



## Lab work: BPM-Analyses

### Goal:

- Learning about the Beam Propagation Method, which is the fundamental tool to simulate wave propagation
- Acquiring knowledge on typical problems and impacts of the calculation procedure
- Studying of typical waveguide structures and optical components

### 1. Technical Requirements

- the BPM simulation software packet
  - BPM\_1-43deutsch.exe
  - BPM\_1-43deutsch.hlp
  - BPM\_tutor.exe
- the BPM lab session files:
  - WG.wgd
  - WG\_Curve1.wgd
  - WG\_Curve2.wgd
  - Y-Coupler.wgd
  - Coupler\_parallel.wgd
  - Coupler\_parallel2.wgd
  - Couper\_spatial1.wgd
  - Input\_4mu\_WG.egf
- there are no specific hardware requirements

### 2. Introduction

The Beam Propagation Method (BPM) is a fundamental simulation methodology for the description of the optical wave propagation. It is usually performed in 2D because of the very high memory needs for precise 3D calculations. Thus, a 3D-to-2D transformation of the waveguides is necessary. The Effective Refractive Index Method /3/ and the Equivalent Waveguide Method /4/ are to be applied.

The kernel of the BPM program consists of the standard FFT split formalism /2/ in an easy form. That means, the first part of one BPM step consists of a FFT of the transversal electrical field distribution at a given point  $z$ . Every component of the transformed field is multiplied with a complex figure. Now, this field is transformed back into the original domain. These steps correspond to a beam propagation in a homogenous medium. An additional multiplication of the field with complex figures is necessary to take the waveguides into account. These complex figures are proportional to the refractive index difference from the waveguide to the substrate and to the propagation step width  $\Delta z$ . A change of the refractive index within this step width is ignored by the program. In consequence the accuracy of the results might not achieve acceptable values. Therefore, the simulation is to be repeated with a smaller step width,

until the solutions converge.

In order to train students with the BPM algorithm and let them evaluate its results all the parameters like the FFT window size, the step size, the number of samples and the kind of absorber at the edge of the FFT window can be adjusted.

### 3. Tasks

#### 3.1 Straight Waveguide

- Get yourself familiar with the BPM program (Under Help you find a tutorial)
- Load the file *WG.wgd* and run the program with default parameters. Take notes of all default parameters
- Explain the reasons for the interference pattern.
- Put the cursor at 105 $\mu\text{m}$  position in the Waveguide frame and analyze the optical field distribution.
- Change the step size to 1 $\mu\text{m}$  and the number of samples to 512 and repeat the calculation. Explain the differences to your former calculation.
- Now, make use of the *Input\_4mu\_WG.egf* file rather than using the exponential field distribution as an input. What is the difference now?

#### 3.2 Curved Waveguide

- Load the *WG\_Curve1.wgd* file and run the program with 1 $\mu\text{m}$  step size, a 128 $\mu\text{m}$  FFT-window and 512 samples. Use the *Input\_4mu\_WG.egf* file as your input field. Analyze your results.
- Load the *WG\_Curve2.wgd* file and run the program with similar parameters. What makes the difference?

#### 3.3 Y-Coupler

- Load the file *Y\_Coupler.wgd* and run the program with the same parameters as before. You will see a warning message. What does it mean?
- Now analyze and explain the wave propagation in the splitting region!

#### 3.4 Parallel-Coupler

- Load the file *Coupler\_parallel1.wgd* and run the program with the same parameters.
- Now analyze and explain the wave propagation! Measure the 'Coupling Length'.
- Run the program with the same parameters as before but use  $\lambda=1.04\mu\text{m}$ . What is the field distribution at the end of the coupler? Explain the difference to your former calculation.
- Load the file *Coupler\_parallel2.wgd* and run again with similar parameters but use  $\lambda=1\mu\text{m}$ . What makes the difference?
- Now run again the program with  $\lambda=1.04\mu\text{m}$  and explain your results.
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#### 3.5 Spatial Coupler

- Load the files *Coupler\_spatial1.wgd* and *Input\_4mu\_WG.egf* and use 4 $\mu\text{m}$  step size, 256 $\mu\text{m}$  FFT window and 512 samples.
- How would you design a 1-to-3 Spatial Coupler?

#### 4. Preparation Questions

- 4.1 What means Effective Refractive Index Method?
- 4.2 What means Equivalent Optical Waveguide Method?
- 4.3 What is the operation principle of the Beam Propagation Method?
- 4.4 What can't be solved by the BPM?

#### 5. Literature

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<http://www.optics.arizona.edu/kost/OPTI%2015%20Web%20Site/Lecture%20Notes/Lecture%2013%20BPM%20Method.pdf>

/2/

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"Mode dispersion in diffused channel waveguides by the effective index method", Applied Optics, Vol 16, No 1. January 1977

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"Equivalent Optical Waveguides", J. Lightwave Technology, Vol LT-2, No 3, June 1984