Course title: Thin film nucleation and growth
Lecturers: Jens Birch, Joe Greene, Ivan Petrov, Kostas Sarakinos,
Period: Winter 2018
Study points: 5 ECTS
Examination method: Written examination (multiple choice with negative grading)
Start: December 2018 (detailed schedule to be announced)

Target group
The course addresses Ph.D. students engaged in both experimental and theoretical research related to thin films.

Objectives
• Understand the primary experimental variables and surface reaction paths controlling nucleation/growth kinetics and microstructural evolution during vapor-phase deposition.
• Develop an appreciation of the advantages/disadvantages of competing growth techniques.
• Learn how to better design film growth processes and control stress and microstructure evolution.

Description
Thin-film technology is pervasive in many applications, including microelectronics, optics, magnetics, hard and corrosion resistant coatings, micromechanics, etc. Progress in each of these areas depends upon the ability to selectively and controllably deposit thin films (thickness ranging from tens of angstroms to micrometers) with specified physical properties. This, in turn, requires control -- often at the atomic level -- of film microstructure and microchemistry.

Essential fundamental aspects, as well as the technology, of thin-film nucleation and growth from the vapor phase (evaporation, MBE, sputtering, and CVD) are discussed in detail and highlighted with "real" examples. The course begins with an introduction on substrate surfaces: structure, reconstruction, and adsorption/desorption kinetics. The effect of reduced dimension (i.e., nanoscale) on fundamental quantities and phenomena encountered during film growth are discussed. Nucleation processes are treated in detail using insights obtained from both in situ (RHEED, LEED, STM, AES, EELS, etc.) and post-deposition (XRD, TEM, and AFM) analyses. The primary growth modes include 2D (step flow, layer-by-layer, and 2D multilayer epitaxy), 3D, and Stranski-Krastanov (quantum dots and wires). The fundamental limits of epitaxy are discussed as well as the growth of new single-layer 2D crystals including silicene and MoS$_2$ and the growth of films on weakly-interacting substrates. Basic concepts of the physics of plasma, discharges, and ion/solid interactions will be introduced.

Experimental results and simulations are used to illustrate processes controlling 3D nucleation kinetics, island shape evolution, island coalescence, clustering, secondary nucleation, column formation, competitive column growth, preferred orientation, microstructure evolution, and film stress. The effects of low-energy ion-irradiation during deposition, as used in sputtering and plasma-CVD, will be discussed with examples. A detailed discussion of the origins, mechanisms, and control strategies, of intrinsic and extrinsic stresses in thin films is provided. The course concludes with a
presentation of a multitude of strategies for synthesizing self-organized thin film nanostructures.

**Course content and lecturers**
1. Surface structure and processes *(Joe Greene)*
2. Introduction to nanostructures *(Joe Greene)*
3. Thin film nucleation *(Joe Greene)*
4. 2D step flow growth and layer-by-layer epitaxial growth *(Jens Birch)*
5. Multilayer growth and formation of 3D islands *(Jens Birch)*
6. Heteroepitaxy and the role of strain *(Jens Birch)*
7. Island and film growth on weakly-interacting substrates *(Kostas Sarakinos)*
8. Polycrystalline film growth and microstructural evolution *(Kostas Sarakinos)*
9. Ion/solid interactions and basic plasma discharge physics *(Ivan Petrov)*
10. Control of film microstructure by low–energy ion bombardment *(Ivan Petrov)*
11. Stress generation and evolution in thin films *(Kostas Sarakinos)*
12. Self-organized nanostructure formation: mechanisms and examples *(Joe Greene)*