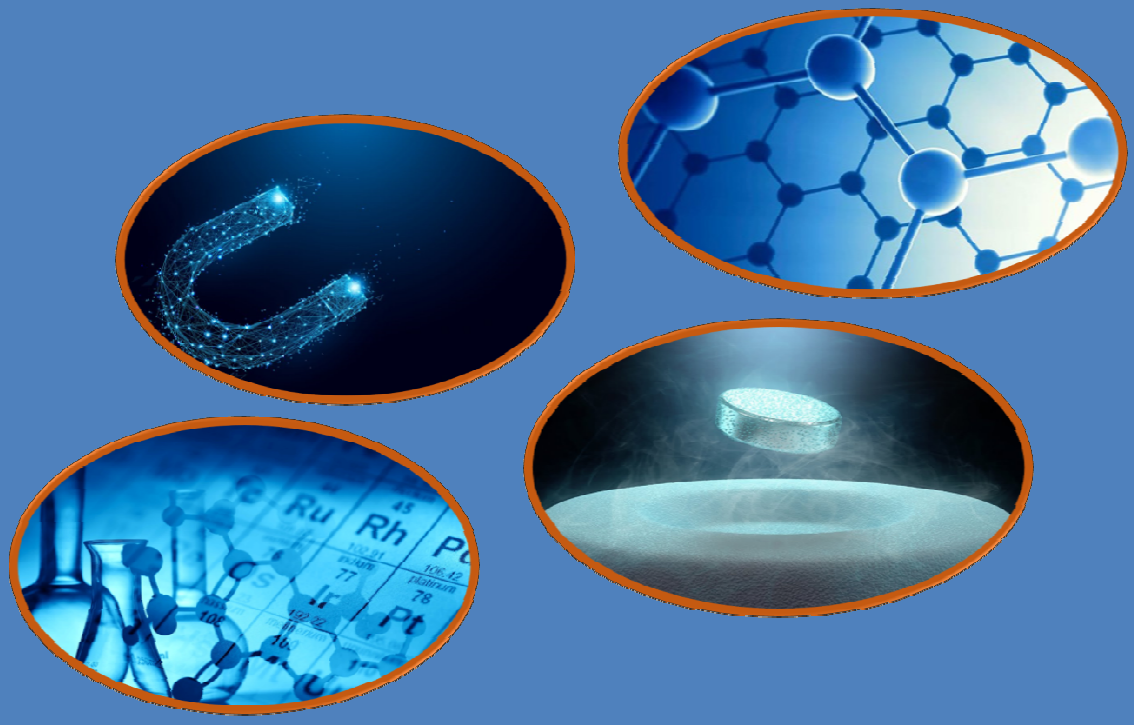

MATERIALS FOR ELECTRICAL ENGINEERING

- Handbook -

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Marius Daniel CĂLIN
Cristian Leonard MUȘUROI

- 2023 -

Transilvania University of Brasov
Faculty of Electrical Engineering and Computer Science

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FOREWORD

This course support is intended for students from the bachelor's program "Electrical Engineering and Computers", taught in English, a program that was organized at the Faculty of Electrical Engineering and Computing Science at Transilvania University in Brasov, since the year 2004. But, this course support is also useful for students from other study programs as well as graduates who want to know new aspects related to the development and use of new categories of materials required by modern technologies.

The proposed lectures cover the subjects for Materials in Electrical Engineering Course proposed for second year of study, and they contain elements necessary for acquiring cognitive and practical and communication skills, which will allow students to explain the basic properties of materials used in electrical engineering, in correlation with intrinsic and extrinsic factors which influence their behaviour under various conditions: electrical, thermal, mechanical, environmental.

After following this course, students will be capable of understanding and assimilate the methodology and measurement techniques of the main parameters of conductive, semiconductive and electroinsulating materials, dielectrics and magnetic materials for optimal choice of materials used in technical applications, in association with their designing, fabrication, testing, exploitation and maintenance processes.

The course benefits from the experience of the authors in their research carried out in the field of materials used in electrical and electronic engineering, included in previously published works:

- Helerea E., Ţiganea D., Stănulet D.: Materiale electrotehnice, Universitatea din Braşov, 1984.
- Helerea E.: Materiale electrotehnice. Dielectrici. Editura Universităţii Transilvania, Braşov, 1998.
- Helerea E., Ţică R., Dumitrescu L.: Materialeelectroconductoare, Materiale electroizolante. Interferenţe cu mediul, Universitatea Transilvania, p.250, 2003.
- Helerea E., Oltean I.D., Munteanu A.: Materials for electrical and electronic engineering, Lux Libris Press House, Braşov, p.158, 2004.
- Călin M.D., Helerea E.: Materiale magnetice pentru maşini electrice utilizate în transport. Metode şi procedure avansate de caracterizare şi modelare, EdituraUniversităţii Transilvania din Braşov, Romania, p.120, 2012.
- Călin M.D., Georgescu M.C., Helerea E., Magnetic materials for electrical machines used in transportation, Editura LAP-Lambert Academic Publishing, Germany, p.132, 2015.
- Helerea E., Călin M.D.: Materials in Electrical Engineering, Editura Universităţii Transilvania din Braşov, Romania, p.377, 2015.

New to this course support is the approach mode. Each proposed subject includes a table of contents, a short summary, followed by a detailed presentation of the proposed subject and at the end a set of self-assessment tests is proposed to evaluate the acquired knowledge.

Lecture 1, *Introduction in Science of Electrical Materials,* includes data on the trends in advanced material development, the objectives of electrical materials course, the structure, properties, parameters and some classification of materials.
Lecture 2, *Electromagnetic Theory and Material Laws,* includes an approach on the macroscopic and microscopic theories of electromagnetism, laws of materials in science, and laws of materials in electrical engineering.
Lecture 3, *Electric Conduction in Metals*, the technique of experimental determination of electrical resistivity of materials is presented, and for the case of metals, the mechanism of the electrical conduction and the expression of electric conductivity are detailed.
Lecture 4, *Energy-Band Model in Crystals and Superconducting State*, includes the energy-bands theory in crystals, electrical conduction in the energy-bands model, and an introduction regarding the superconducting state, characteristics, justification and applications.
Lecture 5, *Electrical Conduction in Semiconductive Materials,* is about the characteristics of semiconductive materials, and debates the electrical conduction in intrinsic and extrinsic semiconductors, and effect of temperature on semiconductor materials.
Lecture 6, *Applications of Semiconductive Materials*, describes the controlled conduction and p-n junction, applications of semiconductive materials for sensors and other devices.
Lecture 7, *Dielectrics in Electrical Engineering*, introduces a new subject regarding the dielectrics, namely, characterization, classification, particularities of electrical conduction and some aspects on electrical breakdown in dielectrics.
Lecture 8, *Dielectric Polarization in Constant Electric Fields*, treats the electronic, ionic and orientation polarizations in constant fields, with examples on each category of dielectrics.
Lecture 9, *Dielectric Polarization in Harmonic Electric Fields*, proposes a model to calculate the complex permittivity of dielectrics, and also the losses in dielectrics.
Lecture 10, *Magnetic Materials in Electrical Engineering*, proposes the characterization and classifications of magnetic materials and it details the characteristics of the materials with magnetic order.
Lecture 11, *Behavior of Materials in Constant Magnetic Fields*, treats the mechanism of diamagnetism, paramagnetism and super-paramagnetism of materials, and applications.
Lecture 12, *Characteristics and Losses in Soft Ferromagnetic Materials*, addresses the characteristics of soft magnetic materials and losses in magnetic materials.
Lecture 13, *Soft Ferromagnetic Materials - Magnetic Domain Structures and Applications,* includes the theory of magnetic domains in ferromagnetic materials, structure of the domains in magnetization process, and applications of soft magnetic materials.
Lecture 14, *Hard Magnetic Materials - Properties and Applications*, treats properties of hard magnetic materials, it describes the permanent magnet operation point and design selection criteria, and evolution and applications of permanent magnetic materials.
We believe that the final chapter, *Homework in Materials for Electrical Engineering*, will be a useful tool for students in applying the acquired knowledge to other disciplines they will follow in the bachelor's cycle, the master's cycle and in later engineering practice.

Authors,
Brașov, February 2023

CONTENT

1. Introduction in Science of Electrical Materials

Contents

1.1. Trends in Advanced Material Development

Section Summary: *In this section, a systematic investigation of materials is done, in which are pointed: new techniques for material properties measurement, new technologies for material processing, new materials and new applications of advanced materials in electrical and electronic engineering.*

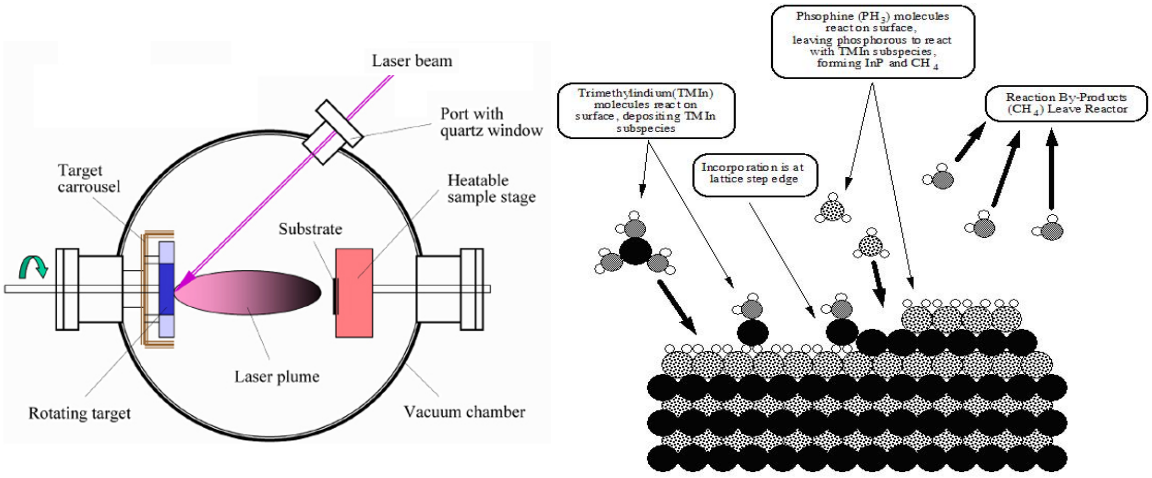
Investigation of the materials used in electrical and electronic technologies is made with tools of different branches of science:

- Physics & Chemistry – for define the composition and the structure of materials,
- Material Science – for describe the composition, structure and properties of materials
- Material Engineering – this includes the methods of manufacturing and processing the materials and semi-products utilized in electrical and electronic devices and equipment.

Today, new techniques for material properties measurement are developed, starting from laser techniques; electronic microscopy; electronic spectroscopy and continuing with special technics, as vibrating sample magnetometry (Fig. 1.1), and others.

Fig. 1.1. New types of magnetometers for magnetic material investigation

Also, new technologies for material processing are applied, as Pulse Laser Deposition (Fig. 1.2.a) and Liquid/ Vapor/Metal-organic Phase Epitaxy (Fig. 1.2.b)



a) b)

Fig. 1.2. New technologies for material processing:
a) Pulse Laser Deposition; b) Liquid/ Vapor/Metal-organic Phase Epitaxy

The actual trends in advanced material development is the introduction on the large scale of the new types of materials, as carbon nanotubes based on graphene, nanoferrites, smart composite materials as shape memory alloys, metamaterials, etc.

Carbon nanotubes are made of carbon, with single-wall or multi-wall carbon structures, having the diameters of order of nanometers. The length typically is much larger than its diameter. The carbon nanotubes havespecific properties: high electric conductivity, high thermal conductivity and high mechanical strength, which directed these materials for electronics, optics, and biomechanics. A synthetic view of the applications of carbon nanotubes is electrical engineering is given in Fig. 1.3.

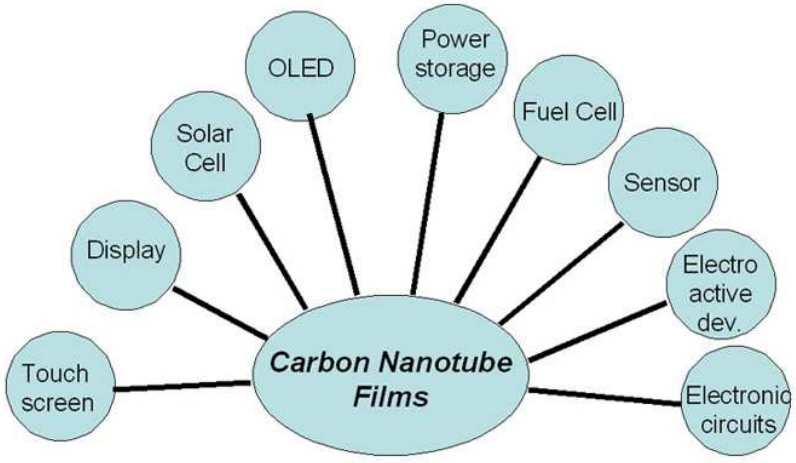


Fig. 1.3. Applications of carbon nanotubes in electrical engineering