Optics and Photonics

Geometric optics, electromagnetic theory, Fourier optics, Computational optics

WS 2016/17

The **Master Course "Optics & Photonics"** provides the fundamental theory needed in a wide range of technical fields. Preliminary knowledge is not needed but a solid knowledge in advanced math and programming are mandatory to master the course.

Structure of the course:

The ***first part*** *of the course covers the fundamentals in optics, the electromagnetic theory, wave and geometric optics. The* ***second part*** *deals with Fourier Optics and the theory needed in the modules on Computational Optics. The* ***third part*** *introduces some basic silicon photonic devices, e.g. waveguide, splitter, taper, coupler, modulator and detector as well as the basics on electro-optics and lasers. The* ***fourth part*** *provides the student with an overview on methods of computational optics, e.g. Plane-Wave Decomposition, Beam-, Wave- and Vector Wave Propagation Methods as well as the Finite Difference Time Domain method. In a final* ***Case Study****, a system will be parametrised, a model created, simulated and optimized with respect to a performance quantity.*

Optical Engineering and Photonics:

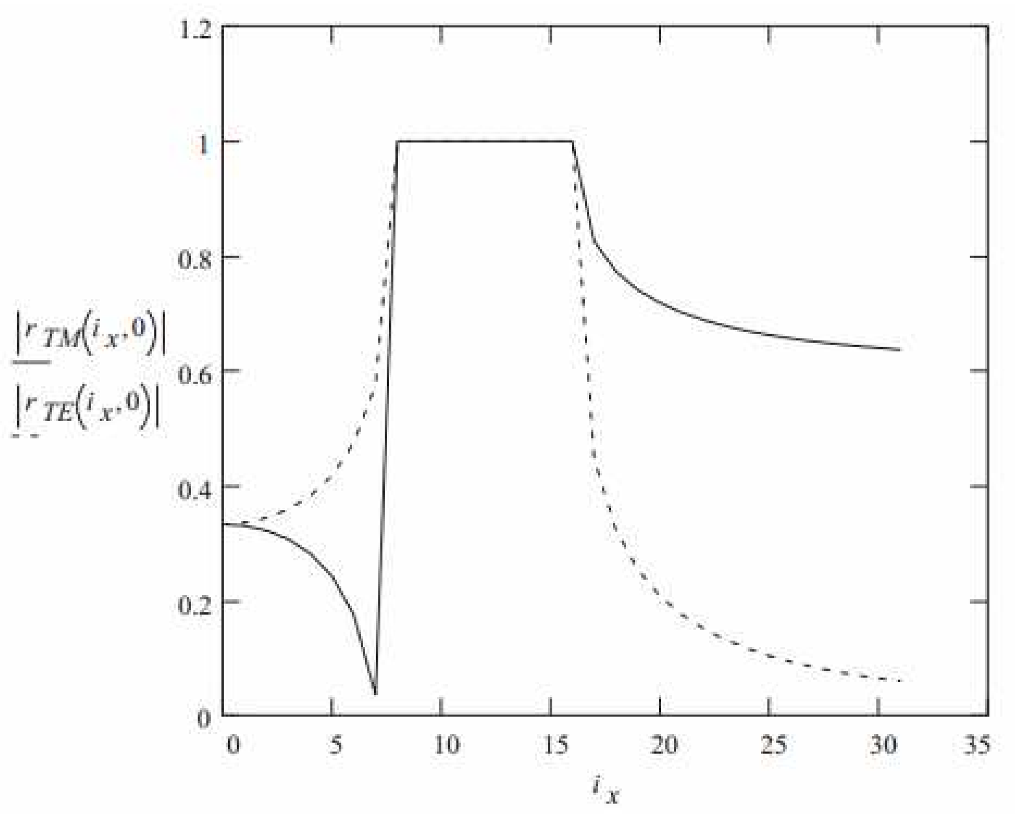
Optical Engineering provides the fundamental principles to create, manipulate and transform electromagnetic fields. Optical Engineering is therefore an important catalyser for various fields of research and development, e.g. IT, Medical and Mechanical Engineering, Green Technology and others.

Photonics can be seen as a specialization of Optical Engineering, where electromagnetic radiation is treated with silicon-based devices of micro- or nanometer dimensions. It is a comparably young field of research. Lots of innovations and advances in the IT and other sectors are based on Photonics, e.g. Wide Area Networks, System Area Networks, High-Performance Computing, Micro-Optics, miniaturization and integrated technologies.

Examples : *Optical and Photonic Engineering delivers key technologies for*

- ***IT-sector.*** *Fibre-optics, optical interconnects, (micro) electro-mechanical elements, electro-optical modulators and others boost the performance of IT-systems*
- ***Green Technologies.*** *Solar cells, solar driven heat exchangers and others*
- ***Mechanical Engineering.*** *Laser welding, laser cutting, vibration analysis of mechanical structures, distance and speed measurements and others are key technologies*
- ***Medical Research and Clinical praxis.*** *"image reconstruction from projections" is applied to visualize chemical and anatomical properties of the human body (CT)*
- ***Automotive Industry.*** *Projection techniques in head-up displays and detection of radiation in night vision systems*
- ***Astronomy.*** *Telescopes use the principles of Geometric and Fourier Optics to inspect the universe in an amazing detail*
- ***Military applications.*** *Heat detectors and laser guidance systems, night vision systems, head-up displays*

1. Electromagnetic Theory, Geometric Optics and Wave Optics



1.1 Fresnel Amplitude coefficients

Absolute of the Fresnel amplitude coefficients for propagating and evanescent modes and s- and p-polarization.

$$r_{TE} = \frac{n_e\cos\theta_e - n_t\cos\theta_t}{n_e\cos\theta_e + n_t\cos\theta_t} = \frac{E_r}{E_e}$$

$$r_{TM} = \frac{n_t\cos\theta_e - n_e\cos\theta_t}{n_t\cos\theta_e + n_e\cos\theta_t} = \frac{E_r}{E_e}$$

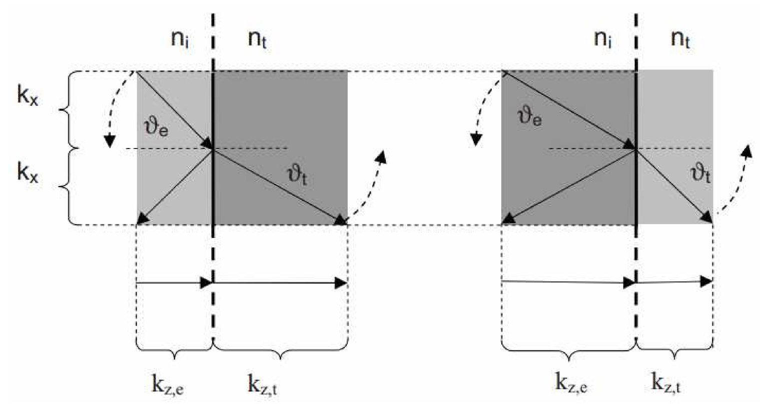
$$t_{TE} = \frac{2n_e\cos\theta_e}{n_e\cos\theta_e + n_t\cos\theta_t} = \frac{E_t}{E_e}$$

$$t_{TM} = \frac{2n_e\cos\theta_e}{n_t\cos\theta_e + n_e\cos\theta_t} = \frac{E_t}{E_e}$$

2. Theory

2.1. Geometric Optics

Internal and external refraction



2.2. Wave Optics

The inhomogeneous wave equation

$$\triangle\mathbf{E} - \frac{\epsilon(\mathbf{r})\mu(\mathbf{r})}{c_0^2}\frac{\partial^2\mathbf{E}}{\partial t^2} = -\left[\frac{\nabla\mu(\mathbf{r})}{\mu(\mathbf{r})}\times(\nabla\times\mathbf{E}) + \nabla\left(\frac{\nabla\epsilon(\mathbf{r})}{\epsilon(\mathbf{r})}\cdot\mathbf{E}\right)\right]$$

2.3. Fourier Optics

The *Plane Wave Decomposition*

$$\mathbf{E}(\mathbf{r}_\perp; z+\delta z) = \frac{1}{2\pi}\iint \tilde{\mathbf{E}}(\mathbf{k}_\perp; z)\, e^{i\phi_z}\, e^{i\mathbf{k}_\perp\cdot\mathbf{r}_\perp}\frac{d^2\mathbf{k}_\perp}{(2\pi)^2}$$

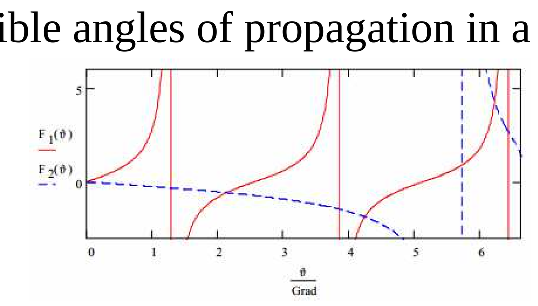
2.4. Computational Optics

Absorption of energy obtained from local electric field distribution

$$\iint \mathbf{S}d\mathbf{A} = \iiint n(\mathbf{r})\kappa(\mathbf{r})\epsilon_0\omega|\mathbf{E}(\mathbf{r})|^2 d^3\mathbf{r}$$

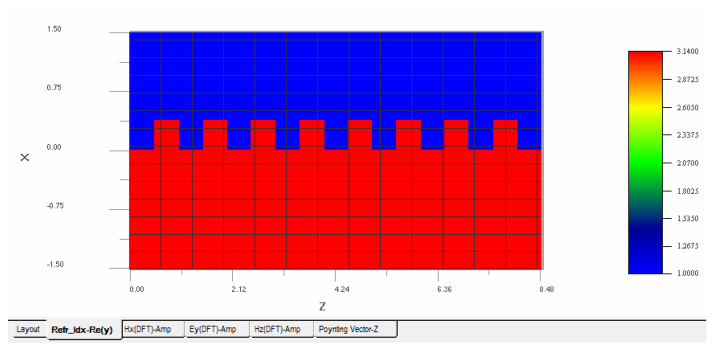
2.5. Photonic components

Eligible angles of propagation in a waveguide

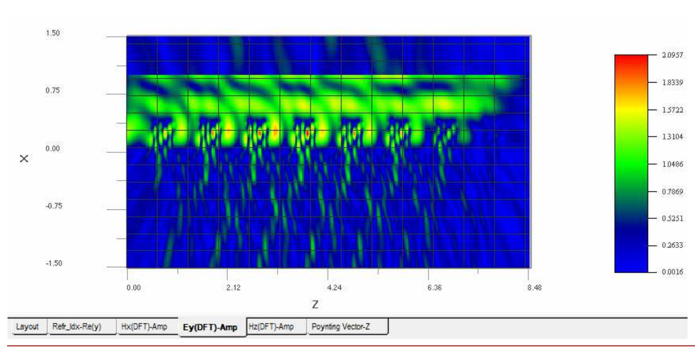


3. Design of a grating filter with the FDTD

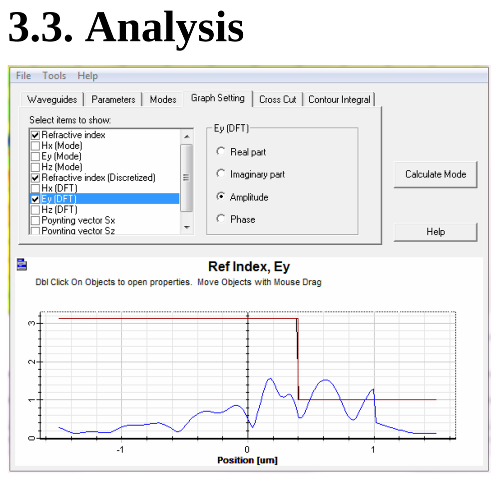
3.1. Layout



3.2. Simulation



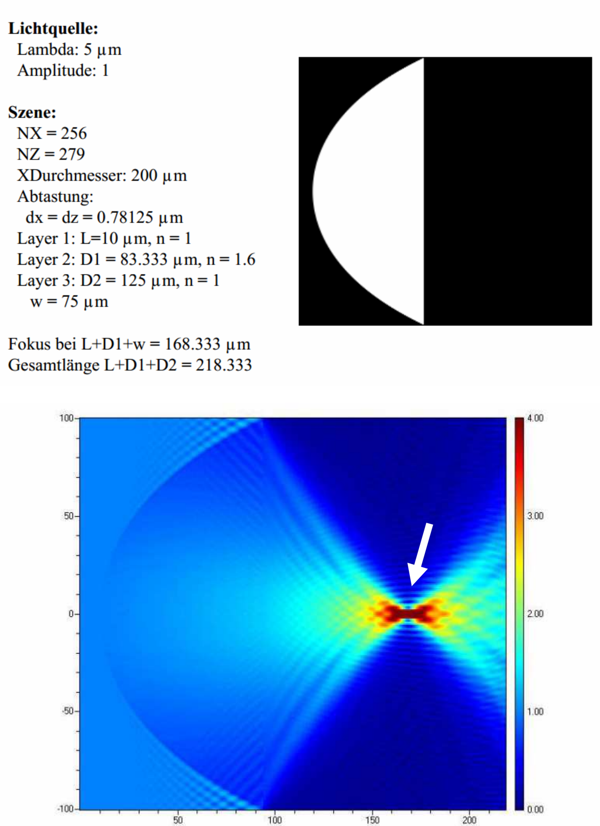
3.3. Analysis



3.4. Optimization in the 3D case (Case Study)

The model is parametrised and the filter characteristics analysed in a parameter sweep. The setting with optimal filter function (e.g. local absorption) yields the final design

4. Fourier-based simulation methods



Simulation of a perfect asphere with the parVWPM

With the parallel version of the Vector Wave Propagation Method, parVWPM (*Fertig 2011*), an efficient parallel simulation of complex systems, composed from a multitude of components, is achieved.

*To verify the method, the shape of a perfect asphere is derived from theory, i.e. lens radius is a function of the position on the lens surface R=f(****r****). There, all rays intersect perfectly at the focal point, which is perfectly shaped and does not show deformations. Such deformations would occur from a lens of a con-stant radius over the entire lens surface.*

The simulation on the left side shows that the asphere creates a perfect focal point without deformations.

5. Summary:

- Course start: winter term 2016/17
- Course language: German, script language: English
- Background in advanced math and programming are mandatory
- Tools: Matlab/Octave, OptiFDTD

6. Literature:

- *Principle of Optics*, Born and Wolf
- *Optics*, E. Hecht
- *Fourier Optics*, J. Goodman
- *Photonics*, Reed and Knights
- *Engineering Optics with Matlab*, Poon and Kim
- *Laser - das andere Licht*, von Ahlfen und Altheide

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