Microphotonics

CAD-Exam

Assignment

19/12/2022

Practicalities

This CAD-exam is **open book**: all course material and personal notes are allowed. You are allowed to ask questions to the supervisors. A separate online document will be provided where you can fill in your answers. Any form of communication is prohibited and you will be monitored through MS Teams. The duration of the exam is limited to 3 hours. Please listen carefully to the explanation before starting the exam. Good luck!

1 Fourier optics

In this question you will make use of MATLAB Fourier GUI. You can assume the lenses are **aberration free** and their diameter is so large that their limiting effect on the resolution of this system can be neglected. You can assume that **coherent light** is used at a wavelength of 1550 nm and all focal distances are fixed at 0.3 m. All files required are in the sub-folder `exam` of the provided zip-file.

1.1 The 4F correlator

Image convolutions are an important tool for object recognition. To detect an object, an image must be convolved with a known reference image or a combination of image kernels. Such convolutions are however computationally intense due to the large number of multiplications needed. In cases where instant detection is required, e.g. missile detection or real-time text-to-speech conversion, this can be too slow.

Figure 1: A single set of digits of the MNIST dataset.

An optical 4F correlator solves this problem by performing an instant convolution in the optical domain. You will simulate the recognition of handwritten digits using the Optical Convolution Processor tool. Fig. 1 shows the set of the MNIST digits that are used in this exercise. To get more insight, first calculate the Fourier spectrum of a single number. This will giver the spectral kernel that represents this character. Use the Diffraction tool for this.

1. Open as source the bitmap `mnist1.bmp` in the Diffraction GUI. What do you see? Is this what you expect and why? Also include a screenshot.

2. Now swith to the Optical Convolution Processor GUI. Open as source the bitmap `mnist1.bmp` and use the filter `filter_OCR.m`, which is the 2D Fourier-transformed version of Fig.1 where the numbers are vertical. What do you see? Give a short explanation on what you see and how this can be used for character detection. Also add a screenshot. Why do you not see a single bright point? HINT: use the image `mnist2.bmp` to verify your explanation.

3. Now use as a source the bitmap `arial8.bmp`. Is the result still clear? Why do you think this is (not) the case? HINT: also have a look at the 1D results!

4. Now use as a source the bitmap `mnist1-offset.bmp`. Can the system detect simultaneously which digit was used as input and also its offset from the center? Why (not)?

2 Waveguides (Lumerical)

In this exercise you will study 2 different waveguides based on InP and SiNx respectively, and the optical coupling between them.

2.1 Study of the waveguide modes

In this task we are going to find the desired width for the InP waveguide by using the Lumerical file `SiN_InP_mode.lms`. To load the file, open EME solver and go to *Script File Editor*, click the second button to select the file. Once the file is loaded, click the 3rd button from the right side to run the script.
In the file, the width of the SiNx waveguide is fixed at 2.0 µm with a thickness of 300 nm, while the thickness of the InP waveguide is 230 nm. The gap between these two waveguides is set to 50 nm.

1. First, calculate the modes of the SiNx waveguide by disabling the InP waveguide, what is the effective index of the fundamental TE mode?

2. Sweep the width of the InP waveguide: to do so, disable the SiNx waveguide and run the simulation. In the *Optimizations and Sweeps* window, you can find the sweep with the name *w_inp_sweep*. Choose a start and stop value for the width of the InP waveguide. After setting up the sweep range, run the sweep and visualize the *n_eff* result. At which width has the InP waveguide the (approximately) same effective index as the SiNx waveguide?

3. Edit the width of the InP waveguide such that it has the same effective index as the SiNx waveguide. Enable both waveguides in the simulation, calculate the mode and look at the first mode you get. Can you describe what you observation and try to explain it a bit?

Provide a screenshot of your results for each mode calculation and parameter sweep (for *n_eff*), with a short description and your interpretation of the results in your answer sheet.

2.2 Coupling between SiNx and InP waveguide via taper

Load the Lumerical script file `Taper_whole structure.lsf`, which in addition to the waveguides now contains a taper for both waveguides. At the beginning of the script (line 7), you should input the width you got from the first part as the InP_taper_tip_width.

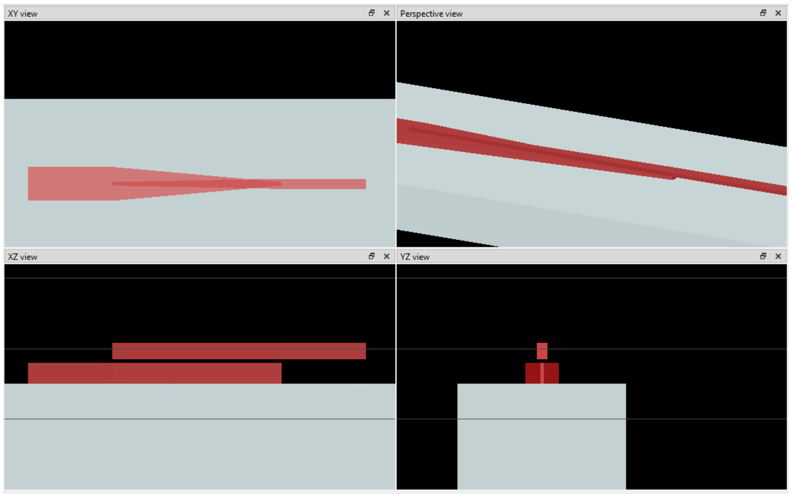

Figure 2: Views of structures with tapers

1. Run the script, and then you will have all the structures. To simulate the light propagation, the EME solver is needed. Load and run another script file `EME_setup.lsf` to set up the EME simulation environment. Now we have all the objects we need for the simulation: to perform the simulation, first we need to select the fundamental TE modes for both waveguides. To do so, go to the objects tree and find *Ports* under *EME*, right-click on *port_1* and choose *Edit object*. In the Edit EME port window, go to *EME port* and click *select mode(s)*, then you can calculate the modes (same as in FDE solver). Do the same for *port_2* to select thefundamental TE mode for the InP waveguide. In this simulation, we can set *port_1* as the input and *port_2* as the output.

2. Run the simulation (it may take 5 minutes). After it is finished, go to the *EME analysis Window* and click *eme propagate*. Since we put an *EMEProfileMonitor* in our simulation, by eme propagate it is intuitive to see how the light propagates. Right-click on the *field_coupling* and visualize the field profile. Provide a screenshot of the field profile. You can clearly see how the light propagates through the structure, if you did every step correctly.

3. In the final task, we would like to investigate a bit more how the length of the taper(s) affects the coupling efficiency. Go to the top right side of the *EME Analysis Window*. Enable the *propagation sweep* and choose *group span 2* (which is the taper part in our structure) for the *parameter*. Choose a start and stop value for the length and then click *eme sweep*. After it is finished click on *visualize eme sweep* and you will find several data sets. For our simulation we are only interested in S21 so you can remove all the other Attributes. To access the coupled power with respect to the length of the taper, select the proper function/unit under the *Scalar operation* and take a screenshot of the result you get. What is the minimum length if we want to limit the power loss to 1 dB?