《Advanced Quantum Materials: Synthesis and Characterization Techniques》 Syllabus

Course Code: _____ Course Name: Advanced Quantum Materials: Synthesis and Characterization Techniques
Lecture Hours: 16
Laboratory Hours: 6
Colloquia Hours: 10
Individual Study Hours: 32
Credits: 2
Occurrence: Summer Course
Prerequisite(s): Solid State Physics*, Quantum Mechanics*, Materials Science*
*Recommended, not required as prerequisite

Course Description:

This course introduces the fundamental principles, key techniques, and recent advances in the synthesis and characterization of advanced quantum materials for senior undergraduate students. Major topics include electron-beam and ion-beam processing of solids, thin-film deposition methods, residual stress analysis, and structural, microstructural, and physical-property characterization. The course integrates frontier scientific topics with research-oriented learning and academic communication training.

Course Outcomes:

1. Describe the basic concepts, research scope, and scientific significance of advanced quantum materials.
2. Explain the physical mechanisms of electron-beam and ion-beam interactions with solids.
3. Identify major thin-film synthesis techniques, including PVD, CVD, ALD, and magnetron sputtering.
4. Analyze the effects of irradiation, stress evolution, and microstructural control in advanced materials.
5. Understand major characterization approaches for crystal structure, morphology, residual stress, and physical properties.
6. Explain the relationship among synthesis conditions, microstructure, and physical properties of quantum materials.
7. Read and discuss representative research literature in advanced quantum materials.
8. Present scientific topics in English through oral reports and group discussion.
9. Develop preliminary research awareness and interdisciplinary perspectives in materials synthesis and characterization.

Course Content, Laboratories and Colloquia Hours:

(1) Introduction to Advanced Quantum Materials (4 Class Hours)

Classroom 2 hours
Colloquia 2 hours
Topics: Overview of advanced quantum materials; superconducting, topological, low-dimensional, and functional materials; research frontiers and technological applications.

(2) Fundamentals of Electron-Beam Treatment of Solids (4 Class Hours)

Classroom 3 hours
Colloquia 1 hour

Topics: Thermal processes during electron-beam treatment; heat-affected zone; melting and evaporation; stress wave generation; capillary forces and Marangoni convection; origin of surface cratering.

(3) Fundamentals of Ion-Beam Treatment of Solids (4 Class Hours)

Classroom 3 hours

Colloquia 1 hour

Topics: Deceleration and scattering of ions into solids; ion ranges; ion distribution profiles; cascades of atomic collisions; ion implantation; solid-phase amorphization under irradiation.

(4) Residual Stresses in the Irradiated Solids (4 Class Hours)

Classroom 3 hours

Colloquia 1 hour

Topics: Origin of residual stresses in the irradiated materials; the modern approaches for evaluation of residual stresses by non-destructive methods.

(5) Thin Film Synthesis (4 Class Hours)

Classroom 3 hours

Colloquia 1 hour

Topics: Overview of PVD, CVD and ALD methods; fundamentals of the cathodic processes; magnetron sputtering; thin film growth and texture.

(6) Characterization Techniques for Advanced Quantum Materials (4 Class Hours)

Classroom 2 hours

Laboratory 2 hours

Topics: Structural characterization by X-ray diffraction; morphological and microstructural analysis; basic concepts of spectroscopic and electrical characterization.

(7) Hands-on Practice at the Quantum Physics Experiment Center (4 Class Hours)

Laboratory 4 hours

Topics: Hands-on practice at the Quantum Physics Experiment Center, including single-crystal growth, high-pressure synthesis, and observation of other characterization techniques.

(8) Research Literature Discussion and Student Presentation (4 Class Hours)

Colloquia 4 hours

Topics: Discussion of representative research papers; group presentation on synthesis and characterization of selected quantum materials; academic communication and critical analysis.

Grading:

Class Participation and In-class Discussion: 20%

Homework / Literature Reading Assignments: 25%

Group Presentation: 25%

Final Report: 30%

Text & Reference Book:

Kumar, C. S., Singh, M. M., and Krishna, R. Advanced Materials Characterization: Basic Principles, Novel Applications, and Future Directions. CRC Press, 2023. ISBN: 9781032375113.

Mwema, F. M., Jen, T.-C., and Zhu, M. Thin Film Coatings: Properties, Deposition, and Applications. CRC Press, 2021. ISBN: 9781032065113.

Das, S. (Ed.). 2D Materials for Electronics, Sensors and Devices: Synthesis, Characterization, Fabrication and Application. Elsevier, 2022. ISBN: 9780128215050.

Al-Douri, Y. (Ed.). Graphene, Nanotubes and Quantum Dots-Based Nanotechnology: Fundamentals and Applications. Elsevier, 2022. ISBN: 9780323854573.
Zhou, Y., and Mora-Seró, I. (Eds.). Halide Perovskite Semiconductors: Structures, Characterization, Properties, and Phenomena. Wiley-VCH, 2024. ISBN: 9783527348091.

Course Lecturer: Xiang Li

Course Lecturer (Signature):