**Syllabus - EE 601**
**Semiconductor device physics.**
**Spring. TTh**
**A. F. J. Levi.**

**Outline and course content**
This is an advanced course in the operation and behavior of nanoscale semiconductor devices. The course is designed for graduate students with an interest in the fundamentals and limitations of our understanding of operation of electronic and photonic components used as the building blocks for more complex circuitry. The course will emphasize the actual calculation of useful parameters relevant to the design and operation of practical and research devices such as scaled transistors and scaled lasers.

Beyond the Moore's Law era, novel combinations of materials and heterogeneous components will likely evolve, changing the design paradigm and requiring knowledge and insight this course aims to provide. In addition to fundamental aspects of device physics, connection to typical SPICE model descriptions will be made and conditions when such models fail will be established.

The course also includes a project involving presentation in class of a selected research paper, analysis, critique, and suggest potential research directions that might emerge from the work described.

***Knowledge*** to the level of EE539 – is helpful, but not a prerequisite for this course. Recommended text books are "Applied Quantum Mechanics" by A.F.J. Levi, Cambridge University Press; 2 edition (June 26, 2006), ISBN-10: 0521860962, and "Optimal Device Design" edited by A.F.J. Levi and S. Haas, Cambridge University Press; (January 29, 2010), ISBN-10: 0521116600,

Some material covered by this course does not appear in any textbook.

**Course content:**

**Review Maxwell equations**. Charge conservation. Classical electromagnetism and numerical solution of Maxwell equations. Radiation and wave-guides.

**Review materials and atomic potentials**. Quantum mechanics. Band structure. Tight binding model. Impurities and doping. Effective electron mass.

**Introduction to electron transport**. Doping in semiconductors and $r_s^*$. The Boltzmann transport equation including conductivity and diffusion in the relaxation-time approximation.

Calculation of tunnel current in the absence of inelastic scattering. Limitations of semi-classical description of electron transport in semiconductors.

**What is a resistor?** Drude model of electron conduction. Nanoscale devices. Quantum conductance.

**What is an inductor?** Classical kinetic inductance. Quantum inductance.

**What is a capacitor?** Quantum capacitance.

**Resonant circuits with damping**. Q, frequency and temporal response. Quantum LCR resonant circuits. Nonlinear oscillators and paths to chaos. Classical description of dissipative processes. Approaches to quantum description of dissipative processes.

**What is a diode**? Applications of diodes in circuits. Mixer and sampler.

**The Field Effect Transistor**. Device modeling. Physical performance limitations. Tunnel-FET concept and lessons learned. CNT and graphene FET device design, performance metrics, and SPICE models.

**Introduction to Coulomb scattering**. Elastic scattering by non-randomly positioned ionized impurities in semiconductors. Estimating electron mobility in semiconductors.

**Lindhard dielectric function**. Application to metals and semiconductors. Single particle excitations and coupled plasmon – phonon collective excitations. Analysis of semiconductor dielectric function and use of MATLAB example code.

**Calculation of electron lifetime and device design**. Calculation of electron lifetime in unipolar transistors. Temperature dependence of non-equilibrium electron scattering rates. Non-equilibrium electron spectroscopy.

**Numerical determination of non-equilibrium electron scattering rates**. MATLAB code example. The truncated parabola of integration. Phase-space and its influence on scattering rate. Evaluation and interpretation of temperature dependence.

**Non-equilibrium electron transport in bipolar transistors**. **Theory.** Minority carriers in conduction band interacting with majority carriers in valence band. Collective and single-particle excitation spectral function in three-band model. Calculation of scattering rates. Parabola of integration. Phase-space and device scaling. Experimental proof that non-equilibrium electron transport dominates the static and dynamic performance of scaled HBTs.

**The semiconductor laser**. Influence of electron and photon quantization on static and dynamic behavior of scaled laser diodes and photon statistics. Failure of the non-equilibrium phase-transition description of laser light emission.

**Scaled semiconductor laser**. Meso-scale lasers. The single quantum dot laser. Cavity QED and non-classical light. MATLAB models of laser behavior.

**Presentation of research papers.** Class discussion and student presentation in class of selected research papers. Specifically, each participant is expected to describe the contents of a selected research paper, analyze the results, provide a critique, and suggest potential research directions that might emerge from the work described.

**Examinations:**
There are two written examinations, each of which will contribute 20% to the final grade. Presentation of a research paper contributes 50% of the final grade. The remaining 10% is for written solutions to written homework problems.

**Statement for Students with Disabilities**

Any student requesting academic accommodations based on a disability is required to register with Disability Services and Programs (DSP) each semester. A letter of verification for approved accommodations can be obtained from DSP. Please be sure the letter is delivered to me (or to TA) as early in the semester as possible. DSP is located in STU 301 and is open 8:30 a.m.–5:00 p.m., Monday through Friday. The phone number for DSP is (213) 740-0776.

**Statement on Academic Integrity**

USC seeks to maintain an optimal learning environment. General principles of academic honesty include the concept of respect for the intellectual property of others, the expectation that individual work will be submitted unless otherwise allowed by an instructor, and the obligations both to protect one's own academic work from misuse by others as well as to avoid using another's work as one's own. All students are expected to understand and abide by these principles. Scampus, the Student Guidebook, contains the Student Conduct Code in Section 11.00, while the recommended sanctions are located in Appendix A:
http://www.usc.edu/dept/publications/SCAMPUS/gov/. Students will be referred to the Office of Student Judicial Affairs and Community Standards for further review, should there be any suspicion of academic dishonesty. The Review process can be found at:
http://www.usc.edu/student-affairs/SJACS/.