Course Specification

(Postgraduate Programs)

Course Title: Heat Transfer in Microelectronic Devices	
Course Code: PHYS 635	
Program: Master of Science in Physics	
Department: Physics	
College: College of Science	
Institution: Majmaah University	
Version: I	
Last Revision Date: 30/12/2024	

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A. General information about the course:

1. Course Identification

1. Credit hours: (3)					
2. Course type					
A.	☐University	☐College	☒ Department	☐Track-2	☐Others
B.	☐ Required		☒ Elective		
3. Level/year at which this course is offered: (1^{st}/ 2)					

4. Course general Description:

This course provides a comprehensive study of heat transfer processes in micro- and nanoscale electronic devices. It begins with an overview of macroscopic heat-transfer mechanisms—conduction, convection, and radiation—and of the fundamental laws governing energy transport. Topics include heat conduction in solids, Fourier's law, the heat equation, thermal resistance, the lumped-capacitance model, and harmonic conduction regimes, followed by a discussion of the limitations of Fourier's law when approaching submicron length scales.
At more minor scales, where classical continuum models break down, the course examines transport phenomena in dilute media. Students are introduced to the distribution function, Boltzmann transport equation, collision and relaxation processes, mean free path, and the Knudsen number, along with the classification of ballistic, semi-ballistic, and diffusive transport regimes.
The final part of the course explores microscopic heat carriers—electrons and phonons. It covers electrical conduction under both collisional and ballistic regimes using a semi-classical approach. It analyzes lattice vibrations, phonon density of states, optical and acoustic modes, heat flux, and heat capacity. The Boltzmann equation for phonon transport, along with single- and dual-phase-lag models, is presented and applied to nanoscale heat-transfer problems, such as heat dissipation in transistors and microelectronic components.
By the end of the course, students will be able to model and analyze heat transfer mechanisms across scales, understand the limitations of continuum theories, and apply advanced transport models to real microelectronic systems.

5. Pre-requirements for this course (if any)**:**

Computational Physics, PHYS 611

6. Co-requisites for this course (if any)**:**

none

7. Course Main Objective(s):

- By the end of this course, students will be able to:
- Understand the fundamentals of heat transfer at different scales, beginning with macroscopic mechanisms (conduction, convection, and radiation), progressing through mesoscopic regimes, and culminating in microscopic heat transport.
- Explain the limitations of classical continuum heat transfer models and describe the transition from diffusive to ballistic transport at the nanoscale.
- Apply the Boltzmann transport equation to model phonon-mediated heat transfer and analyze transport regimes in micro- and nanoscale systems.
- Interpret and use advanced thermal transport models, including the single and dual phase-lag formulations, to study transient and non-Fourier heat conduction.
- Analyze nanoscale heat transfer in microelectronic devices, particularly heat dissipation in transistors and related components.
- Integrate multiscale modeling approaches to evaluate and predict thermal behavior across macroscopic, mesoscopic, and microscopic domains.

2. Teaching mode (mark all that apply)

No	Mode of Instruction	Contact Hours	Percentage
1	Traditional classroom		
2	E-learning		
3	Hybrid • Traditional classroom • E-learning	45	100%
4	Distance learning		

3. Contact Hours (based on the academic semester)

No	Activity	Contact Hours
1.	**Lectures**	40
2.	**Laboratory/Studio**	
3.	**Field**	
4.	**Tutorial**	5
Total		**45**

B. Course Learning Outcomes (CLOs), Teaching Strategies and Assessment Methods

Code	Course Learning Outcomes	Code of PLOs aligned with program	Teaching Strategies	Assessment Methods
1.0	**Knowledge and understanding**			
1.1	Explain the fundamentals of heat transfer across different scales (macroscopic, mesoscopic, and microscopic).	**K2**	Lecture, Solved Problems	Quiz, Exam, Homework
1.2	Discuss the limitations of classical continuum heat transfer models and identify conditions under which they fail.	**K2**	Discussion, Lecture, Solved Problems	Quiz, Exam, Homework
1.3	Describe and differentiate between diffusive, semi-ballistic, and ballistic heat transport regimes at the nanoscale.	**K3**	Discussion, Lecture, Solved Problems	Quiz, Exam, Homework
2.0	**Skills**			
2.1	Apply the Boltzmann Transport Equation to model phonon-mediated heat transfer in micro- and nanoscale systems.	**S1**	Lecture, Solved Problems, Computational labs	Exam, Homework, Simulation report
2.2	Analyze and interpret transport regimes in microelectronic structures using simulation tools or analytical models.	**S2**	Lecture, Solved Problems, Case study	Exam, Homework, Oral discussion
2.3	Evaluate and use advanced thermal transport models, including single and dual phase-lag formulations, to study transient and non-Fourier heat conduction.	**S2**	Discussion, Lecture, Solved Problems	Exam, Homework
3.0	**Values, autonomy, and responsibility**			
3.1	Analyze and assess nanoscale heat-transfer challenges in microelectronic devices, such as transistors.	**V1**	Lecture, Solved Problems, Case study	Exam, Term paper, Presentation

3.2	Integrate multiscale modeling approaches to evaluate and optimize thermal performance in micro- and nanoscale systems.	**V1**	Lecture, Solved Problems, Case study	Exam, Homework
3.3	Predict and interpret thermal behavior across macroscopic, mesoscopic, and microscopic domains.	**V1**	Lecture, Solved Problems, Case study	Final project, Oral presentation

C. Course Content

No	List of Topics	Contact Hours
1.	Introduction to heat transfer, Overview on heat transfer mechanisms, Conduction, Convection, Radiation, Laws of macroscopic heat transfer	12
2.	Transport in dilute medias, Distribution function, Boltzmann equation, Collision, Relaxation, Mean free path, Knudsen number, Various transport regimes (ballistic, semi-ballistic and diffusive), Electrons and Phonons, Electrical Conduction, Semi-classical approach, Electrical conductivity in the collisional regime, Electrical conduction in the ballistic regime, Vibrational modes in a lattice, Density of states, Optical and acoustic modes, Heat Fl,	12
3.	Solution of the Boltzmann Equation for Phonon Transport, Single and dual phase lag models,	12
4.	Application to nanoscale heat transfer, Heat transfer in transistors.	9
Total		**45**

D. Students Assessment Activities

No	Assessment Activities *	Assessment timing (in week no)	Percentage of Total Assessment Score
1.	Homework-1 (Assignment, Problem solving),	2	3%
2.	Quiz	3	5%
3.	Homework- 2 (Assignment, Problem solving)	4	3%
4.	Mid-term-1 Examination	6	15%
5.	Homework -3 (Assignment, Problem solving)	10	4%
6.	Electronic Quiz	10	5%
7.	Mid-term-2 Examination	12	15%
8.	Presentation	13	10%
9.	Final Examination	16	40%

*Assessment Activities (i.e., Written test, oral test, oral presentation, group project, essay, etc.).

E. Learning Resources and Facilities

1. References and Learning Resources

Essential References	Microscale and NanoscaleHeatTransfer, Sebastian Volz, Springer, 2007
Supportive References	none
Electronic Materials	· Saudi Digital Library (SDL) · Web of Knowledge · Physics Today (web version) · MIT Courseware
Other Learning Materials	none

2. Required Facilities and equipment

Items	Resources
facilities (Classrooms, laboratories, exhibition rooms, simulation rooms, etc.)	· Classroom (must be the same for the same subject) · Seminar room · Computer lab for (e-Quiz)
Technology equipment (projector, smart board, software)	none
Other equipment (depending on the nature of the specialty)	none

F. Assessment of Course Quality

Assessment Areas/Issues	Assessor	Assessment Methods
Effectiveness of teaching	students	Direct

Assessors (Students, Faculty, Program Leaders, Peer Reviewers, Others (specify)

Assessment Methods (Direct, Indirect)

G. Specification Approval

COUNCIL /COMMITTEE	Physics Department
REFERENCE NO.	16
DATE	30/12/2024