LASER PROCESSING AND DIAGNOSTICS (ME 290G)

3 Units

Two one and half lectures per week.

Brief Description:

The course provides a detailed account of laser interactions with materials in the contexts of advanced materials processing and diagnostics.

Expanded Description:

Fundamentals of optical energy coupling with materials. Lasers and beam delivery systems. Thermal transport in irradiated targets: conductive heat transfer, stress field, melting and solidification, surface vaporization, explosive phase-change, plasma formation. Ultra-fast (picosecond and femtosecond) laser processing. Laser processing of thin films: continuous wave laser annealing, pulsed laser annealing. Laser-induced surface modification: mass transfer in shallow doping, flow redistribution and topography generation, miniature modification of glass surfaces. Desorption at low energy densities: Time-of-flight spectrometry. Dynamics of laser-ablated plumes: computational modeling, probe beam deflection, emission and laser-induced fluorescence spectroscopy. Processing of polymers. Laser interaction with liquids. Laser cleaning. Laser interactions with nanoparticles and clusters. Advanced microfabrication applications. Laser-assisted nano-structuring of surface properties. Optical measurement of thermal properties. Laser-based sensors and non-contact diagnostics.

Prerequisities:

Graduate standing.

Text Materials Used:

Set of class notes.

Instructor:

Costas P. Grigoropoulos

Grading Policy

Letter

Abbreviated Transcript Title:

LASER PROCESS DIAGN

Tentative Schedule

Week 1: Fundamentals of laser energy absorption
- 1.1 Electromagnetic theory concepts
- 1.2 Optical properties of materials
- 1.3 Absorption in multilayer structures

Week 2: Lasers and optical delivery systems
- 2.1 Lasers used in materials processing
- 2.2 Basic principles of laser operation
- 2.3 Propagation and focusing of laser beams
- 2.4 Laser beam delivery schemes

Week 3: Thermal transport in laser irradiated targets
- 3.1 Conductive heat transfer
  - Time scales and analytical solutions
- 3.2 Stress field
- 3.3 Melting and solidification
  - The classic Stefan problem
  - Departures from equilibrium
  - Computational treatment
- 3.4 Surface vaporization
  - The Knudsen-Hertz relation
- 3.5 Explosive phase-change
  - The thermodynamics of homogeneous nucleation
- 3.6 Plasma formation
  - The initiation of laser-induced plasmas
  - The high-irradiance model
  - Computation of plasma evolution
  - Plasma shielding of irradiated target

Week 4: Ultra-fast laser processing
- 4.1 Nonlinear mechanisms of light absorption
- 4.2 Modeling of material response under femtosecond laser excitation
- 4.3 Phase transformations induced by femtosecond laser irradiation
- 4.4 Breakdown in dielectric materials

Week 5: Laser processing of thin films
- 5.1 Modeling of energy absorption and heat transfer in pulsed laser irradiation of thin semitransparent films
- 5.2 Continuous wave laser annealing
  - Experimental work
  - Computational modeling
  - Phase boundary stability
- 5.3 Inhomogeneous semiconductor film melting
  - Thermal stability analysis

Laser-induced periodic surface structures
5.4 Nanosecond laser-induced temperature field in melting and resolidification of silicon thin films
5.5 Nucleation phenomena in the supercooled liquid
5.6 Lateral crystal growth by spatially modified irradiation
5.7 Mass transfer and shallow doping

Week 6: Laser-induced surface modification
6.1 Flow redistribution and topography generation
Thermocapillarity driven flow
Hydrodynamic instability of melt
6.2 Miniature modification of glass surfaces
The concept of the glass transition temperature

Week 7: Desorption at low laser energy densities
7.1 Time-of-flight (TOF) measurement systems
Linear mass spectrometers
Resonant and non-resonant ionization schemes
Quadrupole mass spectrometers
7.2 Energetics and yield of desorbed particles

Week 8: Dynamics of laser-ablated plumes
8.1 Computational modeling of plume expansion
The Euler equation for the compressible gas dynamics
Direct Monte Carlo simulation
Molecular dynamics models
8.2 Probe beam deflection diagnostics
8.3 Emission spectroscopy
8.4 Laser-induced fluorescence spectroscopy

Week 9: Processing of polymers
9.1 Experimental work
Micro-feature patterning
Ablation rate regimes
9.2 Photochemical and photothermal ablation mechanisms
9.3 Theoretical modeling

Week 10: Laser interaction with liquids
10.1 Vaporization of liquids in contact with a pulsed laser-heated surface
Rapid nucleation and vapor kinetics
Transient temperature and the degree of superheat
Pressure field
10.2 Laser interaction with absorbing liquids
Pulsed laser ablation and acoustic transient generation
Hydrodynamically limited cavity formation

Week 11: Laser cleaning

11.1 Overview of cleaning mechanisms

Particulate contaminants

Organic and inorganic film contaminants

11.2 Dry cleaning

11.3 Wet, “steam” cleaning

Week 12: Laser interactions with nanoparticles and clusters

12.1 Size effects on optical properties

12.2 Melting and sintering of nanoparticles

12.3 Laser-induced fabrication of nanoparticles

Week 13 Microfabrication using lasers

13.1 Laser-induced forward transfer of thin films

13.2 Matrix-assisted pulsed laser epitaxy

13.3 Localized laser-assisted deposition

13.4 Laser-effected rapid prototyping

Week 14: Nano-structuring of surface properties using laser radiation

14.1 Nanopatterning using laser-assisted atomic force and scanning tunneling microscopes

14.2 Processing with near-field optical microscopes

Week 15: Optical measurement of thermal properties of materials

15.1 Single-ended measurements

Reflection

Transmission

Deflection

Pyrometry

15.2 Measurements of periodic response to modulated laser excitation

Amplitude

Phase