Nanoelectronics

Lecturers: Sorin Paraoanu, Alexander Zyuzin, Manohar Kumar and

TAs: Swaminathan Koushik, Varma Sangani, Pereira Elizabeth

Department of Applied Physics, School of Science,

Aalto University, P.O. Box 15100, FI-00076 AALTO, Finland

I. COURSE STRUCTURE

- **WEEK 1**

  Lecture 1: Survival kit Lecturer: Sorin Paraoanu

  Review of key concepts from solid-state physics and quantum mechanics used in this course (second quantization, density of states, etc.) Overview of the systems studied in mesoscopic physics and nanoelectronics.

  Exercise set 1.1: Survival kit TA: Swaminathan Koushik

- **WEEK 2**

  Lecture 2: Semiclassical transport theory Lecturer: Manohar Kumar

  Boltzmann equation. Ballistic and diffusive transport.

  Exercise set 1.2: Survival kit TA: Swaminathan Koushik

- **WEEK 3**

  Lecture 3: Quantum transport Lecturer: Manohar Kumar

  Single electron tunneling, Coulomb blockade, Landauer formalism, electron interference.

  Exercise set 2: Semiclassical transport theory TA: Swaminathan Koushik

- **WEEK 4**

  Lecture 4: Electronic transport in magnetic fields Lecturer: Manohar Kumar

  Transport phenomena for 2D materials in magnetic fields: quantum Hall effect.

  Exercise set 3: Quantum transport TA: Varma Sangani

- **WEEK 5**

  Lecture 5: Low-dimensional materials Lecturer: Manohar Kumar

  Carbon nanotubes, graphene, and transition metal dichalcogenides: structure, properties and nanofabrication.

  Exercise set 4: Electronic transport in magnetic fields TA: Varma Sangani

- **WEEK 6**

  Lecture 6: Superconductivity Lecturer: Alexander Zyuzin

  Phenomenology and BCS description, Josephson effect, SQUIDs, SINIS coolers.

  Exercise set 5: Low-dimensional materials TA: Varma Sangani

- **WEEK 7**

  Lecture 7: Superconducting qubits Lecturer: Alexander Zyuzin

  Capacitive energy and Josephson energy. Lagrangian formalism and quantization of circuits.

  Exercise set 6: Superconductivity TA: Swaminathan Koushik

- **WEEK 8**

  Lecture 8: Noise and correlations. Lecturer: Alexander Zyuzin

  Basic concepts in statistics: momenta, cumulants, etc. Types of noise: thermal, shot noise. Buttiker formalism, Fano factor.

  Exercise set 7: Superconducting qubits TA: Elizabeth Pereira

- **WEEK 9**

  Lecture 9: Electromagnetic cavities and resonators Lecturer: Alexander Zyuzin

  Input-output theory, cavity response.

  Exercise set 8: Noise and correlations TA: Elizabeth Pereira

- **WEEK 10**

  Lecture 10: Quantum amplifiers. Lecturer: Alexander Zyuzin

  Parametric amplification. Phase-sensitive versus phase-insensitive amplifiers.

  Exercise set 9: Electromagnetic cavities and resonators TA: Elizabeth Pereira

- **WEEK 11**

  Lecture 12: Advanced topics in Quantum Transport Lecturer: Manohar Kumar

  Fractional quantum Hall effect, Quantum Anomalous Hall effect

  Exercise set 10: Quantum amplifiers TA: Elizabeth Pereira

- **WEEK 12**

  Lecture 12: Advanced topics in Superconductivity Lecturer: Alexander Zyuzin

  Topological insulators and Majorana fermions.

  Exercise set 11: Revision TA: Elizabeth Pereira, Swaminathan Koushik, and Varma Sangani

II. TEXTBOOKS

The primary textbooks are Ref. [1, 2, 5]. Note also that there is a Ref. [1] blog at http://thephysicsofnanoelectronics.info. You might want to consult as well [3, 4, 6]. There will be also additional reading materials for some lectures.

III. GRADING SYSTEM

The course has 5 credits. The final grade will reflect your activity in the exercise session (60%) and the results from the final exam (40%). The final exam is mandatory. The exercises are due before the exercise session of the week after the corresponding lecture (if your lecture is on Tuesday, then the exercises are due the following week on Wednesday right before the session). They will be collected and graded by your TAs.

---

[1] Tero T. Heikkilä, The physics of nanoelectronics, Oxford University Press (2013).

[2] Yuli. V. Nazarov and Yaroslav M. Blanter, Quantum Transport - Introduction to Nanoscience, Cambridge University Press, Cambridge (2009).

[3] Steven M. Girvin and K. Yang, Modern Condensed Matter Physics, Cambridge University Press (2019).

[4] A.M. Zagoskin, Quantum Engineering - Theory and Design of Quantum Coherent Structures, Cambridge University Press (2011).

[5] Thomas Ihn, Semiconductor Nanostructures - Quantum States and Electronic Transport, Oxford University Press, Oxford (2010).

[6] S. Datta, Electronic Transport in Mesoscopic Systems, Cambridge University Press (1995).