Institute of Metallurgy and Materials Science

Polish Academy of Sciences

Project Nr POKL.04.01.00-00-004/10

Interdisciplinary PhD Studies in Materials Engineering

with English as the language of instruction

A Revised Programme of PhD Studies

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A few remarks on the Programme based on PhD students' opinions and discussions with Lecturers

After completing the first year of PhD studies entitled: **Interdisciplinary PhD Studies in Materials Engineering with English as the language of instruction**, the following suggestions have been made by the Leaders of the Project, lecturers and the PhD students. These suggestions and comments appeared to be very helpful in revising the programme. Especially, the contribution of PhD students to the revision the programme seemed to be particularly valuable in elaborating a series of lectures which should be most profitable for Final Beneficiaries.

The main revisions in the current programme are as follows:

Year 1:

1. Course **Introduction to materials science** will be shifted from Semester II to Semester I.
2. Seminar "**Seminars showing the progress of PhD thesis**" is replaced by the seminar **"How to write scientific papers and prepare PhD thesis"**

Year 2:

1. Course: **Transmission electron microscopy in materials science** will be shifted from Semester II to Semester I
2. Course of **Foreign language** will start in Semester II (30 hours)
3. There will be **Practical Sessions** dedicated to Scanning Electron Microscopy (5 hours), Transmission Electron Microscopy (5 hours) and X-ray Diffraction (5hours)

held in the laboratories under supervision of experienced staff.

Year 3:

1. Course: **Commercialization of scientific research** will be shortened to 10 hours (instead of 15 hours)
2. It is planned to add a course entitled: **Electrochemistry for materials science** in Semester I (10 hours)
3. It is planned to add a course entitled: **Renewable energy technologies** in Semester II (10 hours)

   The final topics and a short description will be given in due course when the final agreement will be reached with potential lecturer.

An additional condition is introduced to the Programme.

PhD procedure will be launched after completing Semester II of the Year 3 of the Studies at the latest. The procedure begins with the PhD seminar during which the student is obliged to presents a substantial progress of the PhD thesis.

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Introduction

The PhD programme is organized into four main areas, i.e.:

1. **Environmental-friendly materials and technologies**
   - Lead-free solders
   - Multicrystalline silicon solar cells
   - Biocompatibile coating in blood contacting materials
2. **Knowledge-based multifunctional materials**
   - Gradient materials produced using different methods
   - Light alloys of new generation with improved mechanical properties
   - Production and optimization of intermetallics properties
   - Bulk metallic glasses
3. **Nano- and microcrystalline materials**
   - Mechanical alloying and hot-pressing of intermetallics
   - Severe plastic deformation and fabrication of ultra-fine grain materials
4. **Development of modern research tools and diagnostic methods**
   - Crystallographic orientation mapping in respect to diagnosis and prognosis of mechanical properties of metallic, ceramic and composite materials based on the scanning and transmission electron microscopy examinations of local grain orientations
   - Data processing of local crystallographic orientations; orientation distribution function, orientation topography, quantitative description of microstructure
   - Complex characteristics of advanced materials using new transmission electron microscopy techniques.

The above fields are only roughly defined. Each member of the Institute scientific staff works in at least two of these fields and a number of subjects appear simultaneously on the lists of research subjects. There is a great deal of interaction between the fields.

Students are expected to learn fundamentals of their chosen field and to develop a deep understanding of one their significant aspects. Students are required to take further subjects designated by their academic advisor. A full range of advanced-level subjects is offered in each field, and arrangements can be made for individually planned study of any topic. Oral examinations in the academic programme for the doctoral degree are designed accordingly. Participation in all Institute seminars is obligatory.

Presently, a large research programme on the structure and properties, preparation, and processing of materials, with emphasis on ceramics, metals and biomaterials, is conducted in the Institute. Students choose research projects from several possibilities that exist within the Institute and work closely with its scientific supervisor. The results of the thesis must be of sufficient significance to warrant publication in the scientific periodicals.

The Institute of Metallurgy and Materials Science has a number of well-equipped research laboratories. There is a close interaction between them including the sharing of experimental facilities and equipment. Most of experimental facilities are extensively used in the frame of Testing Laboratories authorized by Polish Centre for Testing and Certification in accordance with ISO standards. The certificate of conformance with Polish and European standards PN-ISO/IEC 17025:2001 for testing methods in the range of mechanical and structural properties of metals and alloys is valid till the next audit in 2012.

Year 1

Semester I

Course: **Introduction to materials science**

(15 hours, exam)

Course summary

The Course includes an introduction to materials science and engineering focused on science-led approach however it gives little emphasis to design-led. Guiding learning on materials and their structure and properties, crystallography, phase diagrams and phase transformations, processing, diagnostics and application is given. Some information are presented on fundamentals and understanding, control of properties at a different scale as well as materials selection and design. The Course is divided into parts comprising: a basing knowledge, possible application and diagnostics together with examples of chosen experimental results. The Course is dedicated to students motivating their understanding of the nature of modern material design and developing skills.

Course description

1. **Engineering materials**
2. **Atomic bonding and crystallography**
3. **Mechanical properties**
4. **Crystal defects of crystalline structure**
5. **Phase diagrams**
6. **Structure changes**
7. **Metals and alloys**
8. **Ceramic materials and glasses**

9. **Polymers**
10. **Composites**
11. **Intermetallics**
12. **Amorphous and nanocrystalline materials**
13. **Porous materials**
14. **Smart materials**
15. **Biomaterials**
16. **Processing of metals, ceramics, polymers, composites**
17. **Surface engineering**
18. **Nanomaterials and nanotechnologies**
19. **Basis for materials design**

Course is based on the following literature:

- M.Ashby: Materials; engineering, science, processing and design, Elsevier 2010
- R.Pampuch: ABC of Contemporary Ceramic Materials, Techna Group, 2008
- M.Blicharski: Wstęp do inżynierii materiałowej, Wyd. Nauk.-Techn. 2003
- L.A.Dobrzański: Metalowe materiały inżynierskie, Wyd. Nauk.-Techn., 2004
- Mazurkiewicz: Nanonauki i Nanotechnologie, Wyd.Inst.Technol.Ekspl., Radom 2007

Seminars how to write scientific papers and prepare PhD thesis

(15 hours, credit)

Seminar summary

The seminar is aimed at discussing different ways of presentation of results of investigations to scientific community. The discussion of final, partial or even preliminary results with other specialists in the field is one of most important thing in reaching the right solution of the analyzed problem. Presently, scientists may communicate through different channels, like seminars, conferences, international congresses, aside from writing papers to scientific journals. There are well defined rules which such communications should fulfill, i.e. they should be divided to parts which enable easier understanding of their content. Additionally, each part should include strictly pre-defined information. However, all these possibilities require significantly or at least slightly different approach. The presentation of results should be clear and as short as possible but simultaneously properly backed with experimental data. The overview of the field justifying both the start of experiment and publishing its results is one of most important thing. The discussion of results needs its verification in papers listed in overview. All this should be well balanced to make a good paper. The specified above concept of sharing results was elaborated to help to understand each other results. Of course, these rules might be changed in some special case, but such situation should be well documented and explained. Therefore, the present seminar will explain the most important points which should be considered, while writing abstracts, extended abstracts, short communications, and full length papers. Finally, the proper arrangement of Ph. D thesis, i.e. presentation based on only most important results form a study including a four of five years will be proposed.

Seminars with Supervisors

(15 hours, credit)

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Semester II

Course: **Configurational Thermodynamics – an engineering approach**

(15 hours, exam)

Course description

1. **Foundations of statistical thermodynamics.**
2. **Description of atomic configuration in a multicomponent crystalline system: atomic short- and long-range ordering (LRO and SRO), decomposition.**
3. **Ising model in configurational thermodynamics. Characteristics of necessary approximations.**
4. **Cluster Variation Method (CVM).**
5. **Bragg-Williams method as the "zeroth" CVM approximation.**
6. **Basic conditions controlling the occurrence of atomic ordering and decomposition processes.**
7. **Chemical ordering: characteristics of "order-disorder" transitions**
8. **Decomposition: lever rule, miscibility gap, kinetics of spinodal decomposition.**
9. **Monte Carlo techniques in configurational thermodynamics: simulation of Markov chains as a key for the simulation of equilibrium states and relaxation phenomena.**
10. **Metropolis-type and "residence time" algorithms for atomic ordering simulation.**
11. **Monte Carlo simulation of phase equilibria**

Questions concerning phase equilibria and structural phase transitions in multicomponent crystalline systems are discussed. The Course covers both static and kinetic aspects of the phenomena.

Course is based on the following literature:

- R.H. Fowler, E.A. Guggenheim "Statistical Thermodynamics" Cambridge 1956
- R.E. Smallman "Modern Physical Metallurgy" Butterworths 1985
- D. de Fontaine, Solid State Physics, Vol. 34, 73, (1979)
- R. Kozubski, "Metody Monte Carlo w badaniach przemian strukturalnych w stopach i związkach międzymetalicznych w skali atomowej", *Inżynieria Materiałowa* Nr 2, 108-117, (2009).

Seminars how to write scientific papers and prepare PhD thesis

(15 hours, credit)

Seminars with Supervisors

(15 hours, credit)

Total: 90 hours (45 hours in Semester I, 45 hours in Semester II)

Year 2

Semester I

Course: **Advanced scanning electron microscopy in materials science**

(10 hours, exam)

Course description

1. **Electron Beam –Specimen Interaction (part I)**

scope: Elastic and inelastic scattering, interaction volume, Monte Carlo simulation, electron range.

2. **Electron Beam Specimen Interaction (part II)**

scope: Imaging signals from interaction volume (backscatter electrons, secondary electrons).

3. **Scanning Electron Microscope (part I)**

scope: Introductory remarks about spatial resolution and depth of field (focus), electron probe diameter versus electron current, how the SEM works, electron guns and their characteristics.

4. **Scanning Electron Microscope (part II)**

scope: Electron optics, lenses and their aberrations, electron detectors, the role of specimen and detectors in contrast formation.

5. **Energy Dispersive Spectrometry**

scope: Generation of X-Rays production, continuum X-Ray production (Brehmsstrahlung), characteristic X-Ray production, depth of X-Ray production, X-Ray absorption, X-Ray Fluorescence, Energy dispersive X-ray Spectrometer - operating principles, detection process, artefacts.

6. **Wavelength Dispersive Spectrometry**

scope: Introduction, basic principles, diffraction conditions, diffraction crystals, X-ray proportional counter, comparison of Wavelength Dispersive Spectrometers with Conventional Energy Dispersive Spectrometers.

7. **Quantitative X-ray Microanalysis**

scope: Introduction, Quantitative analysis procedures, the approach to X-Ray Quantification: the need of matrix correction, the physical origin of matrix effects, ZAF factors in Microanalysis, calculation of ZAF factors, practical aspects.

8. **Variable Pressure/Environmental Scanning Electron Microscopy**

scope: General principles of VP-SEM: utilizing a gas, imaging and analysis in VP-SEM: the influence of a gas, imaging uncoated specimens in the VP-SEM, X-Ray microanalysis in low vacuum conditions.

9. **Electron Backscatter Diffraction (part I)**

scope: Theoretical framework for electron backscatter diffraction, fundamentals of automated EBSD, the influence of microstructure and SEM settings on quality of diffraction pattern, phase identification.

10. **Electron Backscatter Diffraction (part II)**

scope: Advanced software capabilities for automated EBSD, EBSD from non-conductive specimens, special EBSD techniques: 3 dimensional EBSD, EBSD at elevated temperatures.

Course is based on the following literature:

- Scanning Electron Microscopy and X-Ray Microanalysis (Third Edition), Joseph Goldstein, Dale Newbury, David Joy, Charles Lyman, Patrick Echlin, Eric Lifshin, Linda Sawyer and Joseph Michael, Kluwer Academics/Plenum Publishers, 2003

- Electron Microscopy and Analysis, (Third Edition), Peter Goodhew, John Humphries, Richard Beanland, Taylor & Francis, London, 2001
- Electron Microprobe Analysis, (Second Edition), S.J.B. Reed, Cambridge University Press, 1993
- Electron Probe Quantification, K.F.J. Heinrich and D.E. Newbury, Plenum Press, New York, 1991
- Principles and Practice of Variable Pressure/Environmental Scanning Electron Microscopy, Debbie Stokes, John Wiley &Sons, 2008

Course: **Transmission electron microscopy in materials science**

(10 hours, exam)

Course summary

The course is divided to several parts, i.e. classical transmission electron microscopy (TEM) techniques, advanced techniques including high resolution and energy filtering, sample preparation. The course will be finish with examples of application of TEM method to advanced materials characterization.

The classical transmission microscopy will cover diffraction and mass-thickness contrast problems. The description of diffraction techniques would include setting microscope for obtaining Selected Area (SA) diffraction, micro-diffraction and Convergent Beam Electron Diffraction (CBED). Next, formation of high resolution images at two beam condition and on axis orientation will be discussed. The part of analytical microscopy will concentrate on EDS systems, i.e. interaction of electron beam with a thin foil, proper condition to acquire EDS spectra, its qualitative and quantitative processing as well as possible artifact. The separate time will be assign to energy filtering techniques including and Gatan Image Filtering (GIF). The analytical part will be finished with presentation concerning some special application from that field like Atom Location by Channeling Enhanced Microanalysis (ALCHEMI).

The examples of problem solving with TEM will cover nano-composite CrN/Si_3N_4 coatings, multilayers of Ni/Al, Ni/Cu and Fr/Cr type as well as bulk Alxxxx/Saffil fibers nano-composites. They all were chosen to show a proper way, how to plan such experiments starting from sample preparation stage and finishing on choosing a proper TEM technique.

Course is based on the following literature:

- R. D. Heidenreich, Fundamentals of Transmission Electron Microscopy
- J.W. Edington, Practical Electron Microscopy in Materials Science
- D. B. Williams and C. B. Carter, Transmission Electron Microscopy
- D.B. Williams, Practical Analytical Electron Microscopy in Materials Science
- G. Thomas, Transmission Electron Microscopy of Metals
- J.H. Spence, J.M. Zuo, Electron Microdiffraction
- I.P. Jones, Chemical Microanalysis Using Electron Beams

Course: **Fundamentals of solidification**

(10 hours, exam)

Course description

1. **Fundamentals of solidification**

Description of typical structures appeared in the massive ingot.

Structure formation under positive and negative thermal gradients.

Space-time-structure map for the massive steel/cast iron roll as it results from the temperature field analysis.

Columnar → equiaxed structure transition (CET) due to the thermal gradient field calculated numerically for the solidification of massive ingot.

Scheil's theory for the non-diffusive non-equilibrium solidification/micro-segregation.

Equilibrium solidification as it results from the mass balance (so-called Lever Rule).

New theory for solidification based on two phenomena: solute partitioning and solute redistribution after back-diffusion.

Perfect mathematical reduction of the new theory to the Scheil's model and to the equilibrium solidification.

Development of the Scheil's theory for the multi-peritectic systems and multi-peritectic / eutectic systems.

Principle of unidirectional solidification – the Bridgman's system

2. **Theory of diffusion soldering/brazing**

Description of phenomena which occur during soldering/brazing like: dissolution, solidification, solid/solid transformation.

Diffusion zones within the substrate.

Application of the Umeda-Okane-Kurz criterion to justify the occurrence of technology under meta-stable conditions.

Application of the new theory for solidification based on partitioning and solute redistribution after back-diffusion and accompanied by the undercooled peritectic reactions.

Development of the new theory for the multi-peritectic systems and multi-peritectic/eutectic systems.

Calculations of the phase diagrams for the meta-stable equilibrium (Thermocalc Softaware): a/ for dissolution, b/ for solidification accompanied by the peritectic reactions resulting in the intermetallic phases/compounds formation.

Experimental justification for the non-influence of time and non-influence of real temperature on the average solute concentration within the interconnection.

Determination of the solidification path, solid/liquid interface path and solute redistribution path for the diffusion soldering/brazing.

Simulation of the diffusion joint formation (reproduction of a ratio of the sub-layers thicknesses and the solute concentration profiles across the given joint sub-layers).

Mass balance within the diffusion interconnection.

3. **Model for the solute micro-field ahead of the solid/liquid interface of a growing lamellar eutectic**

Improvement of the Jackson-Hunt's theory for the lamellar eutectic growth.

Replacement of the ideally coupled growth by the coupled growth with differentiated undercooling of both eutectic phases.

New solution to differential diffusion equation.

New boundary condition for the solution to diffusion equation.

Localization of mechanical equilibrium, thermodynamic equilibrium and protrusion of the leading eutectic phase over the wetting eutectic phase.

Application of the calculation of the entropy production due to the new description of the solid/liquid interface.

Total mass balance and local mass balance.

The relationship between growth rate and protrusion.

4. **Theory for the lamella →rod transformation in some eutectic alloys**

Critical discussion of the Jackson-Hunt's theory for the prediction of the lamellar or rod-like structure formation within the eutectic alloys.

Model for the irregular eutectic structure formation based on both a/ criterion of the entropy production minimum and b/ concept of the marginal stability.

Transformation irregular→regular eutectic structure shown on the paraboloid of entropy production on which trajectory of local minima of entropy production for stationary states and trajectory of marginal stability are drawn schematically.

Oscillation of the structure parameters.

Growth laws for the lamellar structure formation and for the rod-like structure formation of regular eutectics developed due to the application of the criterion of the minimum entropy production.

Experimental determination the threshold rate and operating range of growth rates for the lamella → rod transformation of the Al-Si eutectic.

Simulation of the lamella → rod transformation by the selection of lower minimum of entropy production (minimum at which rod-like structure formation occurs or minimum of entropy production at which lamellar structure formation is observed).

Course is based on the following literature:

- W. Kurz, J.D. Fisher, Fundamentals of Solidification, Trans Tech Publications – book
- Prigogine, Introduction a la Thermodynamique des Processus Irreversible – book
- W. Wołczyński, Lectures via Internet: MEtallurgical TRaining Online (METRO)
    - Mass transport at the solid/liquid interface of growing composite *in situ*
    - Transformation: lamella – rod within oriented eutectic Al-Si
    - Solidification / microsegregation model applied to description of diffusion soldering / brazing
- G. Lesoult, M. Turpin, Etude Theorique sur la Croissance des Eutectiques Lamellaires, *Revue Scientifique de la Revue de Metallurgie,* Vol. 66, (1969). pp. 619-631
- E. Scheil, Über die Eutektische Kristallisation, *Zeitschrift für Metallkunde*, Vol. 34, (1942), pp. 70-80

- W. Wołczyński, Thermodynamics of Irregular Eutectic Growth, *Materials Science Forum*, Vol. 215/216, (1996), pp. 303-312
- W. Wołczyński, Back-Diffusion Phenomenon during the Crystal Growth by the Bridgman Method, In: *Modelling of Transport Phenomena in Crystal Growth,* J.S. Szmyd & K. Suzuki, (Ed.), pp. 19-59, WIT *PRESS* ISBN: 1-85312-735-3, Ashurst Lodge, Southampton, UK - Boston, USA (2000)
- W. Wołczyński, Concentration Micro-Field for Lamellar Eutectic Growth, *Defect and Diffusion Forum*, Vol. 272, (2007), pp. 123-138
- W. Wołczyński, Lamella / Rod Transformation as described by the Criterion of the Minimum Entropy Production, *International Journal of Thermodynamics*, Vol. 13, (2010), pp. 35-42

Seminars showing the progress of PhD thesis

(10 hours, credit)

Semester II

Course: **Characterization of materials structure by X-ray diffraction techniques**

(10 hours, exam)

Course description

1. Nature and sources of the X-rays

Natural sources, inducing, X-ray tubes, synchrotrons, characteristic and fluorescent radiation, absorption

effect.

2. Diffraction phenomenon of X-ray. Part I

Diffraction phenomenon and related physical/geometrical laws, diffraction on crystal lattices. Laue equations, intensity of diffracted beam, theories of diffraction, Bormann effect, polarization.

3. Diffraction phenomenon of X-ray. Part II

Elementary cells of crystallographic lattice, crystallographic indexing, reciprocal lattice and interpretation of diffraction effects, detection techniques, position-sensitive detection technique, Si-strip detector.

4. Crystallography and diffraction

Symmetry in the nature, Basic definitions in applied crystallography, stereographic projection, pole figures.

5. Crystallographic texture. Part I

Crystallographic orientation, texture components, texture analysis, orientation distribution function and its interpretation.

6. Crystallographic texture. Part II

Modern quantitative texture analysis, calculation of orientation distribution function, demonstration of the *LaboTex* software, examples and practical remarks.

7. Texture analysis of polycrystalline materials and X-Ray Texture Tomography

Metals, polymers, rocks, bio-materials, fatigue wear, effects of changing deformation router, investigations of metals after severe plastic deformation, EBSD, topography of texture. Texture inhomogeneity, X-Ray Texture Tomography – principles and application.

8. Using X-ray diffraction in materials engineering

Methods of registration the diffraction effects (modes: $\theta-2\theta$, $\omega-2\theta$, ω, 2θ), WAS, SAXS, phase transformation monitored by high/low temperature attachments, high-resolution x-ray diffractometry, perfectness of crystal, *Laue- and Debye'a-Scherr* patterns, indexing the X-ray pattern.

9. X-ray phase analysis

Line profile analysis (programme *DAMfit*), identification of superstructure, X-ray phase analysis (qualitative and quantitative), texture in X-ray quantitative analysis, structure refinement by Rietveld method.

10. Other useful methods and the newest achievements in the field of X-ray diffraction

Estimation of stacking fault energy by X-ray diffraction technique, stress analysis, size of crystallites and lattice distortions, future of X-ray diffraction: free electron laser and high-energy photon beams.

11. Demonstration of the X-ray Laboratory and a final colloquium

Demonstration of measurement procedures, data acquisition and data processing. Examples.

Course is based on the following literature:

- Bojarski, Z., Łągiewka, E.(1988). Rentgenowska analiza strukturalna, PWN, Warszawa.
- Bonarski, J.(2001). Rentgenowska Tomografia Teksturowa, IMIM PAN, Kraków.
- Bunge, H.J.(1982). Texture Analysis in Materials Science. Mathematical Methods. Butterworths Publ. London.
- James, R.W.(1954). The Optical Principles of the Diffraction of X-Rays. London: Bell and Sons Ltd.
- Cullity, B.D.(1978). Elements of X-Ray Diffraction. 2nd Ed., AddisonWaseley Publ.Comp.Inc., London, Amsterdam, Don Mills, Sydney, Podstawy dyfrakcji promieni rentgenowskich. tłum z j. ang., PWN (1964), Warszawa.
- LaboTex.(2000). The Texture Analysis Software.by LaboSoft s.c.
- Luger, P.(1989). Rentgenografia strukturalna monokryształów. PWN Warszawa, tłum. Z ang. Ed. by Walter de Gruyter, Berlin - New York,Modern X-Ray Analysis on Single Crystals
- Przedmojski, J.(1990). Rentgenowskie metody badawcze w inżynierii materiałowej, WNT. Warszawa.
- Sonin, A.S.(1982). O krystalografii, PWN, Warszawa.

Course: **Advanced materials for special applications**

(15 hours, exam)

Course description

1. **Historical view of constructional materials and summary of carbon steels and alloyed steels**
2. **Light alloys and new aluminum and magnesium alloys**
3. **Metallic and ceramic biomaterials**
4. **New titanium alloys for construction and biomaterials including shape memory applications**
5. **Nanomaterials including methods of grain refinement, characterization and application**
6. **Composites, production, properties, structure and applications**
7. **Amorphous materials, manufacturing, characterization, properties and application using unique mechanical and magnetic properties**
8. **Ceramic materials for high temperature use and ultra hard with good wear properties, new materials with high toughness, manufacturing, structure and properties**

Course is based on the following literature:

- Marek Blicharski „Inżynieria Materiałowa” wyd. PWN Warszawa 2002
- A.R. Olszyna „Ceramika supertwarda” Oficyna wyd. Politechniki Warszawskiej, Warszawa 2001
- M. Ashby, D.R. Jones, „Materiały inżynierskie” Wydawnictwo naukowo techniczne, Warszawa 1996

- D.G. Morris "Mechannical Behaviour of nanostructured Materials" Trans Tech Publication Zuerich 2001.
- A.Inoue, "Bulk Amorphous Alloys", Trans Tech Publications, Zuerich, 1999
- H. Buhl, "Advanced Aerospace Materials", Springer Verlag, Berlin, 1992
- H. Morawiec, Z. Lexton, "Materiały z pamięcią kształtu do zastosowań biomedycznych" Wyd. Politechniki Śląskiej 2011
- J. Polmear, „Light Alloys" Amsterdam 2006

Foreign language

(30 hours, credit)

Practical sessions dedicated to:

- **Scanning Electron Microscopy** (5 hours),
- **Transmission Electron Microscopy** (5 hours)
- **X-ray Diffraction** (5 hours)

Seminars showing the progress of PhD thesis

(10 hours, credit)

Total: 120 h (40 hours in Semester I, 80 hours in Semester II)

Year 3

Semester I

Course: **Chemical and kinetic characterization of diffusional phase transformations**

(10 hours, exam)

Course description

1. **Fundamentals of diffusion processes in metals and alloys**
2. **Principles of high resolution chemical analysis on analytical electron microscopy (activated volume of X-ray signal; spatial resolution; relation between specimen geometry, incident electron beam and location of EDX detector in microanalysis of lamellar structures; detectability limit, signal convolution)**
3. **Fundamentals of interface migration during solid-state discontinuous reactions (principles of nucleation and growth of discontinuous precipitation, coarsening, dissolution, ordering, diffusion induced grain boundary migration)**
4. **Characterization of the kinetics of dif-fusion process at migrating interface of dis-continuous precipitates (global characterization, local characterization via AEM, determination of grain boundary diffusivity)**
5. **Determination of interdiffusion coefficient (diffusion couple, precipitation of grain boundary allotriomorphs, diffusion soldering)**
6. **Determination of growth mechanism during phase transformation (solute partitioning in intragranular ferrite, bainitic transformation in CuZnAl alloys)**

Course is based on the following literature:

- Zięba P.: Recent Progress in the Energy Dispersive X-ray Spectroscopy Microanalysis of the Discontinuous Precipitation and Discontinuous Dissolution Reactions, Materials Chemistry and Physics 62, (2000) 183-213
- P. Zieba, Local Characterization of the Chemistry and Kinetics in Discontinuous Solid State Reactions, Cracow 2001

Course: **Electrochemistry for materials science**

(10 hours, exam)

Course summary

Electrochemical processes find a wide variety of applications for the surface treatment. They include cathodic and anodic processes e.g. electroplating, anodization, electropolishing etc. Especially, in the last decade, electrodeposition technology is becoming increasingly important. It is suitable for manufacturing of functional and decorative coatings. Metals, alloys and metal matrix composites are deposited for the fabrication of single films or multilayer coatings with enhanced properties. For an understanding of the technical and practical demands of electroplating technology the theoretical knowledge of the phenomena occurring in electrolyte solutions and at the interface cathode / electrolyte is necessary. Lectures concern of these problems, however they refer only to aqueous solutions. The course is presented in a logical and practical order.

Course description

1. **Properties of aqueous solution of electrolytes**

1.1. Electrolytic dissociation, weak and strong electrolytes, hydrolysis

1.2. True and potential electrolytes

1.3. Ion-water interaction, ion-ion interaction and distribution of ions in solution

1.4. Ionic activity, mean activity of an electrolyte in solution

1.5. Activity coefficient of strong electrolytes in dependence on ionic strength

2. Electrical conductivity of electrolyte solutions

2.1. Electrolytic conductivity, molar and equivalent conductance

2.2. Specific electrical resistance

2.3. Electrolytic conductivity measurement

2.4. Determination of ionic dissociation equilibrium constant in weak electrolyte solutions

2.5. Ostwald´s dilution law, dissociation field effect

2.6. Conductometric titration

3. Equilibrium electrode potential

3.1. Metal-solution interphase

3.2.Electrochemical equilibrium in half-cells and cells

3.3.Cell voltage and electrode potentials

3.4. Measurement of electromotive force (EMF) of cell

3.5. The Nernst equation

3.6. Measurement of equilibrium electrode potentials

3.7. Electrodes of second kind

3.8. Reference electrodes (hydrogen, calomel, silver-silver chloride)

3.9. Standard electrode potentials

3.10. Determination of pH, potentiometric titration, buffers

4. Electrolysis

4.1. Overpotential, decomposition voltage, discharge potential

4.2. Transfer rate of charge carriers across double layer

4.3. Mass transport in electrode processes

4.4. The Faraday laws, current efficiency

4.5. Ion migration in electric field, transference number measurement

4.6. Electrodeposition of metals, alloys and metal matrix composites

5. Electrochemical cells as electric energy sources

5.1. Batteries

5.2. Fuel cells

Course is based on the following literature:

- M. Bełtowska-Brzezinska, Wprowadzenie do elektrochemii, UAM, Poznań 2009 (www.wbc.poznan.pl)
- P.W. Atkins, Physical Chemistry, Oxford University Press, Oxford 1998.
- M. Paunovic, M. Schlesinger, Fundamentals of electrochemical deposition, A Wiley-Interscience Publication, New York, Toronto, 1998.
- Kisza, Elektrochemia I, Jonika, Wydawnictwo Naukowo-Techniczne, Warszawa 2000.
- Kisza, Elektrochemia II, Elektrodyka, Wydawnictwo Naukowo-Techniczne, Warszawa 2001.
- Budniok, E. Łągiewka, Problemy elektrochemii w inżynierii materiałowej, Wydawnictwo Uniwersytetu Śląskiego, Katowice 2009.

Course: **Selected problems of microstructure and texture transformations in deformed metals**

(10 hours, exam)

Course summary

A series of Courses briefly recalls the basic description, definitions and elementary constitutive laws used to describe plastic deformation. Then it covers a description of work hardening at relatively low temperatures (where thermally activated processes do not play a key role) followed by the analysis of some important features of plastic deformation significant for large strains (Course 1 & 2).

Softening processes (recovery, recrystallization and grain growth) and associated microstructural changes will be discussed based on driving force and involved mechanisms. This part provides an overview of several essential parameters including: stored energy of deformation, surface energy and the movement of high-angle boundaries (Course 3).

Course 4 will be dedicated to the description and interpretation of crystallographic textures. After an introduction to the 'world' of graphical representation of texture data, a short survey of the most important cold deformation and recrystallization textures will be presented.

Course 5 will be dedicated to techniques of local orientation measurements based on TEM and SEM techniques. The influence of band like strain inhomogeneities of deformation, their crystallographic nature and role in texture transformation in fcc metals will be thoroughly discussed.

Course description

1. **Plasticity and work hardening**
2. **Instability of isotropic/anisotropic materials in tensile test and under biaxial stresses**

3. **Softening mechanism: recovery, recrystallization and grain growth**
4. **Textural developments during thermo-mechanical processing. Deformation vs. recrystallization textures**
5. **TEM and SEM methods of experimental investigations of texture changes in fcc metals after different deformation modes**

Foreign language

(30 hours, credit)

Seminars with Supervisors

(10 hours, credit)

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Seminars showing the progress of PhD thesis

(15 hours, credit)

Semester II

Course: **Novel technologies in surface engineering**

(15 hours, exam)

Course summary

Multicomponent, nanostructured and functionally graded coatings or thin films may exhibit unique physical, mechanical, chemical properties ensuring remarkable degradation resistance where the surface protection of materials against wear, corrosion, friction is a key issue. A broad overview on modern coating and thin-film deposition technique is presented. The major aim of these Courses is to show and discuss various problems of physics and chemistry involved in the production, characterization and applications of coatings and thin films, which can be variously hard and wear resistant. Attention is paid at the bio-medical coating for tissue contacting materials. A balance is found between fundamentals aspects and experimental results illustrating various models, mechanisms and theories. New trends and new results are also evoked to have an overlook about future developments and applications.

Course description

1. **Scope of „surface engineering"**
2. **Modern methods of fabrication of technological surface layers**
3. **Pressure units**

   Vacuum
4. **Mechanical methods of surface modification**
5. **Chemical methods of surface modification CVD (chemical vapour deposition)**
6. **Solidification from the gaseous phase**
7. **Plasma**
8. **Physical methods of surface modification PVD (physical vapour deposition)**

9. **Ion-electron interaction with solid surface**
10. **Laser beam-solid surface interaction**
11. **Magnetron discharge in plasma processing**
12. **Surface modification by ion interaction**
13. **Surface modification by plasma ion implantation**
14. **Surface modification by low-energy and high-current elektron beam**
15. **Surface modification by laser remelting and alloying**
16. **Laser rapid prototyping**
17. **Pulsed laser deposition using laser ablation**
18. **Surface cleaning by laser ablation**
19. **Surface modification by thermal plasma**
20. **Arc evaporation**
21. **Methods of surface diagnostics**
    a. **spectroscopic method**
    b. **structural (AFM, SEM, TEM)**
    c. **residual stress and methods of measurements**
    d. **micro-mechanical properties**
22. **Hard and super hard coatings on the basis of: nitrides, carbides, borides and nano-composites**
23. **Surface thermal barriers**
24. **Polymer coatings fabricated by plasma polymerization**
25. **Trends in surface engineering in the world**

Course is based on the following literature:

- M.Ashby: Materials; engineering, science, processing and design, Elsevier 2010

- Y.Pauleau: Materials Surface Processing by Directed Energy Techniques, Elsevier 2006
- T.Burakowski, T.Wierzchoń: Inżynieria powierzchni metali, Wyd.nauk.-Techn. 1995
- M.Blicharski: Wstęp do inżynierii materiałowej, Wyd. Nauk.-Techn. 2003
- L.A.Dobrzański: Metalowe materiały inżynierskie, Wyd. Nauk.-Techn., 2004
- Mazurkiewicz: Nanonauki i Nanotechnologie, Wyd.Inst.Technol.Ekspl., Radom 2007

Course: **Renewable energy technologies**

(10 hours, exam)

The final topics and a short description will be given in due course when the final agreement will be reached with potential lecturer.

Course: **Commercialization of scientific research**

(10 hours, exam)

Course summary

The course aims to familiarize participants with global experience in the commercialization of scientific research and to promote open attitudes to science and business cooperation and readiness for commercialization of scientific knowledge. Classes will be conducted in a Course and workshop. Participants will gain knowledge on ways to commercialize research, as well as the ability to develop a plan of commercialization and marketing action plan and seek support in the relevant institutions of the business environment.

Course description

1. Commercialization of systems research - a review of global experience
2. Legal conditions for technology transfer in Poland
3. Use of the innovation system
4. The results of research and development as the object of commercialization
5. Valuation results of R & D
6. Presentation of own technology offer

Course is based on the following literature:

- W. M. Grudzewski, I. K. Hejduk, „Zarządzanie technologiami. Zaawansowane technologie i wyzwanie ich komercjalizacji" Wyd. Difin, 2008
- D. Francis, „Developing Innovative Capability", University of Brighton, Brighton 2001

Seminars with Supervisor

(15 hours, credit)

Seminars showing the progress of PhD thesis

(30 hours, credit)

Total: 165 h (85 h in Semester I, 80 hours in Semester II)

Year 4

Semester I

Course: **Structural effects of phase transformations**

(10 hours, exam)

Course description

1. **Principles of solidification**

   scope: Homogeneous nucleation; heterogeneous nucleation; nucleation and growth in solid-state reactions

2. **Transformations in solids**

   scope: Description of overall transformation; time-temperature-transformation diagrams

3. **Transformation to stable phases**

   scope: The Fe-Fe_3C phase diagram; isothermal transformations in steels

4. **Transformation to stable phases**

   scope: The eutectoid reaction; phases and composition of pearlite; hypo- and hypereutectoid steels; spinodal decomposition

5. **Transformation to transient phases**

   scope: Controlling the eutectoid reaction; the bainitic reaction; the martensitic reaction and tempering

Course is based on the following literature:

- Leszek A. Dobrzański, „Materiały inżynierskie i projektowanie materiałowej" Wydawnictwo Naukowo-Techniczne, 2006
- A.G. Guy, „Introduction to Materials Science", Techbooks 1991

Course: **Crystal diffraction and diffraction based methods of orientation and strain determination**

(10 hours, exam)

Course summary

In the research on (poly)crystalline materials, it is frequently necessary to investigate orientations of crystals (or crystallites) and geometry of the crystal lattice. In particular, crystal orientations and strains are determined locally to create orientation or strain maps. These techniques rely on electron and X-ray diffraction.

The course will be focused on means of getting orientations and strains based on diffraction patterns obtained from individual crystals. To calculate orientations or strains, intermediate steps like pattern indexing or determination of lattice parameters are necessary. A comprehension of all computational stages leading to orientations and strains requires some notions from geometric crystallography and a thorough understanding of diffraction by crystals. Both fields will be covered at the outset of the course. Then, we will proceed to algorithms for indexing, lattice parameter determination, and for computation of orientations and strains. At the end, example packages of relevant software will be presented.

Course description

1. **Elements of geometric crystallography**
2. **Geometric theory of diffraction**
3. **Kinematic theory of diffraction**
4. **Dynamic theory of (electron) diffraction**
5. **Indexing of diffraction patterns**
6. **Example methods of local strain determination (CBED and Kossel**

microdiffraction)

Course is based on the following literature

- C. Giacovazzo, , H.L. Monaco, D. Viterbo, F. Scordari, G. Gilli, G. Zanotti, M. Catti, *Fundamentals of Crystallography*, Oxford University Press, Oxford, 1992.
- Some sections of *International Tables for Crystallography* (volumes A and B), Springer Verlag, Berlin, 2002.
- P. Engel, *Geometric Crystallography: An Axiomatic Introduction to Crystallography*, Reidel, Dordrecht, 1986.
- W.H. Zachariasen, *Theory of X-Ray Diffraction in Crystals*, Dover, New York, 2004.
- Guinier, *X-Ray Diffraction: In Crystals, Imperfect Crystals, and Amorphous Bodies*, Freeman, London, 1963.
- Morawiec, *Orientations and Rotations, Computations in Crystallographic Textures*, Springer Verlag, Berlin, 2004.

Course: **Introduction to computations in crystallographic textures**

(5 h, exam)

Course summary

The field of crystallographic textures is an area of materials science concerned with orientations of crystallites in polycrystalline materials, distributions of orientations, orientation differences and their impact of materials properties. The field relies heavily on computations.The main objective of the course is to convey essential notions, concepts and computational methods of analysis of crystallographic textures.

Course description:

1. **Parameterizations of orientations**
2. **Geometry of the orientation space**
3. **Statistics in the orientation space**
4. **Impact of symmetries**
5. **Standard (mis)orientation distributions**
6. **Example application: effective elastic properties of polycrystals**

Course is based on the following literature:

- Morawiec, *Orientations and Rotations, Computations in Crystallographic Textures*, Springer
- Verlag, Berlin, 2004 (and some references therein)
- U. F. Kocks, C. N. Tom´e, H.R. Wenk, *Texture and Anisotropy: Preferred Orientations in*
- *Polycrystals and their Effect on Materials Properties*, Cambridge University Press, Cambridge,1998.
- H.J. Bunge, *Texture Analysis in Materials Science*. Butterworths, London, 1982.
- A.Morawiec, Orientations and rotations, Springer 2004.

Course: **Introduction to economy - selected issues**

(30 hours, exam)

The final topics and a short description will be given in due course.

Seminars with Supervisors

(15 hours, credit)

Seminars showing the progress of PhD thesis

(15 hours, credit)

Semester II

Seminars with Supervisors

(15 hours, credit)

Seminars showing the progress of PhD thesis

(15 hours, credit)

Total: 115 hours (85 hours in Semester I, 30 hours in Semester II)

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