Micro-Electro-Mechanical Systems

23MEOE323

(COURSE HANDBOOK)

Department of Mechanical Engineering

COURSE CO-ORDINATOR:

Mr. Santhosh Acharya
Assistant Professor

1. GENERAL INFORMATION

Welcome to the course on “Micro-Electro-Mechanical Systems”!

This course explores the interdisciplinary field of Micro-Electro-Mechanical Systems (MEMS), a transformative technology that integrates mechanical engineering, electrical engineering, materials science, and advanced manufacturing. The course is structured to provide a comprehensive understanding of MEMS technologies and their effective application in diverse engineering and commercial domains.

The course begins with an introduction to the fundamentals of MEMS, emphasizing micro-scale phenomena, scaling laws, and emerging trends in miniaturization. It then advances to a detailed study of MEMS materials, micromachining and fabrication processes, and the underlying principles governing the design and operation of micro-sensors and micro-actuators. The final module focuses on real-world industrial applications, supported by case studies that demonstrate the impact of MEMS technology in sectors such as automotive, biomedical, and consumer electronics.

Throughout the course, emphasis is placed on understanding the challenges and opportunities introduced by miniaturization. The curriculum covers microdevice design, material selection, fabrication technologies, and packaging requirements necessary to ensure reliable performance at the micro scale. Both theoretical foundations and practical problem-solving approaches are integrated to link core principles with real-world engineering challenges.

By the end of the course, students gain the necessary knowledge and technical competence to work effectively with MEMS technology, critically evaluate its capabilities and limitations, and contribute to the development of next-generation microelectromechanical systems. The course handbook provides essential details on course structure, learning outcomes, assessment methods, and supporting resources, serving as a guide throughout the academic journey.

1.1. Course Objectives

This course is designed to

- Impart the knowledge of Micro-Electro-Mechanical Systems (MEMS) and their emerging trends
- Familiarize the micromachining and fabrication techniques used in MEMS
- Provide the working principles of various micro sensors and actuators
- Impart the concepts on MEMS design, material selection, manufacturing, and packaging techniques for Microelectronics and Microsystems

1.2. Course Outcomes

At the end of the course, the student will be able to:

1. Explain the fundamentals of MEMS, scaling laws, materials, fabrication techniques, and the working principles of micro sensors and actuators.
2. Apply scaling laws in miniaturization and the intrinsic characteristics of MEMS
3. Apply the principles of micro sensors and micro actuators to enhance operating performance

4. Explain the design considerations, material selection, and manufacturing processes, and packaging for MEMS
5. Explain the industrial applications of MEMS with case studies

1.3. Set Text and Suggested Sources

All the textbooks listed below are available in the ground-floor library.

Key Text Books:

1. Tai-Ran Hsu, "MEMS and Microsystems: Design and Manufacture," 1st Edition, McGraw-Hill, 2002
2. G.K. Ananthasuresh, K.J. Vinoy, S. Gopalakrishnan, K.N. Bhat, V.K. Aatre, "Micro and Smart Systems," 1st Edition, Wiley, 2012
3. Chang Liu, "Foundations of MEMS", 2nd Edition, Pearson Education Inc., 2012

Reference Books:

1. Marc Madou, "Fundamentals of Microfabrication: The Science of Miniaturization" 2nd Edition, CRC Press, 2002
2. Mohamed Gad-el-Hak, "The MEMS Handbook," 1st Edition, CRC Press, 2005
3. Stephen D. Senturia, "Microsystem Design," 1st Edition, Springer, 2013
   Vijay K. Varadan, K. J. Vinoy, and S. Gopalakrishnan, "Smart Material Systems and MEMS: Design and Development Methodologies," 1st Edition, Wiley, 2006

2. THE COURSE

2.1. Course Description

Micro-Electro-Mechanical Systems			
Semester	**VI**	CIE Marks	**50**
Course Code	**23MEOE323**	SEE Marks	**50**
Teaching Hours/Week (L:T:P)	**3:0:0**	Exam Hrs	**03**
Total Hours	**42**	Credits	**03**

The Micro-Electro-Mechanical Systems (MEMS) course is designed to provide students with comprehensive knowledge in MEMS design, fabrication, and industrial applications. This 42-hour course spans Semester VI with a total of 3 credits, and consists of 5 modules that cover essential topics in microelectromechanical systems, from fundamental principles to real-world case studies. Each week includes 3 hours of lectures focused on theoretical concepts, practical applications, and design analysis relevant to MEMS technology. This course is assessed through Continuous Internal Evaluation (CIE) for 50 marks and a Semester-End Examination (SEE) for 50 marks, with a 3-hour exam duration. This structure ensures a balanced and comprehensive learning experience for students, combining theoretical rigor with practical engineering insights.

2.2. Initiating Contact with Staff and Other Students

We promote open communication and welcome your questions about the course. However, due to the technical depth and demanding nature of MEMS content, we request that you use email to schedule faculty office hours. Before reaching out with questions, please review the materials provided in this handbook and check whether your query has already been addressed in previous class communications or online resources. Additionally, we encourage you to engage with your peers for discussion and collaborative learning, as this will enhance your understanding of complex MEMS concepts and help foster a supportive academic community within the class.

2.3. Resources

As an institute that emphasizes research and development, students are provided with access to a variety of resources that not only facilitate learning but also spark curiosity and offer valuable insights. These resources include dynamic tools such as digital libraries, e-learning platforms, and research databases, providing anytime, anywhere access to academic materials and interactive courses.

Through the college website, students can explore resources such as the VTU Consortium, e-learning platforms, and open-access repositories like NPTEL and NDLI. These digital tools provide access to e-books, research papers, video lectures, and interactive tutorials, thereby creating a flexible and enriching learning environment.

E-learning platforms and digital library resources can be accessed via the college website: https://mite.ac.in/ (Campus Life section > Library > VTU Consortium/e-learning platforms/additional sources).

2.4. Staff

Course Convenor: Mr. Santhosh Acharya
Cabin: 1st floor, PG Block
Email: santhoshacharya@mite.ac.in

2.5. Topics and Reading materials for each module

Module 1 *No. of Hrs: 8*

Topic: Introduction to MEMS

- Introduction, new trends in engineering and science, micro and nano scale systems, intrinsic characteristics of MEMS.
- Scaling laws in miniaturization: introduction to scaling and scaling in geometry, Numerical examples.
- Multidisciplinary nature of MEMS and the advantages and challenges of MEMS

Essential Readings:

- Tai-Ran Hsu, "MEMS and Microsystems: Design and Manufacture," 1st Edition, McGraw-Hill, 2002
  - ✓ Chapter 1: Sections 1.1, 1.5, 1.6
  - ✓ Chapter 6: Sections 6.1, 6.2, 6.3

- Chang Liu, "Foundations of MEMS," 2nd Edition, Pearson Education Inc., 2012
  - ✓ Chapter 1: Sections 1.1, 1.2

Module 2 *No. of Hrs: 9*

Topic: MEMS Materials and Micromachining Technologies

- Materials: Silicon Compounds, Quartz, Piezoelectric Crystals, and Polymers.
- Micromachining Technologies: photolithography, etching: wet and dry, thin-film deposition techniques, and bulk micromachining.
- Surface micromachining and the LIGA process. Chemical and physical considerations in MEMS fabrication

Essential Reading:

- Tai-Ran Hsu, "MEMS and Microsystems: Design and Manufacture," 1st Edition, McGraw-Hill, 2002
  - ✓ Chapter 7: Sections 7.5, 7.8, 7.9, 7.10
  - ✓ Chapter 8: Sections 8.2, 8.6, 8.7, 8.9
  - ✓ Chapter 9: Sections 9.1, 9.2, 9.3, 9.4
- G.K. Ananthasuresh, K.J. Vinoy, S. Gopalakrishnan, K.N. Bhat, V.K. Aatre, "Micro and Smart Systems," 1st Edition, Wiley, 2012
  - ✓ Chapter 3: Sections 3.2, 3.3, 3.4

Module 3 *No. of Hrs: 9*

Topic: Micro Sensors and Actuators

- Micro sensors: Acoustic wave, biomedical, chemical, optical, pressure and thermal sensors.
- Micro actuators: Actuation using thermal forces, shape-memory alloys, piezoelectric crystals, and electrostatic forces. Numerical examples on actuators

Essential Reading:

- Tai-Ran Hsu, "MEMS and Microsystems: Design and Manufacture," 1st Edition, McGraw-Hill, 2002
  - ✓ Chapter 2: Sections 2.2, 2.3, 2.4

Module 4 *No. of Hrs: 8*

Topic: MEMS Design and Packaging

- Design Considerations: Design constraints and selection of manufacturing processes.
- Process Design: Photolithography, thin-film fabrication, and geometry shaping.
- Microsystems Packaging: Mechanical packaging of microelectronics and general considerations in packaging design

Essential Reading:

- Tai-Ran Hsu, "MEMS and Microsystems: Design and Manufacture," 1st Edition, McGraw-Hill, 2002
  - ✓ Chapter 10: Sections 10.1, 10.2, 10.3
  - ✓ Chapter 11: Sections 11.1, 11.2, 11.3

Module 5 *No. of Hrs: 8*

Topic: Industrial Applications of MEMS

- MEMS Case Studies: Inertial sensors in Automobiles: Airbag deployment, automobile navigation, gyroscope and accelerometer.
- MEMS devices in commercial applications: Inkjet printers, digital micro-

mirror devices, radio frequency MEMS switches, scanning tunneling microscopes

Essential Reading:

- Chang Liu, "Foundations of MEMS," 2nd Edition, Pearson Education Inc., 2012
  - ✓ Chapter 15: Sections 15.3, 15.4

3. ASSESSMENT

The assessment for the Micro-Electro-Mechanical Systems module is divided into two components: Continuous Internal Evaluation (CIE) and Semester-End Examination (SEE), each accounting for 50% of the total marks.

Continuous Internal Evaluation (CIE) comprises two internal tests, scheduled for 8th and 14th week, which together contribute 30% of the total marks. Additionally, students can earn 20% through the completion of assignments.

Semester End Examination (SEE) constitutes the remaining 50% of the total marks and is conducted as a 3-hour written examination. Key information regarding examination dates and related details can be accessed via the college website (Academics and Courses section > Calendar of Events > UG Even Sem).

Rubrics for Assignment Evaluation (Total: 20 Marks / 40% of CIE)

ASSIGNMENT–1 (10 MARKS)

Title: MEMS Devices in Daily Life – Identification, Working, and Applications

Assignment Description:

Students are required to identify any one MEMS device commonly used in daily life (such as a smartphone accelerometer, pressure sensor, or gyroscope) and explain:

- The type of MEMS device
- Its working principle
- Applications in real-life systems

Students should include neat sketches/block diagrams wherever applicable.

Evaluation Criteria / Rubric

Criteria	**10 Marks (Excellent)**	**8 Marks (Good)**	**6 Marks (Fair)**	**3–5 Marks (Poor)**
MEMS Device Identification & Relevance	Device is clearly identified, relevant to daily life, and well justified	Device identified with minor gaps in relevance	Device identified but explanation lacks clarity	Device poorly identified or incorrect
Understanding & Clarity	Demonstrates strong understanding of MEMS concepts	Good understanding with minor gaps	Basic understanding evident	Very limited or no understanding

ASSIGNMENT–2 (10 MARKS)

Title: Case Study on a MEMS Sensor – Construction, Working, and Applications

Assignment Description:
Students are required to select any one MEMS sensor, such as a pressure sensor, accelerometer, gyroscope, biomedical sensor, or optical sensor, and prepare a detailed case study. The case study should explain the construction and structural components of the selected sensor, describe its working principle, outline the basic fabrication approach, and discuss its applications in real-life systems. Additionally, students should highlight the advantages of the chosen MEMS sensor.

Part A: Case Study Undertaking (5 Marks)

Criteria	**5 Marks (Excellent)**	**4 Marks (Good)**	**3 Marks (Fair)**	**1–2 Marks (Poor)**
Selection & Understanding of MEMS Sensor	Appropriate MEMS sensor selected; construction and working clearly understood and highly relevant	Suitable sensor selected with good understanding	Acceptable selection but limited understanding	Inappropriate sensor selection or very poor understanding
Technical Analysis & Application Identification	Clear analysis of sensor operation with well-identified applications and performance relevance	Applications identified with basic analysis	Applications vaguely identified with minimal analysis	No clear analysis or applications identified

Part B: Report Submission (5 Marks)

Criteria	**5 Marks (Excellent)**	**4 Marks (Good)**	**3 Marks (Fair)**	**1–2 Marks (Poor)**
Selection & Understanding of MEMS Sensor	Appropriate MEMS sensor selected; construction and working clearly understood and highly relevant	Suitable sensor selected with good understanding	Acceptable selection but limited understanding	Inappropriate sensor selection or very poor understanding
Technical Analysis & Application Identification	Clear analysis of sensor operation with well-identified applications and performance relevance	Applications identified with basic analysis	Applications vaguely identified with minimal analysis	No clear analysis or applications identified