UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Metals Science and Sustainability

2526-1-FSM02Q009

Aims

Understand the peculiar properties of metallic materials and alloys, the main processes that occur in them (nucleation of defects, atomic diffusion, phase transformations) and the role of metallic elements in functional applications, with a focus on their relative scarcity and recycling. In summary, students will acquire:

1. Knowledge and understanding of the thermodynamics and kinetics that govern physical processes in metals (physical metallurgy)
2. Applying knowledge and understanding to the synthesis and the recovery processes of rare metals in waste electrical and electronic equipment (WEEE)
3. Making judgment in the use of some metals or others in the main technologies of the industrial products.
4. Communication skills in the context of phase diagrams that govern the design of new metallic alloys, or intermetallic compounds.
5. Learning skills of new metallic materials not covered in the course, through the knowledge of the very general thermodynamic methodologies that they have assimilated in the lessons.

Contents

Introduction to metallic materials and alloys
Physical metallurgy
Sustainability in metal applications

Detailed program

INTROUCTION TO METAL SCIENCE

- Elements of macroscopic, structural and functional properties
- Alloys and intermetallic compounds
- Cohesion energy of simple metals
- Structural stability of simple metals
- Cohesion energy in transition metals
- Structural stability of transition metals
- Refresh of thermodynamics
- Refresh of thermodynamics and kinetics
- Embedded atom potential for vacancies

PHYSICAL METALLURGY
- Equilibrium density of vacancies and interstitials
- Dislocations I
- Dislocations II
- Dislocations III
- Dislocations IV
- Metal surfaces
- Interfaces in metals
- Basics of phase diagrams
- Free energy of mixing
- Equilibrium between two phases
- Systems with full solid solubility
- Systems with a miscibility gap
- Notable phase diagrams
- Basics of diffusion in solids
- The diffusion coefficient
- Chemical potentials vs concentration
- Reference frames for the 2nd Fick law
- Irreversible thermodynamics and diffusion
- Contributions of interfaces and strain to diffusion
- Analytical solutions for diffusion equation
- More solution of diffusion equation
- Classification of phase transformations
- Homogeneous and heterogeneous nucleation
- Shape of nuclei depending on strain
- Interface-controlled growth
- Diffusion-controlled growth
- Avrami equation and coarsening
- Continuous transf. and spinodal decomposition I
- Spinodal decomposition II
- Order-disorder transformations
- Martensitic transformations I
- Martensitic transformations II
- Martensitic transformations III

SUSTAINABILITY IN METAL APPLICATIONS
- Metal content in wastes
- Strategic metal needs of EU
- Conventional metal recovery techniques
- Elements of bioleaching
- Recycling electronic waste
- Recycling energy-storage waste

Prerequisites

Elements of Solid State Physics, elements of Thermodynamics and phase diagrams. Basic inorganic chemistry.

Teaching form

48 hours of one-hour lessons in erogative modality in presence. No remote lessons will be envisaged, but for extraordinary cases of syncronous erogation at the same time, in case rare external events, hindering the partecipation in presence.

Textbook and teaching resource

Main text: Gregory N. Haidemenopoulos, Physical Metallurgy, CRC Press 2018. For the sustainability part: Hong Hocheng et al., Biohydrometallurgical Recycling of Metals from Industrial Wastes, second edition, CRC Press, 2025. In addition, all the pdfs of the powerpoint presentations of the lessons, including few suggested sources for further study, are uploaded on the e-learning page of the Course.

Semester

second semester of the first year

Assessment method

Oral exam, starting from the end of the course, in nine annual exam sessions: interview on the topics covered in class through three questions. The skills acquired in the lessons will be assessed, as described in the pdf of the related presentations made available to students, and the student's arguing skill, also through the use of graphs and equations.

Office hours

Available to student request by means of one appointment, arranged by e-mail

Sustainable Development Goals

CLEAN WATER AND SANITATION | AFFORDABLE AND CLEAN ENERGY | INDUSTRY, INNOVATION AND INFRASTRUCTURE | SUSTAINABLE CITIES AND COMMUNITIES | RESPONSIBLE CONSUMPTION AND PRODUCTION