berlin — [3]Universität Duisburg-Essen, D-47048 Duisburg — [4]Georg-August-Universität Göttingen, D-37077 Göttingen — [5]Karlsruhe Institute of Technology, D-76021 Karlsruhe — [6]Leibniz-Institute for Solid State and Materials Research Dresden, D-01171 Dresden

The new class of FeAs based high-T_c superconductors exhibits a complex interplay between electronic, magnetic and lattice degrees of freedom. Here we report on electron-phonon coupling in $EuFe_2As_2$ and $BaCo_{0.15}Fe_{1.85}As_2$ investigated by femtosecond (fs) time- and angle-resolved photoelectron spectroscopy (trARPES). The samples were excited by 1.5 eV fs laser pulses, at 100 K equilibrium temperature. The temporal evolution of their electronic band structure after photoexcitation was probed by time-delayed 6 eV fs pulses. In this way a periodic oscillation of the electronic structure in the vicinity of the Fermi level was observed, which is attributed to coherent phonon modes and electron phonon-coupling. Comparison with Raman scattering results[1] allows to assign the mode with the highest frequency to the A_{1g} mode, which modifies the Fe-As distance and could be involved with the mechanism leading to superconductivity in these materials.

[1] A.P. Litvinchuk *et al.*, Phys. Rev. B **78**, 060503(R) (2008)

Topical Talk TT 28.4 Thu 10:45 H18

Time resolved photoemission and THz spectroscopy of high temperature superconductors — •Luca Perfetti — Laboratoire des Solides Irradiés, École Polytechnique, 91128 Palaiseau Cedex, France — Fachbereich Physik, Freie Universitaet, Arnimallee 14, 14195 Berlin, Germany

I will review some of the open questions concerning the mechanism of high temperature superconductivity. Our approach makes use of non-equilibrium techniques in order to disentangle electronic degrees of freedom from lattice modes. The time resolved photoemission technique and time resolved THz spectroscopy will be presented. These experiments provide novel information on the elementary interactions dressing the quasiparticles as well as on the calorimetry of the electrons. The relaxation time of the photoexcited state indicates that the electron-phonon coupling is too weak in order to provide the pairing interaction. Simple considerations based on the energy conservation allow for an extraction of the electronic specific heat over a wide temperature range. These results offer new insights on the phase diagram and the occurrence of a pseudogap in underdoped compounds.

15 min. break

Topical Talk TT 28.5 Thu 11:30 H18

Relaxation of strongly correlated electron systems: Insights from nonequilibrium dynamical mean-field theory — •Martin Eckstein — Theoretische Physik, ETH Zürich, 8093 Zürich, Schweiz

Pump-probe experiments with femtosecond time-resolution provide a unique way to observe the nonequilibrium dynamics of correlated electron systems after a strong laser excitation, before the electrons have equilibrated and the lattice dynamics becomes dominant. The bare timescales for the electronic relaxation are set by the Coulomb interaction and the hopping amplitude. However, the formation of photo-excited states and the electronic thermalization are not well understood, and neither are the timescales involved in those processes. Nonequilibrium dynamical mean-field theory (DMFT) allows to address those fundamental questions. We have combined DMFT with a recently developed real-time Quantum Monte Carlo impurity solver to investigate the thermalization of correlated electrons in the Hubbard model [1]. We find that the relaxation behavior undergoes a qualitative change at an intermediate value of U. This transition, which coincides with a pronounced minimum in the thermalization time, occurs for rather general initial states, although the location of the transition depends on the initial state. We also discuss the possibility to observe similar relaxation phenomena in pump-probe experiments.

[1] M. Eckstein, M. Kollar, and P. Werner, Phys. Rev. Lett. 103, 056403 (2009); arXiv:0910.5674.

TT 28.6 Thu 12:00 H18

Quantum interference between photo-excited states in a solid-state Mott insulator — •Simon Wall[1,5], Daniele Brida[2], Stephen R. Clark[3,1], Dieter Jaksch[1,3], Arzhang Ardavan[1], Stefano Bonora[2], Giulio Cerullo[2], and Andrea Cavalleri[1,4] — [1]Department of Physics, Clarendon Laboratory, Oxford UK — [2]Dipartimento di Fisica, Politecnico di Milano, Italy — [3]Centre for Quantum Technologies, National University of Singapore — [4]Max Planck Research Group for Structural Dynamics, University of Hamburg-CFEL — [5]Department of Physical Chemistry, Fritz Haber Institute of the Max Planck Society, Berlin, Germany

We show that, by measuring on an ultrafast timescale, the coherent quantum evolution of a correlated solid after photoexcitation can be observed during the first few femtoseconds. By using nearly-single-cycle, sub-10 fs IR pulses, we measure the time-dependent evolution of the optical conductivity in the quasi-1D organic ET-F2TCNQ after photoexcitation. By comparing our results to numerical calculations we are able to identify two regimes, one incoherent regime occurring

on long timescales in which the dynamics are dictated by the electronic population in the excited state, and a second, coherent regime occurring within the first 40 fs, where interference effects between excited states dictates the dynamics. These experiments bridge the gap between fully coherent temporal evolution observed in optical lattices and the incoherent dynamics usually observed in condensed phase materials.

Topical Talk TT 28.7 Thu 12:15 H18

Two-Component Dynamics of the Order Parameter of High Temperature $Bi_2Sr_2CaCu_2O_{8+\delta}$ Superconductors Revealed by Time-Resolved Raman Scattering — •Michael Alexander Rübhausen — Institut für Angewandte Physik & Center for Free Electron Laser Science, Universität Hamburg

We study the dynamics of the superconducting order parameter in the high-T_c cuprate $Bi_2Sr_2CaCu_2O_{8+\delta}$ by employing a novel time-resolved pump-probe Raman experiment. We find two different coupling mechanisms that contribute equally to the pair-breaking peak. One coupling sets in very fast at 2 ps and relaxes slowly, while the other one is delayed and sets in roughly at 5 ps and relaxes fast. A model that couples holes through phonons is able to reproduce one part of the condensate dynamics; thus, we argue that hole-spin interactions are of importance as well.

I will also give an brief outlook on future options to perform time resolved inelastic light scattering experiments with table top and free electron laser sources.

In collaboration with: R. P. Saichu, I. Mahns, A. Goos, S. Binder, P. May, S. G. Singer, B. Schulz, A. Rusydi, J. Unterhinninghofen, D. Manske, P. Guptasarma, M. S. Williamsen, and M. Rübhausen

TT 28.8 Thu 12:45 H18

Ultrafast non-equilibrium dynamics in conventional and unconventional superconductors — •Andreas Schnyder and Dirk Manske — Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, D-70569 Stuttgart, Germany

We present simulations of the ultrafast dynamics of conventional and unconventional superconductors using density-matrix theory. In particular, we study how the optical conductivity evolves in response to ultrashort optical pulses in the frequency range of the superconducting gap, i.e., in the terahertz regime. The dominant relaxation process is assumed to be due to electron-phonon collisions. Employing a second order cluster expansion and assuming that the phonons remain equilibrated, Boltzmann type equations for the dynamics of the quasiparticle occupations and coherences are derived. We apply our theoretical model to the study of non-equlibrium dynamics in the two-gap superconductor MgB_2.