Scuola di Dottorato Leonardo da Vinci – a.a. 2012/13

Laser: caratteristiche, principi fisici di funzionamento, applicazioni e nanoscopia

Durata del corso: 23 ore accademiche tra il 18 Giugno e il 26 Luglio 2013

CONTENT OF THE LECTURES

1- PARTICLE AND WAVE DESCRIPTION: generalities of electromagnetic waves, plane monochromatic waves: intensity (Poynting vector), polarization, frequency, wavevector. Wave equations and wave functions in classical terms: superposition of coherent waves, wavepackets. Wave matter duality and de Broglie wavelength. Photons and their properties.

2. CLASSICAL PICTURE OF LIGHT/MATTER INTERACTION: forced electron oscillations as the source for reflected and transmitted waves. The Lorenz model for dielectric elemental material: reminders of damped and forced oscillations, complex dielectric constant and refractive index, dispersion and resonant absorption. Behavior of the metals (bulk): plasma frequency, transparency and absorption. Brief discussion of the black-body problem and photons and matter in thermal equilibrium. The black-body spectrum and the properties of conventional (non-laser) light sources.

3. SEMICLASSICAL PICTURE OF LIGHT/MATTER INTERACTION: basics of quantum mechanics: matter waves, wave functions and their physical interpretation, Schroedinger equation, steady states, eigenfunctions and eigenvalues. A few problems of quantum mechanics. Quantum matter and discrete energy levels: the example of the hydrogen atom. Optical transitions and conservation rules. Spontaneous emission: rate and broadening effects. Perturbative approach to optical transitions (hints): absorption and stimulated emission and their rate. Rate equation model for a two level system: Einstein’s coefficients.

4. LASERS AND ACTIVE MEDIA: population inversion and amplification of light through stimulated emission: pumping of the quantum matter (active medium), rate equations in a pumped system, steady state solutions for the photon flux and explanation of coherence. Three level system and master equations (hints). Methods for pumping and overall laser efficiency. Materials for the active medium and pumping strategies. Historical overview of lasers: ruby, HeNe, Ar+, CO2, solid state lasers (Nd:YAG and similar rare earth ion lasers, Ti:Sa), excimer lasers and pulsed operation, dye lasers and related issues. Examples of commercial laser systems, their features and main applications.

5. LASER RESONATORS: the role of optical feedback and the transition from amplifier to oscillator (laser source). Active resonators: simple ring cavity and plane parallel mirrors cavity, losses, Q-factor and finesse. Pumping and gain threshold in the pumped three level system. Longitudinal modes and free spectral range of a laser cavity: single/mutimode laser operation, laser linewidth and mode jumps. Examples of resonators in practical laser systems. Behavior in the transverse direction: diffraction and diffraction losses, transverse modes supported by a cavity (hints), stability of the resonator, confocal cavity. Optical properties of the laser beam: BPP and M2 factors, examples in practical laser systems.

6. DIODE LASERS AND APPLICATIONS: market issues and examples of gorundbreaking applications of diode lasers: the crucial role of lasers in optical telecommunications and in optical data storage and the opportunities offered by diode lasers. Reminders on the formation of bands in cristalline materials: semiconductors and their doping, p-n junctions and diode. Pumping in the junction: homojunction laser and its drawbacks. Heterostructures, quantum wells and excitons (hints) and heterojunctions: gain and index guided diode lasers. Examples and properties. Coupling with external cavities and

microfabricated diode lasers: DBR, DFB, VCSEL and their performance. Nanofabrication of precise multilayers and Quantum Cascade Lasers (QCLs): basics of the operating principle, features, properties and applications in molecular fingerprinting.

7. APPLICATIONS OF LASES IN THE NANOWORLD: back to interference and the key need for monochromaticity and coherence, coherence time and length of wavepackets, examples. Michelson's and Fizeau's configurations: the concept of optical (non-contact) profilometry, Differential Interference Contrast (DIC) and Nomarski microscope, holography and related metrology methods (hints), speckle interference and examples of metrological applications. Optical microscopy and its limitations: diffraction from a circular aperture, Airy disk, numerical aperture, Rayleigh's criterion and Abbe's limit. Suppression of stray light in laser scanning confocal microscopy. The promises of STimulated Emission Depletion (STED) microscopi and requirements on the laser source (tunability, pulsed operation). Overview of Scanning Near-field Optical Microscopy (SNOM): non propagating (evanescent waves), approach, sub-diffraction spatial resolution and related technlogies.

The slides of the lectures and the diary of the course are available at http://www.df.unipi.it/~fuso/dida/phd1213.html

Reference text (a selection):

1. A.E. Siegman, *Lasers* (USB, 1986).
2. O. Svelto, *Principles of Lasers* (Plenum Press, 1998).
3. W. Demtroeder, *Laser Spectroscopy* (Springer-Verlag, 1991).
4. R. Eisberg and R. Resnick, *Quantum Physics of…* (Wiley, 1985).
5. E. Hecht and A. Zajac, *Optics* (Addison-Wesley, 1974).
6. J. Hecht, *Understanding lasers* (IEEE Press, 2003).
7. R. Waser (ed.), *Nanoelectronics and information technology* (Wiley-VCH, 2003).
8. E. Arimondo, *Struttura della Materia* (ETS, 2006).
9. R. Pratesi, *Dispense di Fisica dei Laser*, Università di Firenze ed INO, (http://www.ino.it/home/pratesi/DispenseL&A.htm).