Solution to Problem Set 7
Optical Waveguides and Fibers (OWF)

Exercise 1: Effective-index method applied to a rib waveguide.

Consider the rib waveguide shown in Fig. 1. The effective index of the guided modes of this waveguide can be calculated by approximating the structure with related slab waveguide. In a first step, we need to calculate the effective indices of two horizontal slab waveguides of different thicknesses, corresponding to the slab heights in the regions 1 and 2, as indicated in the figure. We will then use these indices to define a new vertical slab waveguide. The solution of that waveguide will give the effective index of the rib waveguide mode.

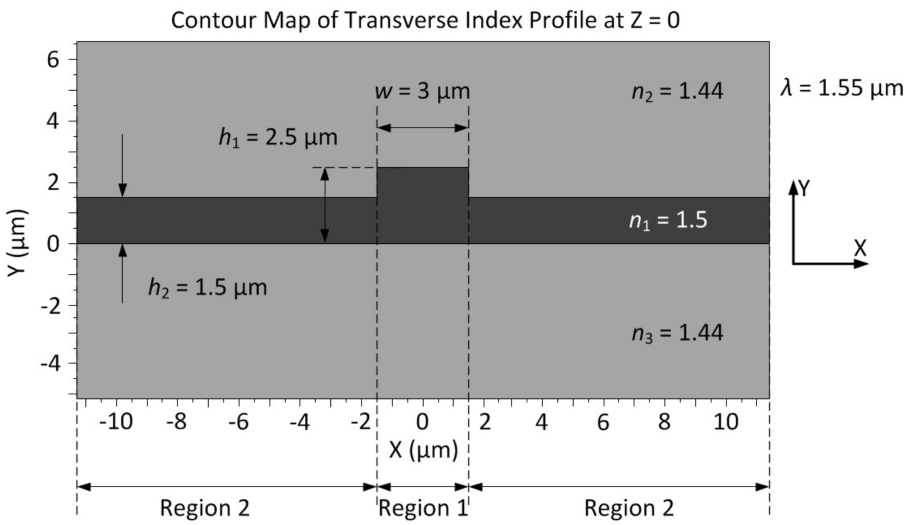

Figure 1: Rib waveguide with the definition of the dimensions and the refractive indices.

a) Assume a wavelength of $1.55\,\mu$m, and consider the $\mathcal{E}_y$-modes only. Choose the appropriate polarization and calculate the effective indices n_{es1} and n_{es2} in the two horizontal slab waveguides corresponding to the regions 1 and 2 in Fig. 1. You can either use the matlab code you already prepared in the Problem Set 4, or the online solver available on the following website:

   http://www.computational-photonics.eu/oms.html.

   Solution: Since we are looking for $\mathcal{E}_y$-modes that have the non-vanishing components $\mathcal{E}_y$, $\mathcal{E}_z$ and $\mathcal{H}_x$, we need to use the TM polarization. For the regions 1 and 2, we get the following values for the effective indices: $n_{\text{es},1} = 1.4727$, $n_{\text{es},2} = 1.4849$.

b) Choose again the appropriate polarization, and calculate the effective index of the fundamental mode in the vertical slab waveguide defined by n_{es1} and n_{es2}. How many guided $\mathcal{E}_y$-modes exist?

   Solution: We need to use the TE polarization here. Using the effective indices calculated in a), results in $n_e = 1.4790$. There is only one guided $\mathcal{E}_y$-mode. A numerical simulation of this structure (assumed to be correct) yields $n_e = 1.4785$.

c) Consider now a channel waveguide (rectangular cross section) made of silicon ($n_1 = 3.48$) and surrounded by silica ($n_2 = 1.44$). The width and the height of the waveguide are $w = 0.4\,\mu$m and $h = 0.2\,\mu$m, respectively. Calculate the fundamental $\mathcal{E}_y$-mode by using the same method as before.

   Solution: By using the same method as in a) and b), we first solve a horizontal waveguide and get $n_{\text{es},1} = 1.8922$. In the next step, we define a vertical slab waveguide with the refractive index of the slab equal to $n_{\text{es},1}$, and get $n_e = 1.6595$.

d) Exchange the height with the width ($w = 0.2\,\mu$m and $h = 0.4\,\mu$m) i.e., rotate the waveguide by 90°, and calculate the fundamental $\mathcal{E}_x$-mode. Compare this result with the result that you got at c) and explain the differences.

Solution: In this case, the TE polarization has to be used in the first step, and the TM polarization in the second. This gives $n_{\mathrm{es},1} = 3.1942$ and $n_e = 1.7612$. We got different results in c) and d), but in fact, they should be equal. The thing is that the initial conditions for using the effective index method are not fulfilled in both cases, namely, the index contrast is too high. The numerical calculation (assumed to be correct) yields $n_e = 1.5843$. We see that the estimation in c) is better than the estimation in d). This is because the effective index method works better for waveguides with a large aspect ratio (width divided by height.)

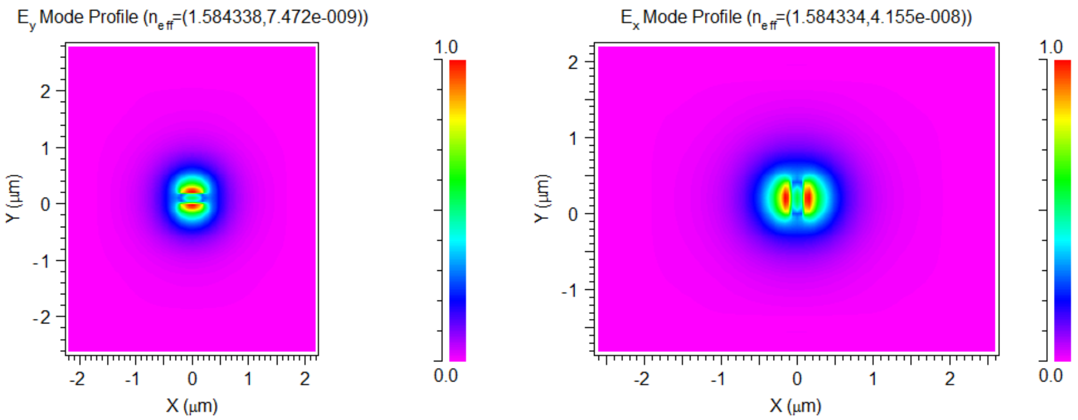

Figure 2: Numerical simulation of part c) (left) and part d) (right.)

Questions and Comments:

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