1 Final Assignment

(1)

See associated scripts:
`1-geometry-setup.lsf`
`1-0-script-fdtd-meshing-accuracy-sweep.lsf`
`1-1-a-geometry-for-mesh-override-sweep.lsf`
`1-1-b-script-for-mesh-override-sweep.lsf`
`1-2-a-geometry-for-source-distance-sweep.lsf`
`1-2-b-script-source-distance-sweep.lsf`

The simulation setup begins with defining the geometry. Two waveguides (L, R) and Disc are <object-defined dielectric> with $n = 3.45$ and Substrate is a rectangle with $n = 1.45$.

The following parameters define the geometry in script.
L is defined by: x|max=-g/2, x|min=-3.2e-6, y=0, y span=400e-9, z min=0, z max=250e-9, n=3.45;
R is defined by: x max=+3.2e-6, x min=+g/2, y=0, y span=400e-9, z min=0, z max=250e-9, n=3.45;
Disc is defined by: x=0, y=640e-9, z min=0, z max=250e-9, r=340e-9, n=3.45;
Second disc for (4) is defined by: x=0, y=-640e-9, z min=0, z max=250e-9, r=340e-9, n=3.45;
Substrate is defined by: x=0, x span=4.4e-6, y=0.4, y span=3, z max=0, z min=-5e-6 n=1.45;
FDTD simulation box is defined by: x=0, x span=4.3e-6, y=0.4e-6, y span=2.9e-6, z=0.2e-6, z|span=3e-6, n=1;
Boundary conditions: stretched coordinate PML, standard,

Mesh override is defined by structures: Disc, L and R, with the buffer of 50 nm, which allows for the space between the disc and the waveguides to be meshed with the desired accuracy. A limiting factor to the simulation time is length of the waveguides. It is difficult to predict what would be the shortest possible waveguide to facilitate fidelity of simulation, however, length of 3 um must be around the optimal value, as comparable length is used by the authors of the original publication.

To define the source as a right or left-handed polarized wave, one can use superposition of two sources (Ex, Ey) in the same exact position, where each is defined by plane wave with polarization angle and phase difference both set to 90 deg at desired wavelength.

Turning off `optimize for short pulse` proved to produce more reproducible result by allowing more time for the pulse to propagate in the system.

The results of the meshing accuracy show that for the mesh override of >20 nm in all directions, the setting does not influence the simulation results (Figure 1).

The mesh override then is one of the critical parameters. Unfortunately, the system converges rather poorly when the size of the mesh override dx, dy and dz is decreased (Figure 2). However, below 10 nm there are not many fluctuations, hence the preference.

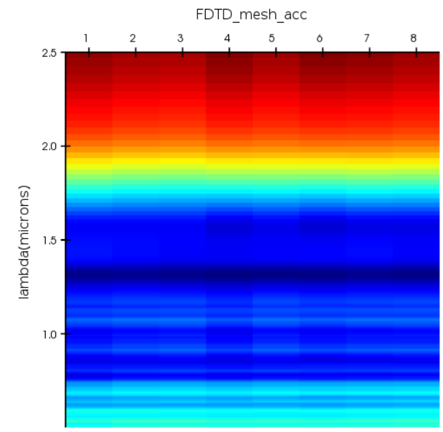

Figure 1: FDTD meshing accuracy sweep (1-8) against transmission of the left waveguide.

Careful selection of the source also plays a major role. E- and M-dipoles, Gaussian beams and Plane wave-sources were tested for convergence. The tests indicate that the dipoles and the Gaussian beams are, expectidly, very sensitive to their positioning in x, y, and z coordinates. Therefore the plane wave source is preferred for its robustness.

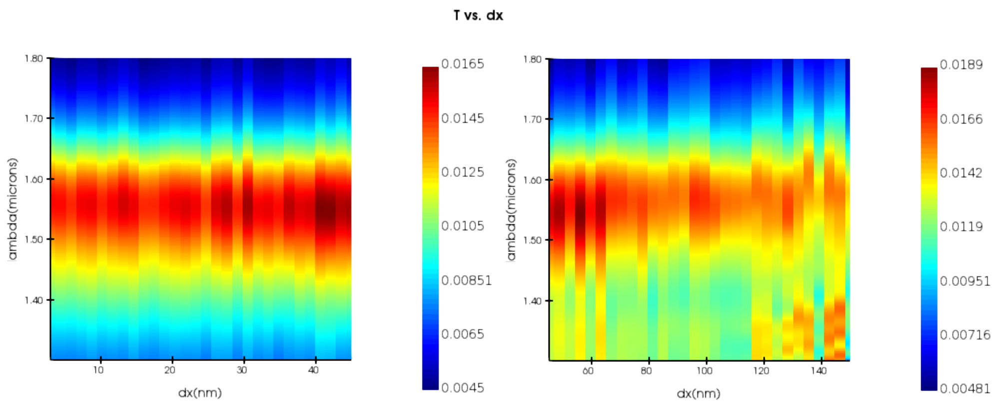

Figure 2: FDTD meshing override sweep: 3-45 nm (left) and 50-150 nm (right) against transmission of the right waveguide.

Finally, the separation between the source and the surface of the structure plays key role. It has to be at least as large as the maximal wavelength, however, any separation larger than 2 um produces the same result (Figure 3). Importantly, this would not be the case for the other aforementioned sources.

(2)

Associated script: `2-gap-sweep.lsf`

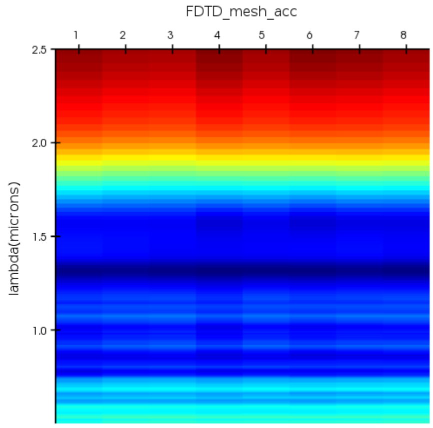

Figure 3: Sweep of the distance between the source and the top surface of the structure against transmission of the left waveguide.

The article mentions α, β as coefficients of power in corresponding waveguides for either left- or right-hand circularly polarized light. To plot the required parameters α, β we have to measure the transmission (or, equivalently, power, because the two differ only by a multiplier, not in character) in left and right waveguide with combination of circularly polarized light. Because we would like to determine the peaks of these functions, we have to make sure the plane monitors, which are placed at the cross-section of the waveguide, are in such positions to measure maximal power. For this purpose we sweep position of left and right monitors and plot their transmission (Figure 4). Once these positions were determined, a sweep could be performed to plot the α, β and FOM (Figure 5). It is important to note that symmetric positioning of the monitors produces fluctuating results.

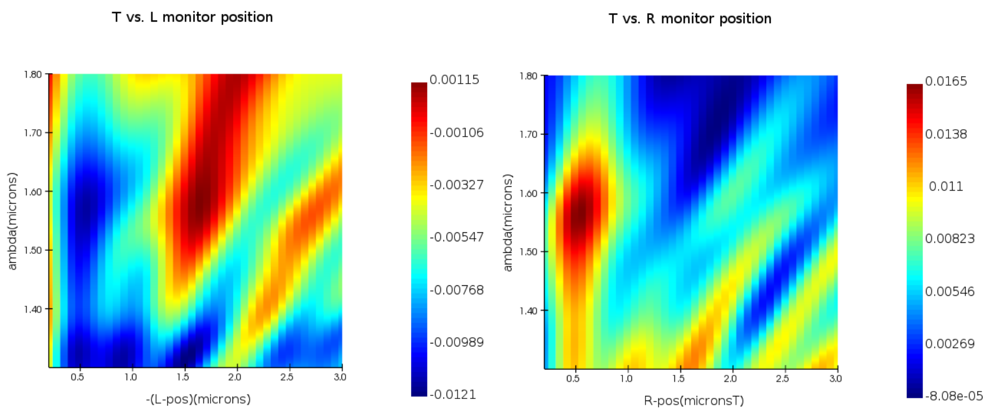

Figure 4: Sweeps for left and right waveguide transmission against position of 2D power monitors.

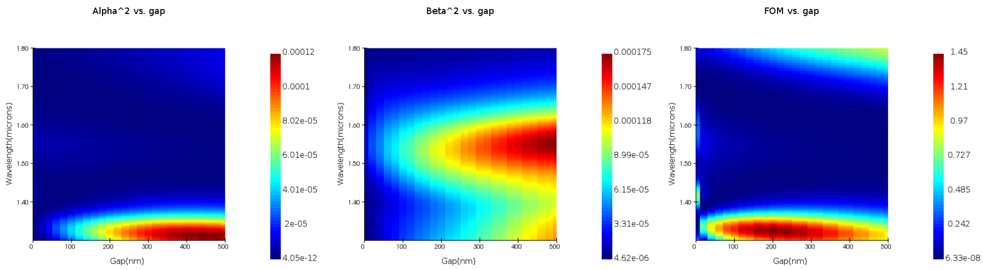

Figure 5: Sweeps for left and right waveguide transmission against the gap, and the figure of merit.

(3)

Associated script: `3-geometry-fields-imaging.lsf`

To reproduce the results of Fig. 1(b,c) we have to excite the modes most efficiently. For this we can use superimposed Gaussian beam sources, whose phase and polarization is offset by 90 deg, situated directly above the center of the disc at the distance of 450 nm above the disc surface. To optimize the simulation time and increase quality of reproduced images, most illustrative guiding condition were found for fields inside waveguides and disc, and Poynting vector propagation was recorded at different heights and using different size of monitors (Figure 6).

(4)

Associated scripts:
`4-1-a-geometry-one-disc.lsf`
`4-1-b-plot-one-disc.lsf`
`4-2-a-geometry-two-discs.lsf`
`4-2-b-plot-two-discs.lsf`

In order to reproduce the reception experiment, a sweep was set up to change the polarization angle of the single plane-wave source from 0 to 360 degrees in a number of steps while simultaneously recording the transmission of one of the waveguides. After running the simulation with single disc present, a second disc was added to the simulation, and the process was repeated (Figure 7).

(5)

Associated scripts:
`5-a-geometry-emission.lsf`
`5-b-sweep-emission.lsf`

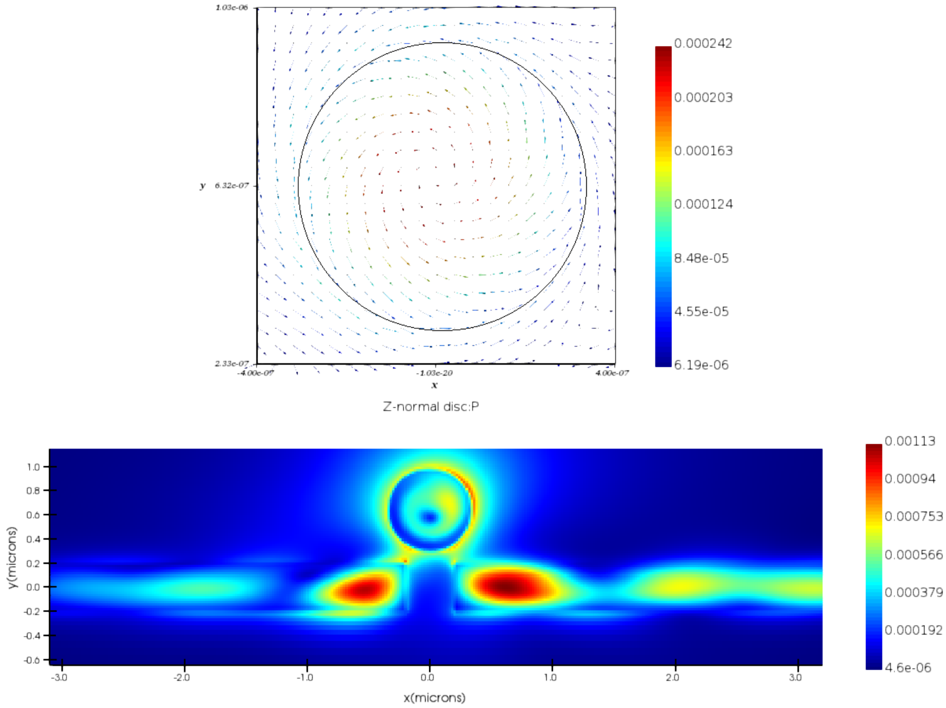

Figure 6: Poynting vector plots (vector and intensity) for the modelled system.

In order to reproduce the results of the emission experiment, power was introduced into the system via the fundamental modes of the two waveguides, directed towards the disc. The emission of the disc was measured by a plane frequency and power monitor right above it and with the same overall dimensions.

The sweep parameter in this case is the phase difference between the sources, running from 0 to 720 deg (Figure 8). The data from the monitor was exported to Matlab and converted to a polar plot with normalized intensity in grey-scale by the following script:

```
M=readmatrix("data.txt");
img=mat2gray(M);
[h,w,¬] = size(img);
s = min(h,w)/2;
[rho,theta] = meshgrid(linspace(100,s-1,s), linspace(0,2*pi));
[x,y] = pol2cart(theta, rho);
z = zeros(size(x));
subplot(121), imshow(img)
subplot(122), warp(x, y, z, img), view(2), axis square tight off
```

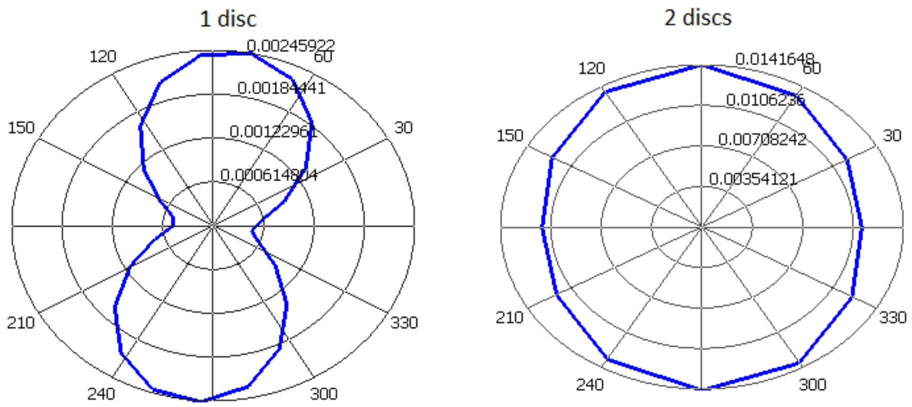

Figure 7: Transmission in the waveguide as function of polarization angle of the source for the system containing one (left) and two (right) discs.

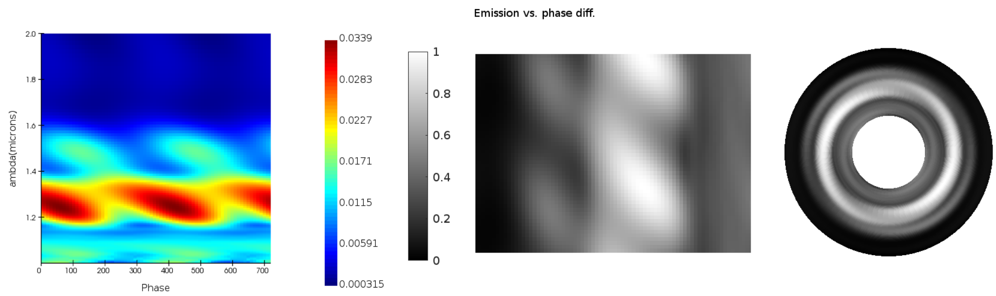

Figure 8: Emission above the disc as function of the phase difference between the sources in the waveguides. Left image: Lumerical. Middle and right images: post-processing in Matlab.

(6)

Associated script: `6-mode-overlap.lsf`

We can supplement the brute-force sweep of the gap with a different simulation. Instead of re-running the full simulations concurrently, which demands long computation time, we can obtain similar result with only two simulations. The only significant difference between this simulation and the initial setup is the presence of a mode expansion monitor with the same position as one of the power monitors in, for example, the left waveguide. First, the system is computed as usual, and one of the modes is selected. Second, the system is slightly changed: the index of the waveguide under test is set to 1.0, which makes it consist of air but hold the same mesh override, the second waveguide is removed completely. A chosen number of power monitors is placed along the "air" waveguide close to the zero-X and the simulation is ran to capture the fields of the modes of the disc at these selected positions. Then the mode profiles (Figure 9) are extracted from the aforementioned monitors and the mode overlap is calculated with respect to the selected mode in the actual waveguide. This graph of the overlap shows the most effective position of the waveguide to couple light from the disc into a waveguide. The results for both TE01 and TM01 modes (Figure 10) suggest total gap of 800 nm, which is not the same as the optimal gap found previously. This can be contributed to non-optimal mesh override size and difference in material models used in simulation. The intricate shape of the modes provides insight in the distribution of the energy, which reassures the importance of determining the position of maximal energy concentration along the waveguides.

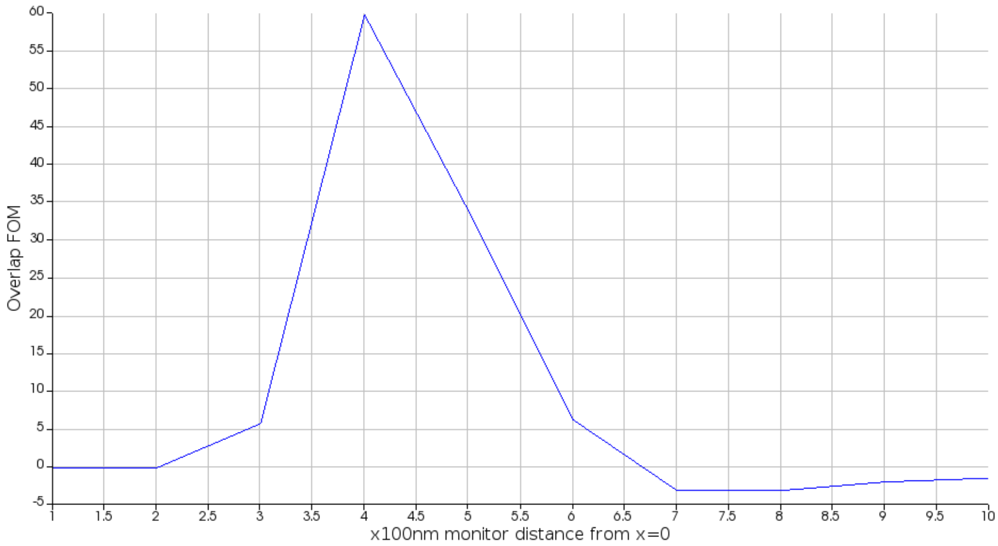

Figure 9: Calculated mode overlap versus position of the monitor.

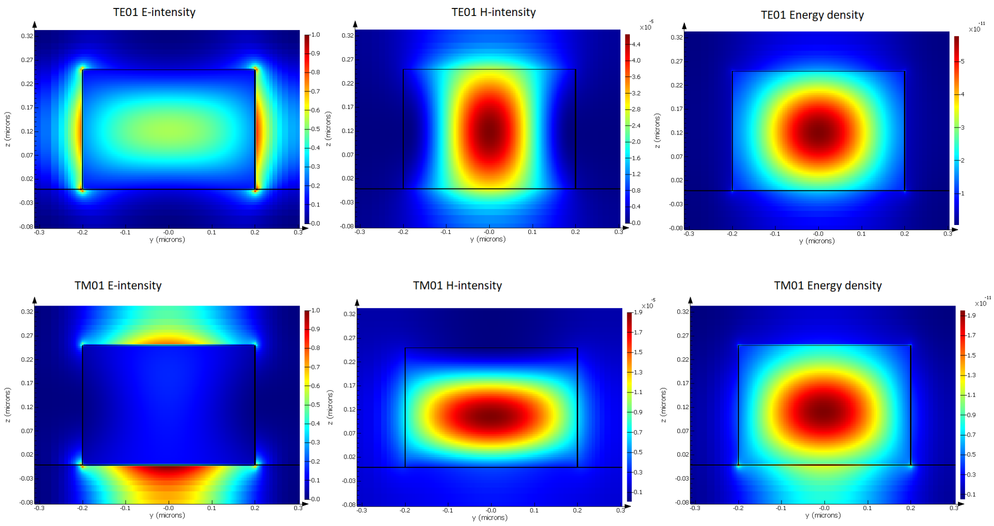

Figure 10: Mode profile of TE01 (top row) and TM01 (bottom row) modes in the waveguide. Left: E-field intensity. Middle: H-field intensity. Right: Energy density.