The basic course of 10 lectures

Physics of electronically and optically active synthetic materials as low dimensional correlated electronic systems.

The electronically and optically active synthetic materials are designed to possess the desired physical properties and applications. The main classes include the conjugated polymers, fullerenes, organic conductors, chain materials. These are the correlated electronic systems showing various kinds of cooperative phenomena: superconductivity, magnetism, ferroelectricity, density waves and charge ordering. Their physical properties are studied by all advanced methods: NMR, STM, femtosecond optics, X-rays, etc. Theoretical methods and concepts involve many-body effects including the local nano-scales and transient processes, electronic and crystal instabilities, exotic objects like solitons and electronic vortices. The great variety of materials and effects makes the synthetic conductors to be the best tutorial for all concepts in solid state theory and beyond. The aim of this course is to give a panorama of this vast science and to use its diversity as a tutorial for condensed matter science.

Keywords: Conducting polymers, organic charge transfer conductors, electronic crystals, Peierls and Mott insulators, density waves, charge ordering, electronic ferroelectrics, solitons.

Required qualification:

An acquaintance with basics of the solid state physics will be assumed:
crystals –metals and semiconductors, band structure, electron and phonon excitations. Additional recommended chapters: optical excitons, polarons.

1. Introduction. Origin of the science of Synthetic Metals

The beginning: W.Little idea for high temperature polymeric superconductors and subsequent major steps. Classes of synthetic metals:
organic crystals, inorganic chain compounds, conducting polymers, fullerenes.
Main differences from traditional materials:
low dimensional structure (chains, planes), enormous variety of elements and their compositions, their impacts upon electronic properties.

2. Forms of carbon and its small systems.

Carbon valences, sigma and pi electrons, hybridization, circles, cages, crystals.
Fullerenes: structures and oping and, Jahn-Teller effect for electrons and excitons.
Local phase transformations under doping.

3. Theory I.

Bands, electrons, holes, phonons.
Excitons – from molecules to semiconductors.
Frenkel and Wannier-Mott excitons.
Peculiarities of 1D systems. On-chain and inter-chain excitons.
Selftrapping: Jahn-Teller effect, polaron.

4. Electronically and optically active polymers for applications.

Electronic band structure of conjugated polymers.
Excitons and polarons in light emitting and light harvesting polymer.
Optics: linear and nonlinear, with femto-second time resolution, photoconductivity.
Electronic correlations and their manifestation.

5. Theory II. Collective ground states and spontaneous symmetry breaking.
Interactions: electron- phonon, electron-electron and their combination.
Multiple ground state instabilities. Peierls effect, Charge density wave, Spin density wave, Spin-Peierls state, Charge ordering, Superconductivity.
Band insulator, Mott insulator, and Peierls insulator.
Solitons - history introduction: from tsunami to domain walls and dimerization defects.
Exact solutions for solitons and their lattices.

6. Chains with a spontaneous dimerization.
Polyacethylene invention: dimerized ground state, spin and charge solitons, polarons, excitons. Optics: direct and photoinduced; solitons manifestation.
Spin-charge decoupling. Solitons' confinement, bipolarons, excitons, ferroelectric polymers. Non-integer charges.
Doping, interplay of structure and electronic properties. Solitonic lattices.
Chains from surface adsorption.

7. Conducting organic crystals.
Main (quai-1D and quasi-2D) families of organic metals.
Firework of spontaneous phases: Charge and Spin Density Waves, Spin-Peierls state, Superconductivity, Charge Disproportionation (Wigner crystallization) , Ferroelectricity, High Magnetic Field phases.

8. Ferroelectricity in organic and polymeric materials.
Charge Ordering and electronic ferroelectricity in organic metals and polymers.
Realizations: substituted polyacetylene, donor-acceptor stacks, organic conductors with Mott, Peierls and spin-Peierls transitions. A workshop of solitons.

9. Charge Density Waves in inorganic chain systems.
Types of materials: tri- and di-chalcogenides of transition metals, blue bronzes.
The common instability towards incommensurate charge waves.
Collective sliding and gigantic dielectric response.
Conversion of electrons and plastic flows.
Topological defects: solitons and dislocations.
Macroscopic and microscopic identification of intrinsic defects via space- resolved X-ray diffraction, coherent microdiffraction, STM.

10. Transformations of cooperative electronic states by impacts of optical pumping or high electric field.
Electrostatic doping by super-strong electric fields:
search for a switchable superconductivity and Mott state.
High power ultra-short optical pumping:
Evolution of cooperative electronic states, dynamical phase transitions, coherent oscillations, pattern formation, phenomenological modelling.