

# *Optical Waveguide Theory (A)*



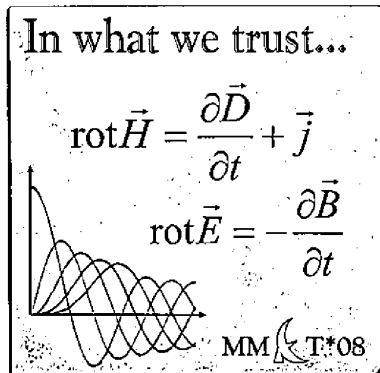
Manfred Hammer\*

Theoretical Electrical Engineering  
Paderborn University, Germany

*Paderborn University — Summer Semester 2018*

*\* Theoretical Electrical Engineering, Paderborn University  
Warburger Straße 100, 33098 Paderborn, Germany*

*Phone: +49(0)5251/60-3560  
E-mail: manfred.hammer@uni-paderborn.de*



*MMET'08, Mathematical Methods in Electromagnetic Theory  
Odesa, Ukraine, June 29 – July 2, 2008*

## Maxwell equations

SI, in matter, time domain, differential form:

$$\begin{aligned}\nabla \cdot \mathbf{D} &= \rho_f, & \mathbf{E}(\mathbf{r}, t): & \text{electric field,} \\ \nabla \times \mathbf{E} &= -\dot{\mathbf{B}}, & \mathbf{D}(\mathbf{r}, t): & \text{(di-)electric displacement,} \\ \nabla \cdot \mathbf{B} &= 0, & \mathbf{B}(\mathbf{r}, t): & \text{magnetic induction (field, flux density),} \\ \nabla \times \mathbf{H} &= \mathbf{J}_f + \dot{\mathbf{D}}, & \mathbf{H}(\mathbf{r}, t): & \text{magnetic field (. . .),} \\ & & \rho_f(\mathbf{r}, t): & \text{density of free charges,} \\ & & \mathbf{J}_f(\mathbf{r}, t): & \text{density of free currents,} \\ \mathbf{D} &= \epsilon_0 \mathbf{E} + \mathbf{P}, & \mathbf{P}(\mathbf{r}, t): & \text{polarization,} \\ \mathbf{B} &= \mu_0 (\mathbf{H} + \mathbf{M}). & \mathbf{M}(\mathbf{r}, t): & \text{magnetization,} \\ & & \epsilon_0: & \text{free space permittivity,} \\ & & \mu_0: & \text{free space permeability.}\end{aligned}$$

(+ constitutive relations)

Valid for more than a century, firm basis for further considerations.

### Optical waveguide theory

- A Photonics / integrated optics; theory, motto; phenomena, introductory examples.
- B Brush up on mathematical tools.
- C Maxwell equations, different formulations, interfaces, energy and power flow.
- D Classes of simulation tasks: scattering problems, mode analysis, resonance problems.
- E Normal modes of dielectric optical waveguides, mode interference.
- F Examples for dielectric optical waveguides.
- G Waveguide discontinuities & circuits, scattering matrices, reciprocal circuits.
- H Bent optical waveguides; whispering gallery resonances; circular microresonators.
- I Coupled mode theory, perturbation theory.
  - Hybrid analytical / numerical coupled mode theory.
- J A touch of photonic crystals; a touch of plasmonics.
  - Oblique semi-guided waves: 2-D integrated optics.
  - Summary, concluding remarks.

## *Formalities*

---

Organization of the course:



- Lectures ( $\approx 14\times$ )
- Homework ( $7\times$ )
- Tutorials, Exercises ( $13\times$ )
- Exam

Related textbooks (examples):

C. Vassallo, *Optical Waveguide Concepts*, Elsevier, Amsterdam (1991),  
K. Okamoto, *Fundamentals of Optical Waveguides*, Academic Press, San Diego, USA (2000),  
R. März, *Integrated Optics: Design and Modeling*, Artech House, Norwood, USA (1995),  
A.W. Snyder, J.D. Love, *Optical Waveguide Theory*, Chapman and Hall, London, UK (1983);  
& general introductory texts on classical electrodynamics.

## Optical waveguides: phenomena, examples

- Beam propagation in free space
- Guided light propagation
- Waveguide end facet
- Crossing of two waveguides
- Modes of 1-D multilayer slab waveguides
- Modes of 2-D channel waveguides
- Evanescent coupling between waveguides
- Bent waveguides
- Circular microring-resonator
- Microdisk resonator
- CROW
- Waveguide corner
- Photonic crystal waveguide
- Exciting TET !



## Optical waveguide “theory”

Task: solve

$$\begin{aligned}\nabla \times \mathbf{E} &= -\dot{\mathbf{B}}, & \nabla \cdot \mathbf{D} &= \rho_f, & \mathbf{D} &= \epsilon_0 \mathbf{E} + \mathbf{P}, \\ \nabla \times \mathbf{H} &= \mathbf{J}_f + \dot{\mathbf{D}}, & \nabla \cdot \mathbf{B} &= 0, & \mathbf{B} &= \mu_0 (\mathbf{H} + \mathbf{M}), \quad (\& \dots).\end{aligned}$$

In this course:

- specialization to problems relevant for integrated optics,
- theoretical basis for the — mostly — numerical solution,
- approximate concepts,
- examples.

## Upcoming

---

Next lectures:

- Brush up on mathematical tools.
- Maxwell equations, different formulations, interfaces, energy and power flow.
- Classes of simulation tasks: scattering problems, mode analysis, resonance problems.

