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Assignment No. 4
Design and simulation of a spot-size converter for edge coupling

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1 Abstract

In this assignment, a structure of an efficient novel Spot-size converter (SSC) or an inverse taper having submicron-thick over cladding has been constructed which helps us to understand the design parameters which one should taken into account to achieve high transmission efficiencies and coupling of modes across passive optoelectronic devices. The light propagation in the proposed SSC structure was simulated in MODE solutions using a plane wave source operating at wavelength of 1.5 μm. The transmission efficiency and field profile has been obtained for different taper length and wavelength range through the graphs shown in different figures across the assignment. The result demonstrates high transmission efficiencies for SSC with size greater than 140 microns by taking into consideration the CVCS subcell method of the EME solver in the MODE solutions .Also the field profile attribute helps us to analyze the variations in the fields when the plan wave source propagates inside the structure where ripple around the variations are evidence of poor coupling.

2 Introduction to the concept of Edge Coupling

The whole assignment mainly centered around the concept of edge coupling. Edge coupling, also known as end fire coupling, is the standard technique for coupling to and from a single-mode fibre for most photonic devices such as DFB lasers, modulators, and high-speed detectors. Edge coupling generally offers a very broadband response and features low insertion loss (lower than 0.5 dB). It also couples both TE and TM polarizations. The challenges with edge coupling are related to the need for precision alignment, polishing/etching the facet, beam astigmatism, and the need for anti-reflection coatings.

Therefore this whole concept generally requires addressing both the mode-size mismatch as well as the effective index mismatch of the fibre and waveguide modes when we assumed it for the coupling of modes from the fiber to the waveguide. Therefore in the next subsequent sections I discuss the design and modelling of a novel spot size converter geometry. For the purpose ,the proposed structure is designed and optimized using EME solver of the Lumerical MODE solution.The EME method is generally considered as one of the ideal solvers to design passive optoelectronics devices due to its ability to sweep comparatively large lengths quickly without having to calculate any additional modes.

3 Simulation Setup of the proposed SSC

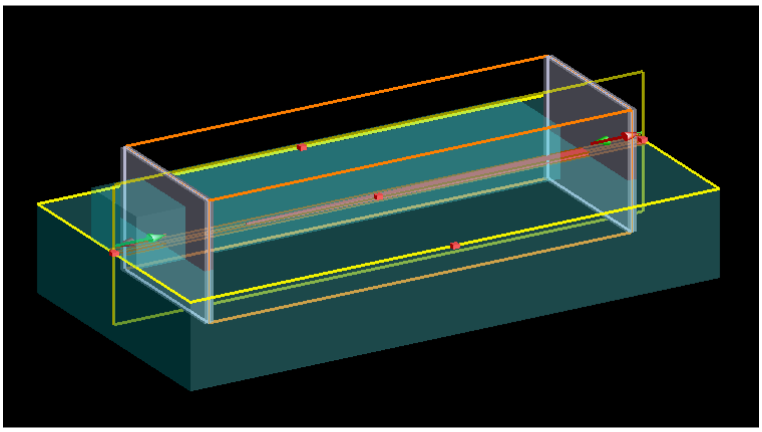


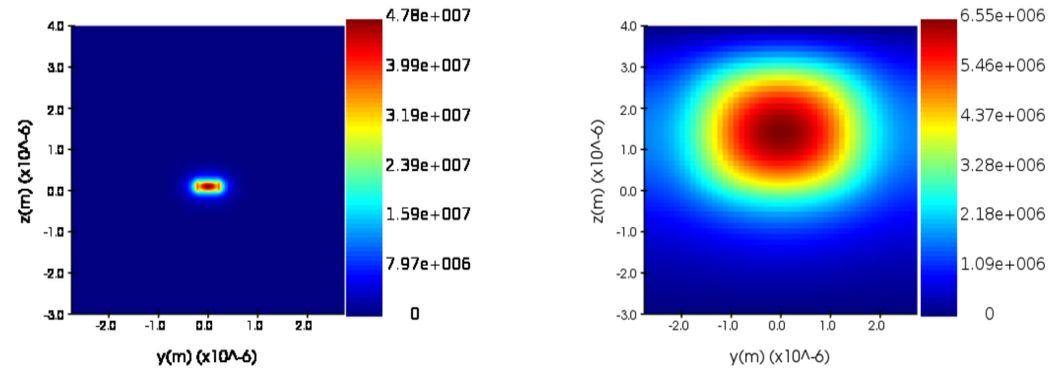
Figura 1: Proposed Spot Size Converter (SSC) designed in Lumerical MODE solution

The proposed structure of the spot size converter for edge coupling consist of a substrate (n=1.465), a high index input waveguide (Si, n=3.47), the tapered portion of the high index waveguide with varing y-span, and low index polymer waveguide (SiON,n=1.5) which act a sub micron cladding for the inverse taper, as shown in Fig. 1. The simulation area is defined in the

XY plane with perfectly matched boundary conditions.
The bidirectional eigenmode expansion (EME) solver is used to design and optimized the proposed SSC structure. For the analysis three different cell groups are used.One of which is for the input waveguide, another one for the tapered region and the last one for the output waveguide. A finer transverse mesh is used over the tapered section of the high index waveguide using the mesh override function.Apart from this, two monitors namely the EME index & EME field profile are added to study the refreactive index variation and field intensity distribution across the proposed SSC structure.
A parameter sweep is performed by varying the length of the nano-taper, to determine the length required for efficient coupling.Similarly sweep for the wavelength was performed to determine the suitable wavelength for max transmission efficiency. Also, apart from all this the S paramtere matrix was calculated for different taper length (for 10,50,100,200 μm) to visualize the insertion and return loss associated with the structure.

4 Results and Discussions

In this section,I try to provide a concise and intuitive observations about the objectives that were asked in the given assignment. Firstly, I plot the mode profile at the input and output port of the



(a) Mode Profile at the Input Port or Port 1

(b) Mode Profile at the Output Port or Port 2

Figura 2: Mode Profile at input and output port of the SSC

designed SSC as shown in Fig 2. As we know that mode profile shows us the intensity distribution across the device, here also the small round mode profile in the first part signifies the mode intensity distribution at the very first port 1 which is much smaller in comparison to the another port 2 where the mode intensity distribution is quite large due to their respective size of the facets, which is quite evident from the figure. In the second part of this figure, I do observe some evacasent fields which are escaping out from the output port or port 2 . I believe this thing can be corrected if we model the output port dimension a little bit which will eventually lead to proper couling of modes across the SSC length.

The Fig. 3, represents the index variation (top view) across the whole region or structure which comprises of the cladding, inverse taper and the substrate. It can be easily conclude from the figure that the mode will properly confine across the inverse taper due to large index contrast of it in respect to the other parts of the whole structure SSC.

Here in Fig. 4, the transmission through the taper is analzed for taper length ranging from 10 μm to 200 μm in part 1 and wavelength ranging from 1.5 to 1.6 microns in part 2 with the CVCS (Continuously Varying Cross-sectional Subcell) method in MODE Solutions. The main reason behind choosing this method is to avoid the stair casing effect which help in resolving geometrical or material variations along the direction of propagation.

The coupling efficiency of the spot size converter can be judged from the field profile graphs

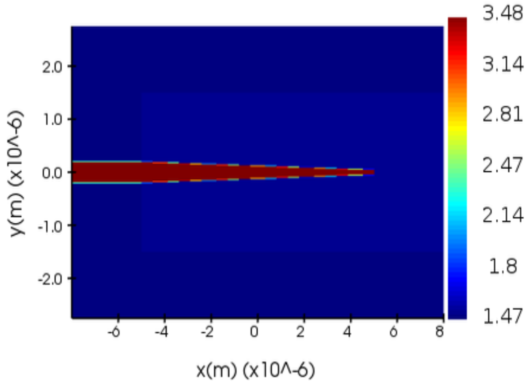
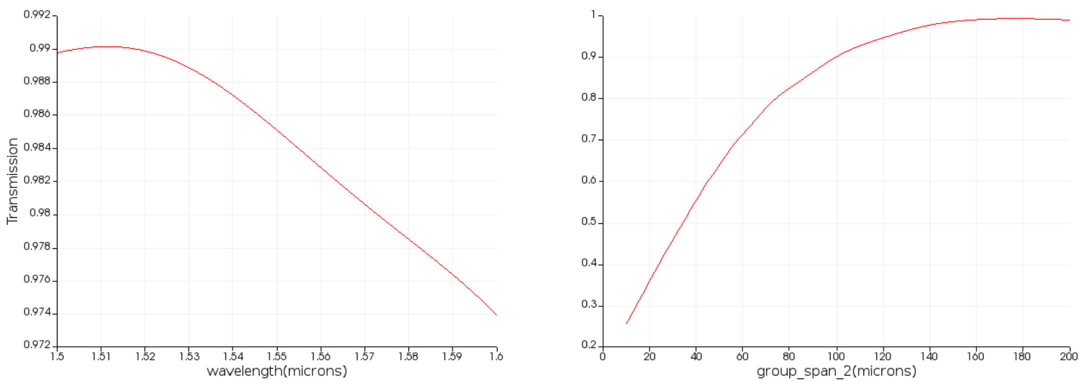


Figura 3: Index variation across the SSC structure

along different propagation lengths as shown in Fig. 5 .Here the discontinuities in the end of these graphs represents the extent to which the coupling has been affected.



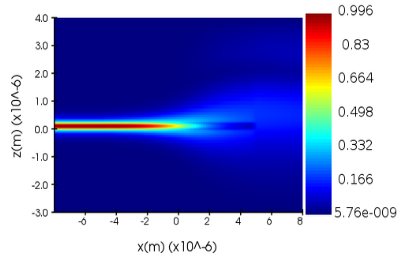
(a) Plot of transmission as a function of wavelength in the interval [1.5-1.6 μm]

(b) Plot of transmission as a function of taper length in the interval [10-200 μm]

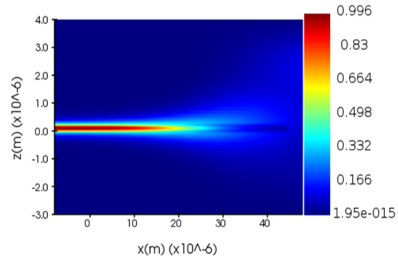
Figura 4: Transmission as a function of taper length and wavelength

The simulated results show that a 120 microns-long adiabatic inverse taper can achieve a transmission of around 98.3%. The second part of Figure 5 shows the transmission spectra. The Si wire waveguide terminated with the conventional SSC exhibited a significant decrease of transmittance around a wavelength of 1510 nm, which would be due to the absorption of N-H bonds remaining in the SiON layer. I have read in a paper by Yuriko Maegami on "Spot-size converter with a SiO2 spacer layer between tapered Si and SiON waveguides for fiber-to-chip coupling", that if we want to reduce the N-H absorption of the SiON secondary waveguide a SiO2 spacer must be inserted between the Si tapered waveguide and the SiON core of the secondary waveguide. In this way,I believe we can actually avert the decrement of the transmission for the given wavelength to some extent.

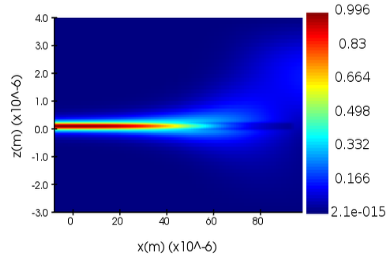
After this, I came down to analyse the real and imaginary part of the scattering matrix which we calculated for successive taper lengths 50,100,200 μm, the values of which are tabulated in table 1. Since the S-parameters are generally complex, therefore the real values matrix represents an amplitude response while the imaginary values matrix represents the phase response.From the basic definition, the Scattering parameters (S-parameters) are basically used to describe the behaviour of a linear time-invariant network. Traditionally, this concept is used to describe the response of electrical devices as a function of frequency. S-parameters are particularly useful for experimental characterization of electrical devices, using a vector network analyzer (VNA). They can also



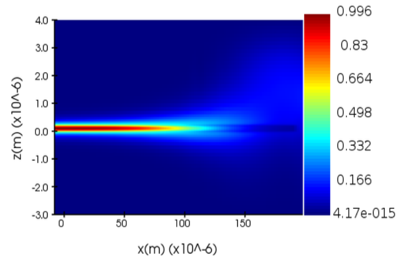
(a) Field profile-XZ for 10 μm taper



(b) Field profile-XZ for 50 μm taper



(c) Field profile-XZ for 100 μm taper



(d) Field profile-XZ for 200 μm taper

Figura 5: Figure shows the simulated results for the field propagation down the taper, for the top and cross-section views.The simulation shows some spatial oscillations, which are due to the reflection at the oxide–air interface. The field is seen to expand as it propagates from left to right.

be used to describe optical devices, with experiments conducted using an optical vector network analyzer (ONA). In both cases, measurements are performed over a range of frequencies – typically GHz frequencies in the electrical RF domain and THz frequency in the optical domain.

The S-parameters are generally complex, meaning they include an amplitude response and a phase response. In most cases the main focus of interest is always been the amplitude response rather than the phase. However while building circuits (e.g. ring resonators, interferometers), the phase response needs to be included in the compact model.

A two-optical-port device (e.g. section of a waveguide, a waveguide taper, a waveguide bend, a fibre grating coupler), can be described as a matrix

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = S \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \tag{1}$$

where a_1 describes the light incident on the device on port 1, b_1 describes the reflected light, b_2 describes the transmitted light, S_{11} is the reflection coefficient, and is S_{21} the forward gain. The other parameters are similarly defined for light incident on port 2 and, in particular, there can be light incident on both ports simultaneously.

Common parameters for describing optical devices are the return loss,$RL = -20log_{10}|S_{11}|[dB]$,and the insertion loss,$IL = -20log_{10}|S_{21}|[dB]$. Therefore, in order to draw some meaningful inference from this s-parameter section of the given assignment, I calculated the insertion loss and return loss associated with each of the different taper length geometries which ultimately provide me a direction to choose the most apt geometry while building such device.

Since passive optical devices are reciprocal, the same transmission result should be obtained by having the incident light on port 2, or $S_{12} = S_{21}$.Thats the main reason why we are getting the same values of S_{12} & S_{21} from the calculated matrices for different taper lengths.

T.L.=10μm	T.L.=50μm	T.L.=100μm	T.L.=200μm
$S_{11} = 0.000413025$	$S_{11} = -6.26E - 17$	$S_{11} = 3.67E - 16$	$S_{11} = 6.77E - 16$
$S_{12} = .505452$	$S_{12} = 0.48125$	$S_{12} = 0.33525$	$S_{12} = 0.611192$
$S_{21} = .5054520$	$S_{21} = 0.48125$	$S_{21} = 0.33525$	$S_{21} = 0.611192$
$S_{22} = -0.00214114$	$S_{22} = 4.11E - 16$	$S_{22} = -9.04E - 17$	$S_{22} = 1.05E - 15$

Tabela 1: Real S-Matrix values for different taper length (T.L.)

T.L.=10μm	T.L.=50μm	T.L.=100μm	T.L.=200μm
$S_{11} = -0.000170797$	$S_{11} = 2.76E - 17$	$S_{11} = -5.80E - 16$	$S_{11} = -7.86E - 16$
$S_{12} = -0.00919373$	$S_{12} = 0.64021$	$S_{12} = -0.888287$	$S_{12} = 0.78499$
$S_{21} = -0.00919373$	$S_{21} = 0.64021$	$S_{21} = -0.888287$	$S_{21} = 0.78499$
$S_{22} = -0.00323528$	$S_{22} = 1.87E - 16$	$S_{22} = 1.55E - 15$	$S_{22} = -1.43E - 15$

Tabela 2: Imaginary S-Matrix values for different taper length (T.L.)

The S_{21} value from table 1 has been used into table 3 to analyse the trend in the insertion loss for different taper lengths. Insertion loss in generic term can be defined as the extra loss produced by the introduction of the device under test (DUT) between the 2 reference planes of the measurement. From the table 3 we can clearly see that there has been there has been increment in the insertion loss till 100 microns value however when we visualize it on the 200 micron taper length it comes out to be pretty much less in comparison to all the taper length which we have taken into account. It can be justified from the transmission vs taper length graph shown in second part of Fig. 4 where we get max transmission efficiency for 200 micron taper length in comparison to any other taper length which we analysed.

5 Conclusion

Here in this work,a novel SSC structure has been designed. Where different performance indicators like S-matrix, mode profile, index variation, transmission spectra etc were evaluated for different taper length. This utimately lay the foundation for designing efficient spot size converter for a desired application.

	$IL = -20log_{10}\|S_{21}\|[dB]$
T.L.=10μm	5.926
T.L.=50μm	6.352
T.L.=100μm	9.492
T.L.=200μm	4.276

Tabela 3: Insertion Loss (IL) in the taper for different taper lengths