Jena, 22.2.2009

Examination Optical Modeling and Design I

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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 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.

Examination Introduction to Optical Modeling and Design

Docents: Prof. Dr. Frank Wyrowski and PD Dr. Uwe Zeitner
Place and Date: Jena, 04.02.2014

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

1. Assume an optical setup composed of two lenses (focal lengths f_1 and f_2) which are placed at a small distance d on the optical axis. Calculate the ABCD-matrix for this setup. Compare the matrix element C with the basic matrix of a thin lens in order to derive the formula for the effective focal length of the two-lens-system.

2. Make a sketch of the image formation with an idealized lens of negative optical power ($f < 0$). Mark the relevant quantities, planes, and distances.

3. What is the Abbe Number? What are the two main categories of glass materials with respect to their dispersion properties? Make a sketch of $n(\lambda)$ in a $\lambda-n$-diagram for both categories.

4. What effect is described by the field-curvature aberration? You can make a sketch to illustrate the effect. How can field curvature be minimized?

5. What limits the spot size of a beam focused by a lens in case the lens has no aberrations? How can this spot size be calculated?

6. General harmonic fields:

aberrations? How can this spot size be calculated?

6. General harmonic fields:

   (a) Define a harmonic (monochromatic) electromagnetic field in the frequency and time domain (with vector signs!).

   (b) How many components are independent in a homogeneous dielectric? Give a basic (no derivation) explanation for your statement.

   (c) How are harmonic fields polarized? Explain your statement.

   (d) What is a paraxial field?

   (e) What is the difference between globally and locally polarized paraxial fields?

7. Thin element approximation (TEA): $\mathcal{E}(x)=$

   (a) Assume a height profile $h(x)$ between two media with refractive indices n and n'. Derive the effect on an incident plane wave (propagating along optical axis, wavelength λ) on the phase of the field.

   (b) Calculate the maximum height of $h(x)$ if the maximum phase shift due to the profile should be 2π. Assume $\lambda = 632$ nm, $n = 1$ and $n' = 1.5$.

8. Propagation in free space:

   (a) The spectrum of plane wave propagation integral (SPW) is given by

$$\begin{aligned} V_\ell(\boldsymbol{\rho}, z) &= \mathcal{P}V_\ell(\boldsymbol{\rho}, 0) \qquad (1)\\ &= \mathcal{F}^{-1}\left\{\left(\mathcal{F}V_\ell(\boldsymbol{\rho}, 0)\right) e^{ik_z z}\right\}. \end{aligned}$$

(b) What is the numerical limitation of the SPW integral? Explain the reason.

(c) Describe and discuss the paraxial approximation.

(d) Formulate (no derivation!) the Fresnel integral to propagate a field from one plane to another (see also Eq. (2)).

(e) Why has the Fresnel integral numerical advantages compared with the SPW integral in case of larger propagation distances?

9. Collins integral:

(a) The Collins integral (for systems embedded in media $n \approx 1$) is given by

$$V_\ell(\boldsymbol{\rho}, z) = \mathcal{P}_\mathrm{C} V_\ell(\boldsymbol{\rho}, 0) = \alpha(\boldsymbol{\rho}, z)\, \mathcal{F}_\beta \left[V_\ell(\boldsymbol{\rho}', 0) \exp\left(\mathrm{i} \frac{k_0 A}{2B} \boldsymbol{\rho}'^2 \right) \right]_{\beta = \frac{k_0}{B} \boldsymbol{\rho}} \tag{2}$$

with

$$\alpha(\boldsymbol{\rho}, z) = \frac{k_0}{\mathrm{i}B} \exp(\mathrm{i}kL) \exp\left(\mathrm{i} \frac{k_0 D}{2B} \boldsymbol{\rho}^2 \right) \tag{3}$$

and the elements of the ABCD-system matrix. What is the theoretical model behind this result? (Give just a short explanation of the basic assumptions.)

(b) Consider a $2f$-setup. What is the conclusion of the Collins integral for the resulting optical effect on the input field? Argue with the ABCD matrix of the $2f$-setup.