Optical Modelling and Design

Final exam questions, 21.02.2011, Abbe School of Photonics, M. Sc. in Photonics

1. Why ray-based light representation is well suited for the modelling of imaging systems? What are the basic functions of the imaging system?
2. Make a sketch of the image formation with an ideal lens, which has negative refractive power ($f' < 0$). Mark relevant quantities, planes and distances.
3. Which quantity (single number) can be used to describe index of refraction on the wavelength dependency? How is it defined? Considering this quantity: how should the two different materials of an achromatic doublet be choosen?
4. Consider an imaging system composed of two lenses, where the first acts as an aperture stop. Make a sketch and mark the position of the exit pupil. Describe what the concept of exit and entrance pupils is used for.
5. Name five Seidel aberrations. Make a sketch of wavefront aberration crossection (optical path difference plot) for one aberration (choose which you like).
6. Name the units of $\vec{E}$ and $\vec{H}$.
7. Matter equations
   a) Write down three material equations in frequency domain.
   b) What is the relationship between refraction index and electric field permittivity?
8. Plane waves
   a) What is the definition of the homogenious and inhomogenious (evanescent) plane waves?
   b) What is the criteria in terms of k_x and k_y wavenumbers to distinguish between homogenious and inhomogenious waves?
   c) Calculate the cutoff value for wavelength 532 nm and $n = 1.5$.
9. Polarization
   a) Why harmonic fields are always polarized?
   b) Describe the general case of harmonic fields polarization.
   c) Discuss the difference between globally and locally polarized paraxial fields.
10. The z-component of harmonic field can always be calculated from it's x and y components. What are the basic arguments for deriving this dependency?
11. Spectrum of plane waves (SPW) integral
    a) Formulate SPW integral for one component.
    b) Derive the formula!
    c) Is this formula also valid for the magnetic field?
12. Paraxial approximation
    a) What is the paraxial approximation?
    b) Give z-component of the wave vector in the paraxial approximation.

Jena, 22.2.2009

Examination Optical Modeling and Design I

Docents: Prof. Dr. Frank Wyrowski, Dr. Uwe D. Zeitner

Answer all questions in your own words and with mathematics where needed for your argumentation.

1. Give the name of five typical types of optical surfaces/interfaces?
2. What do the Sellmeier formulas describe? Do they include the optical absorption of a material?
3. When do we speak about homogeneous, isotropic and non-dispersive media respectively?
4. Formulate the three linear matter equations in the frequency domain.
5. In optics electromagnetic fields are typically described by complex generalizations of the real fields. How are both field expressions related?
6. What is the mathematical definition of a harmonic field?
7. Define a plane wave mathematically. Discuss in words or/and formulas conditions on the parameters of a plane wave, which makes them to a solution of Maxwell's equations in a homogeneous and isotropic dielectric. What is the difference between homogeneous and inhomogeneous plane waves?
8. How many components of the electric and magnetic field vectors are independent in homogeneous and isotropic media? Discuss the reasons with your own words.
9. What are basic concepts which constitute the use of geometrical optics to propagate fields through optical surfaces?
10. Make a sketch of the image formation with a real lens of thickness *d*. Mark the relevant quantities, planes, and distances.
11. What are the five primary types of aberrations in an imaging system?
12. Describe what needs to be considered for the construction of an achromatic doublet lens. What is the condition of achromasie?
13. Consider an imaging system composed of two lenses with the first lens (the one near the object) acting as stop. Sketch the position of the exit pupil. Describe what the concept of entrance- and exit-pupil can be used for.
14. What is the main property of a ray-cone emitted by an object point when it can be called "object-side telecentric"? Where is the location of the limiting aperture in an object-side telecentric imaging set-up consisting of only a single lens?

Optical Metrology and Sensing

Final exam questions, 14.02.2011, Abbe School of Photonics, M. Sc. in Photonics

1. Give examples for two interferometers with division of amplitudes and for two interferometers with division of wavefronts (sketches). (8p)
2. Explain the spatial and the temporal coherence. (8p)
3. What does the degree of coherence describe and how does it influence the law of two-beam interference? (6p)
4. Explain the physical meaning of the free spectral range in Fabry-Pérot interferometer. How is it defined? Is there a difference with regard to the grating interferometer? (8p)
5. How can white-light interference patterns be generated with a Michelson interferometer? (4p)
6. What is the grating period of the interference pattern, if two plane monochromatic waves interfere within glass under the angle of 60^o (wavelength 510 nm, refractive index of glass 1.5)? Draw a sketch. (4p)
7. Could you explain the work principles of adaptive mirrors? (4p)
8. What is the meaning of optical phase conjugation? How can it be realized experimentally? (6p)
9. Explain the principle of holographic recording and reconstructing of wavefronts. (6p)
10. Could you explain the principle of holographic interferometry? (4p)
11. Explain the principles of the wavefront measurement with Hartmann and Hartmann-Shack sensors. (6p)

Structure of Matter

Important topics

1. *Types of crystalline bonds: van der Waals, ionic, covalent, metallic, hydrogen*
2. Lennard-Jones potential
3. *Lattice, basis, primitive translation vectors, conventional and primitive cells*
4. Lattice symmetry
5. *14 Bravais lattices*
6. *Packing fraction*
7. *Structure of CsCl, NaCl, diamond*
8. Wigner-Seitz cell and Brillouin zones
9. Scattering theory, scattering vector
10. Reciprocal lattice, relations between real and reciprocal lattices
11. Miller indices and reciprocal lattice
12. Ewald's sphere, diffraction condition
13. Bragg law
14. *Structure factor, atomic form factor*
15. Debye-Waller factor
16. Lattice vibrations of crystals with monoatomic and multiatomic basises in chain
17. Dispersion relation and first Brillouin zone
18. Group velocity $v_G = \frac{\partial \omega}{\partial k}$ $k = \vec{q}$
19. Acoustic and optical branches
20. ~~Quantisation of lattice vibrations and phonons~~
21. Scattering of light in Crystals: Rayleigh, ~~and~~ Brillouin and Raman
22. *Phonon heat capacity* $C = \frac{\partial U}{\partial T}$
23. *Phonon density of states* Bose-Einstein!
24. *Specific heat in Debye approximation*
25. *Debye density of states, Debye velocity, Debye temperature*
26. Lower Dimensional systems, zero-point energy, number of thermally excited phonons
27. Free electron Fermi gas
28. Sommerfeld model
29. Electron density of states
30. Fermi energy and Fermi sphere
31. Fermi-Dirac distribution and Fermi-Dirac statistics $\frac{1}{\exp\left(\frac{\epsilon-\mu}{k_B T}\right)+1}$
32. Chemical potential
33. Fermi energy, Fermi temperature $T_F = E_F/k_B$
34. Electron heat capacity
35. *Effective mass, thermal effective mass*
36. Bloch functions, Bloch theorem $D(E)dE = \rho \int dq^3$
37. ~~Nearly free electron approximation~~
38. ~~Energy dispersion curves: extended, reduced and periodic zone schemes~~
39. ~~Tight Binding model~~
40. Energy bands. Metals and insulators $U - U_F = \int_0^\infty E\, D(E)\, n(E,T)\, dE$
41. ~~Brillouin zones and Fermi surfaces~~
42. ~~Density of states?~~
43. ~~Electrons as wave packets~~
44. ~~Electron quasi momentum~~
45. Electrons and holes
46. Drude model of electrical conductivity
47. Sommerfeld model of electrical conductivity
48. ~~Bolzmann transport equation~~
49. ~~Displacement of Fermi sphere~~

1^{st} Exam

Structure of Matter, Prof. Meyer, WS2010

Notes: *Please support your answers with drawings when usefull. Explain your solutions.*

1. Please answer the following questions shortly. *(7 points)*
   (a) What is the reason for the existence of a repulsive force between two atoms in the case of ionic and van der Waals crystals?
   (b) What is the physical meaning of the MADELUNG constant?
   (c) How is the LENNARD JONES potential defined? For which systems is it well suited?
   (d) How is a crystal defined?
   (e) Define and explain the Wigner-Seitz-cell and the first Brillouin-zone.
   (f) What is the difference between crystaline and amorphous materials?
2. Suppose the interaction energy between two atoms is given by *(9 points)*

   $$E(r) = -\frac{\alpha}{r^3} + \frac{\beta}{r^{10}}\ , \quad \alpha, \beta > 0\ ,$$

   and that the two atoms form a stable molecule with equilibrium distance r_0 and equilibrium energy $E(r_0)$.
   (a) Make a schematic drawing of the potential and the force.
   (b) Derive the expressions for determining the parameters α and β in terms of r_0 and $E(r_0)$.
   (c) Which are the units of α and β?
   (d) Derive an expression for the force required to break the molecule.
3. Assume the atom radii of Na and Cl are R_1 and R_2. The lattice parameter is a. *(9 points)*
   (a) Make a schematic drawing of the NaCl structure.
   (b) Deduce a general expression (with a and R_1 as parameters) for the packing fraction p of a sodium chloride (NaCl) crystal using the "hard-spheres" model.
   (c) For which ratio $\frac{R_1}{R_2}$ is p maximal?
   (d) What is the minimal packing fraction?

Please turn page.

Final Exam

Structure of Matter, Prof. Meyer, WS2010

Notes: *Please support your answers with drawings when usefull. Explain your solutions.*

√ 1. Please answer the following questions shortly. *(10 points)*

   (a) Explain primitive and conventional cell with one or two sentences.

   (b) List the types of bindings you know.

   (c) Why is the momentum of phonons called "quasi momentum"?

   (d) What is the difference between optical and acoustical phonons?

   (e) What is the definition of the Fermi-Dirac distribution $f(E)$? How does the Fermi-Dirac distribution look like at $T = 0$? What is the physical meaning of the Fermi energy?

   (f) Sketch the energy bands in metals, semiconductors and insulators. What are the differences between these materials?

   (g) What is the difference between the Drude and the Sommerfeld model?

   (h) Why do electrons in a solid move orthogonal with respect to an applied magnetic field?

2. Assume a diamond crystal. *(8 points)*

   √ (a) Which type of binding we have in diamonds?

   √ (b) Identify the Bravais lattice and give a set of translations vectors as well as the vectors of the atomic basis.

   √ (c) What is the corresponding reciprocal lattice?

   √ (d) Calculate the packing fraction. Use the model of hard spheres.

   √ X (e) Assume a X-ray diffraction experiment. Would you expect reflexes on the (100) and on the (111) plane? Why?

3. Consider a one-dimensional monatomic lattice with lattice parameter a. The interaction between neighboring atoms is described by the force constant f. *(8 points)*

   √ (a) Calculate the dispersion relation of phonons for an infinite lattice.

   √ (b) Derive the dispersion relation of phonons for a finite lattice with N atoms (N large). Use periodic boundary conditions. Interpret your result shortly.