Syllabus for PHYS 230 Advanced Solid-State Physics [S 2023]

Optics of Quantum Materials

Description

A broad overview of optical phenomena in solid-state materials and nanostructures ranging from conventional metals, insulators, semiconductors, and superconductors to correlated electron systems, atomically thin crystals, and topological materials. Also considered are applications of modern near-field optics to probing optical constants and imaging surface collective modes. Nonlinear, ultrafast optics, and other topics may be covered if time permits. *Prerequisites*: Core physics graduate courses (CM, E&M, QM, Stats) plus a graduate-level condensed-matter class (Phys 211AB).

Outline

- **General properties**
  Macroscopic electrodynamics. Linear response functions: permittivity, permeability, conductivity. Frequency and momentum dispersion. Fundamental constraints: reciprocity, K-K relations, sum rules. Electromagnetic excitations in anisotropic media
- **Insulators**
  Drude-Lorentz model. Phonon-polaritons. Surface phonons
- **Metals**
  Kubo formula and RPA. Interband response. Bulk and surface plasmons, Landau damping. Plasmon-phonon coupling
- **Semiconductors**
  Direct and indirect gap semiconductors. Electron-hole interaction and exciton effects. Nanostructures: energy bands, direct and indirect excitons.
- **Strong electron-phonon interactions**
  Optical response of polarons. Charge density-wave materials
- **BCS superconductors**
  Energy gap and superfluid stiffness. Optical response of dirty and clean SC
- **Correlated electron systems**
  Phenomenological models (extended Drude, memory function). High-Tc superconductors. Correlated oxides
- **2D, layered, and Dirac materials**
  Graphene: optical response and plasmons. hBN: hyperbolic polaritons. TMD: excitons. vdW heterostructures: hybrid collective modes, superlattice effects. Topological insulators, Dirac, and Weyl semimetals
- **Near-field optics**
  Diffraction by small apertures. Scattering by a dipole near an interface. Aperture-type and scattering-type microscopy. Polaritons as a spectroscopic tool
- **Inhomogeneous media**
  Impurity spectra. Effective medium theory. Metamaterials and photonic crystals
- **Nonlinear optics**
  Nonlinear susceptibility. Sum and difference frequency generation, SHG. Four-wave mixing. Raman scattering, its frequency and polarization dependence
- **Ultrafast optical spectroscopy (time permitting)**

- **Magneto-optics (time permitting)**

Books and textbooks

- L. D. Landau, L. P. Pitaevskii, and E. M. Lifshitz, Electrodynamics of continuous media (1984)
- M. Dressel and G. Grüner, Electrodynamics of solids (2002)
- D. B. Tanner, Optical effects in solids (2019)
- M. Fox, Optical properties of solids (2011)
- F. Wooten, Optical properties of solids (1972)
- D. van der Marel and T. Giamarchi, Introduction to Correlated Matter (2019)
- D. Pines and P. Nozieres, Theory of quantum liquids (1989)
- G. D. Mahan, Many-particle physics (2000)
- V. M. Agranovich and D. L. Mills (eds) Surface polaritons (1982)
- L. Novotny and B. Hecht, Principles of nano-optics (2006)
- E.L. Ivchenko and G.E. Pikus, Superlattices and other heterostructures. Symmetry and optical phenomena (Springer, 2012)
- R. W. Boyd, Nonlinear optics (2008)

Review articles

- F. Gervais, Optical conductivity of oxides, Mat. Sci. Eng. Rep. 39, 29-92 (2002)
- J. Millis, Optical conductivity and correlated electron physics, In: D. Baeriswyl, L. Degiorgi (eds) Strong interactions in low dimensions, pp. 195-235 (2004)
- D. N. Basov and T. Timusk, Electrodynamics of high-Tc superconductors, Rev. Mod. Phys. 77, 721-779 (2005)
- Electrodynamics of correlated electron materials, Rev. Mod. Phys. 83, 471-541 (2011)
- D. N. Basov et al., Colloquium: Graphene spectroscopy, Rev. Mod. Phys. 86, 959-994 (2014)
- D. N. Basov, M. M. Fogler, F. J. García de Abajo, Polaritons in van der Waals materials, Science, 354, aag1992-1 (2016)
- G. Wang et al., Colloquium: Excitons in atomically thin transition metal dichalcogenides, Rev. Mod. Phys. 90, 021001 (2018)
- N.P. Armitage et al., Weyl and Dirac semimetals in three-dimensional solids, Rev. Mod. Phys. 90, 015001 (2018)

Schedule

- Lectures: MW 2:00p-3:20p MHA 2702
- DI: M 4:00-4:50p, MHA 2702 (as needed)

Grading

- In-class presentation (80%) + homework (20%).
- Homework: typically, weekly reading assignments

Instructor information

Prof. Michael Fogler, mfogler@ucsd.edu, Office hours: MW 3:20p-4:00p, Mayer Hall 5406

Dealing with stress and life issues

Throughout your time at UC San Diego, you may experience a range of issues that can negatively impact your learning. These may include illness, housing or food insecurity, depression, anxiety, high levels of stress, alcohol and drug problems, interpersonal or sexual violence, and grief. These issues may lead to diminished academic performance and affect your ability to participate in day-to-day activities. If there are issues related to coursework that are a source of particular stress or challenge, please speak with me. Other UCSD-provided resources include the following:

- **Counseling and Psychological Services** (858-534-3755 | caps.ucsd.edu)
- **Student Health Services** (858-534-3300 | studenthealth.ucsd.edu)
- **CARE at the Sexual Assault Resource Center** (858-534-5793 | care.ucsd.edu)
- **The Hub Basic Needs Center** (858-246-2632 | basicneeds.ucsd.edu)

Subject to Change

Some elements of this syllabus may be subject to change depending on the public health situation, labor disputes, and any other circumstances of this kind. The changes may concern curriculum, schedule, and in-person vs. remote modality.