Examination

Introduction to Optical Modeling and Design

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

1. A microscope is dedicated to generate a magnified image of small objects. Consider the magnified image formation at the objective lens of a microscope. For simplicity assume that the objective is composed of a single (thin) lens.
   (a) Construct (as exact as you can) the magnified image formation at this lens. Denote the relevant quantities in your sketch. (4P)
   (b) In which distance range from the lens the object needs to be placed in order to obtain the magnified image? (1P)
   (c) Derive the ABCD-matrix of the complete imaging set-up (remember the correct signs of the quantities!). (3P)
   (d) Use the result of task 1c) to derive the Lens-makers equation which relates the object- and image distance to the focal length of the lens (again: remember the correct signs! Hint: consider a specific object point in the usage of the ABCD-matrix to derive the equation). (2P)
2. What is described by the Wave-Front-Aberration Function (also known as OPD in Zemax)? At which position this function is defined? How should this function look like in case of diffraction limited imaging? (3P)
3. How can the minimum focal spot size be calculated in case the lens has no aberrations? (1P)
4. What is the origin of spherical aberration? Explain this e.g. at a simple lens with spherical surfaces. (2P)
5. Bonus: Which Seidel-aberration can be minimized by using a combination of lenses with positive and negative focal lengths? (1P)
6. What are the Maxwell's equations in frequency domain if we consider them in a homogeneous and isotropic medium ($\check{n} = n + in'$)? (2P)

7. What is the mathematical expression of the complex field vector of an harmonic (monochromatic) electromagnetic field in frequency and time domain? What is the corresponding real field in time domain? (3P)

8. Plane waves:

   (a) What is the complex amplitude expression of the electric field vector of an electromagnetic plane wave. (1P)

   (b) What is the difference between homogeneous and inhomogeneous plane waves? (1P)

   (c) What is the dependency of thecomplex k-vector $\breve{\boldsymbol{k}} = \boldsymbol{k} + \mathrm{i}\boldsymbol{k}'$ for homogeneous plane waves, when we know the complex refractive index as $\breve{n} = n + \mathrm{i}n'$? (2P)

   (d) How would you prove, that homogeneous plane waves are always of this form? (4P)

   (e) Let us assume, that you have a plane wave with $\Re \breve{k} = 2k_0\breve{n}$ and a media with $n' = 0$. Is this plane wave homogeneous or inhomogeneous? What is the decay distance and wavelength for this plane wave. (6P)

9. Electric field in a plane

   (a) The z-component of the electric field vector of a plane wave can be calculated from the other ones by the formula

$$\breve{E}_z = -\frac{\breve{k}_x \breve{E}_x + \breve{k}_y \breve{E}_y}{\breve{k}_z} .$$

   From which Maxwell's equations can that be concluded? (2P)

   (b) How can we generalize this formula to general fields in a plane z_0, that means how to calculate the z-component of the electric harmonic field vector $\boldsymbol{E}(x, y, z_0)$ from $E_x(x, y, z_0)$ and $E_y(x, y, z_0)$. (Basic argumentation is sufficient together with final formula.) (5P)

10. Propagation in free space:

    (a) We have derived the SPW integral to model the propagation of fields through homogeneous and isotropic media. From that follows, that propagation in a homogeneous media causes a low-pass filtering in terms of spatial frequencies. Explain this effect. (3P)

    (b) Sketch the basic concept of the derivation of the SPW operator. (3P)