

## **Integrated Design and Simulation Tools for Silicon Photonic Arrayed Waveguide Gratings.**

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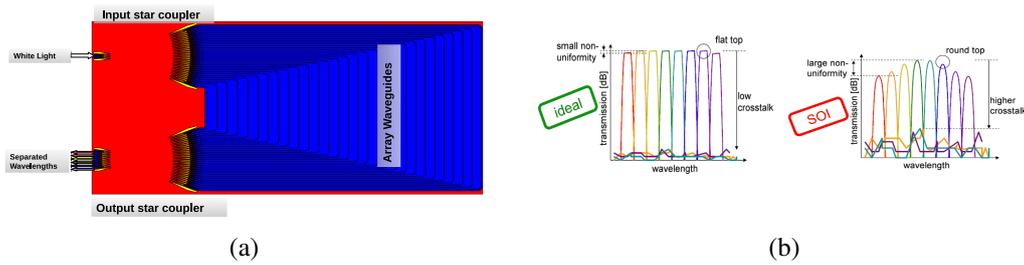
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*We developed a semi-analytical simulation tool in Python for arrayed waveguide gratings (AWG) integrated with our mask design framework. Our simulation model calculates the transmission matrices of all the parts of AWG using the most suitable tools for different structures. This framework allows us to design, simulate and finally fabricate using the same script. Simulation results of our semi-analytical model are very similar to the experimental results. This framework allows us to use a cyclic work flow between design, simulation and fabrication for improved AWG.*

### **Introduction**

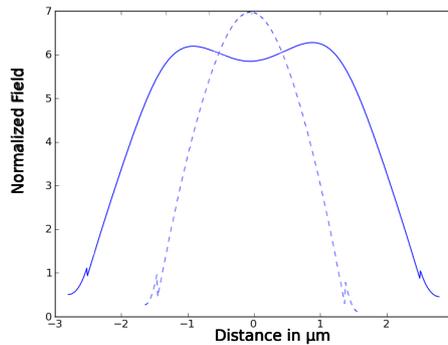
Wavelength Division Multiplexing (WDM) components and systems have more and more commercial interest because of high transmission capacity and more flexibility in the telecommunication network. One of the vital components in WDM systems is the Arrayed Waveguide Grating (AWG), which works as both wavelength division multiplexer and demultiplexer. An AWG consists of two free propagation regions called star couplers and an array of waveguides with a linear increment length. Figure 1(a) shows a schematic diagram of a 8X200 GHz AWG. A light beam propagating through the waveguide enters into the first star coupler and diverges. On arriving at the output apertures of the input star coupler, the light beam is coupled with the arrayed waveguides and propagates through it towards the input aperture of the second star coupler. The length difference of the array waveguide is  $\Delta L = m \cdot \frac{\lambda_c}{N_g}$ , where  $m$  is the order of the phased array,  $\lambda_c$  is the center wavelength in vacuum, and  $N_g$  is the effective index of the waveguide. For this center wavelength the fields arrive at the input aperture of the second star coupler with equal phase, will interfere at the free space region and generate an interference pattern at the output aperture of the star coupler. In this way for center wavelength input field at the object plane is transferred to the center of the image plane. [1] For other wavelengths the fields arrive at the input aperture of the second star coupler are no longer in the same phase due to the periodic increment of length of the array waveguides. So the interference pattern at the output aperture of the second star coupler is shifted from the center of the image plane for different wavelengths and by placing a waveguide at the proper position we will receive fields for each wavelength at different output waveguides.

For many applications, a flattened passband is required in WDM systems. By placing a short multi mode interference (MMI) power splitter at the end of the input aperture of the input star coupler is one of the methods to achieve this goal [1]. The length of the MMI is chosen such a way that it produces a twofold image of the input field at the end of the MMI aperture [2], which is shown in Figure 2. By changing the MMI width we can control the



**Figure 1:** (a) Schematic diagram of 8X400 GHz AWG consists of input star coupler, array waveguide and output star coupler. (b) Transmission spectrum of a 8X400 GHz AWG for ideal case and On SOI

separation between the peaks to achieve a flattop pattern at the output of the AWG. Main drawback of this method is high insertion loss due to the mismatch between the input field and the mode of output aperture.



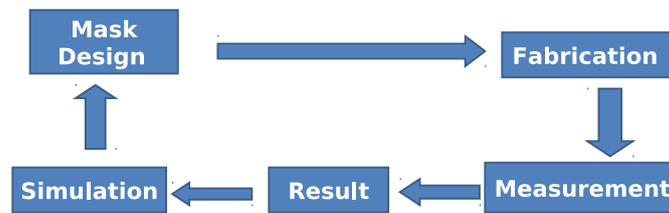
**Figure 2:** Field pattern of a MMI aperture (solid lines) and field pattern of a aperture without MMI (dashed lines).

## Simulation Framework

Our simulation framework is fully integrated with our design framework, which contains a library of photonics components and AWG is one of components of this library. All the components available in this library are parametrized cells (P Cells) enriched by mixins. Using a simple script it is possible to design AWG with large parametric sweep.

### Cyclic Work-flow

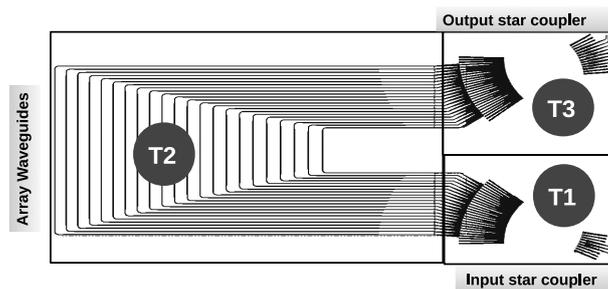
Our simulation framework creates a cyclic work-flow between design and fabrication. Figure 3 shows the diagram of cyclic work-flow between simulation, diagram, fabrication and results. A pre-simulated design is fabricated and measured. This measurement results gives a deviation between simulated design and fabricated structures by comparing with simulation results. The deviation helps to know about the fabrication limitation and dependence with mask design which introduces a correct modification of the mask design for better result.



**Figure 3:** Diagram of Cyclic work-flow.

### Simulation of AWG

Our approach is to calculate the transmission matrices(T matrix) of all the parts of the AWG and multiplication of all the T matrices gives the T matrix of the entire AWG. Figure 4 shows our simulation approach for a AWG. Let consider a AWG have  $n$  number of input,  $m$  number of output channels and  $p$  number of arms. Then the T matrix of the input star coupler is  $T1_{np}$ , T matrix of the output star coupler is  $T3_{mp}$  and T matrix of the array waveguides is  $T2_{pp}$ . So T matrix ( $T_{mn}$ ) of the AWG is equal to  $T3_{mp} \cdot T2_{pp} \cdot T1_{np}^T$ .



**Figure 4:** Diagram of Simulation approach for a AWG.

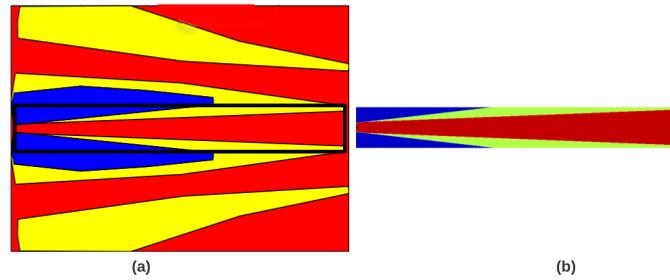
Approach for T matrix calculation for both star couplers is same. First we simulate the mode profile of the input aperture of the star coupler by the help of mode solver called CAMFR. Figure 5(a) shows input aperture of a star coupler and Figure 5(b) shows the selected portion of that aperture use for input mode profile simulation by CAMFR called CAMF stuck. Mode profile of this CAMFR stuck is used to calculate the field in the slab region by the free propagation calculation and finally to construct the T matrix, we overlap the field with mode profile of output aperture the star coupler after the angle correction of each and every input and output aperture. For the array waveguides T matrix calculation is the transmission of waveguides with certain increment of lengths.

### Compare Between Simulation and Experimental Result

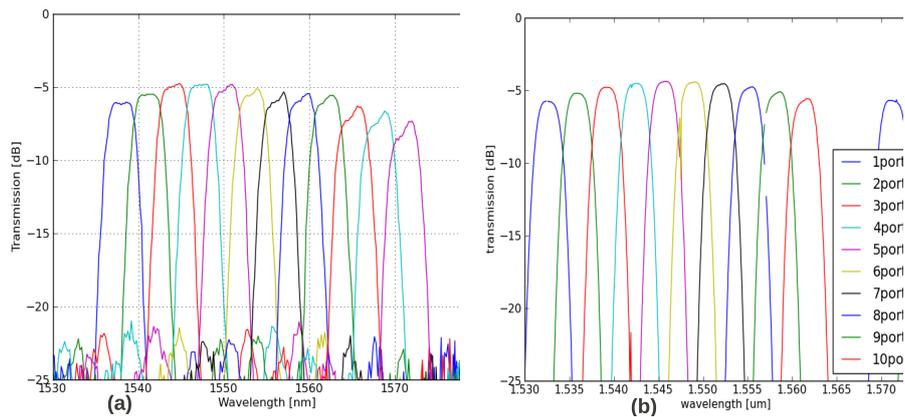
We compare the simulation result(Figure 6(b)) with our measurement result (Figure 6(a)), for MMI input AWG, where both the design of AWGs are identical.

In both cases

- a. center channel loss is around -5 db.



**Figure 5:** (a) Aperture of the star coupler. (b) Selected portion of the aperture use as a CAMFR stuck.



**Figure 6:** (a) Measurement result of a mmi input AWG. (b) Simulation result of a mmi input AWG.

- b. only 3<sup>rd</sup>, 4<sup>th</sup>, 5<sup>th</sup> channel have flat top behavior.
- c. 1<sup>st</sup> and 2<sup>nd</sup> channels have little bit increment at the left side.
- d. Rest of the channels on the right side have increment in the right side.

## Conclusion

From above compared results we can concluded that our simulation framework is reliable for AWG simulation which is important for any simulation framework. This will help to demonstrate AWGs with appropriate parameters first in simulation and later in experiment for different applications. In the simulation result the cross talk level is low and the pass band width is narrow compare than the experimental result due to phase noise in the waveguide not taken into account here, but supported by the model.

## References

- [1] Meint K. Smit and Cor van Dam. Phasar-based wdm-devices: Principles, design and applications. *IEEE Journal of Selected Topics in Quantum Electronics*, 2(2), June 1996.
- [2] Daoxin Dai, Weiquan Mei, and Sailing He. Using a tapered mmi to flatten the passband of an awg. *Optics Communications*, 219(1):233–239, April 2003.