Single Mode rib waveguide design using Machine Learning techniques

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Abstract. This work aim to determine a Single Mode (SM) Silicon-On-Insulator (SOI) rib waveguide using Machine learning (ML) techniques, which learn automatically by matching the input data with the target property. Random Forest (RF) is the ML algorithm used in this work. The accuracy of the model reaches 99% by using R^2 score. The device is a rib waveguide based on Silicon (Si), with a cladding made of Silica (SiO_2). The results obtained illustrate the conditions for SM, with the width and the rib etch-depth found to be relatively smaller compared to the total thickness. The ML approach have proven to be quick and effective regarding this problem.

1 Introduction

Waveguides are the fundamental building block for Photonic Integrated Circuits (PICs), allowing to guide, confine and modulate the electromagnetic signal [1]. Therefore, due to the important role of the waveguides, many researchers have investigated different waveguide parameters to achieve adequate proprieties for photonic applications. However, many of these works adopt, or aim to design, Single Mode (SM) waveguides, which is an important and crucial property to reduce modal dispersion and prevent the excitation of higher-order modes. These works rely on different methods and techniques to determine the conditions for SM. For instance, R.A. Soref et. al investigate the SM conditions by using Mode-matching and Beam-propagation methods [2]. These conditions depend on optimization of two coefficients, namely the ratio (H-h)/H in Fig. 1, and a pure number named α [2], which have both received several tunings over the years. For example, Pogossian et al. found different values of these coefficients compared to Soref work [3]. Another common method to find SM is by using complex numerical techniques such as finite element method. However, these methods are time consuming and require high computational resources.

In this work, we develop a Machine Learning (ML) model using Random Forest algorithm to determine the SM property for a rib waveguide based on the same geometry of Fig. 1. The ML approach provides a quick estimation of the concerned property by mapping the input to the output and form a general function approximation. This approach is considered much simpler and quicker than the methods discussed above.

2 Dataset Construction

The type of waveguide used in this work is shown on Fig. 1. The dataset was prepared by using Mode solver of Lumerical modeling software. The geometry of the waveguide was varied while recording the effective index and the polarization of the founded modes.

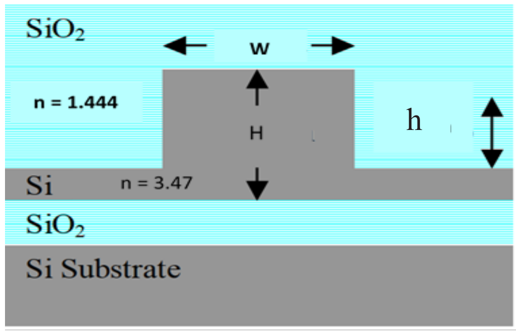

Fig. 1. Cross-section of Rib waveguide

Width, Height, Etch-depth and Polarization are used as inputs for the ML model, while the SM condition is the output, determined by checking that the effective index of the waveguide was higher than that of the slab. If we found only one guided mode for each polarization, then we considered this device as a SM waveguide. This dataset consists of 3096 data samples. Hereupon, we applied a pre-processing methods on the dataset, such as cleaning and imputation, to remove the unmatched and corrupted data samples, and standardization to transform the input in a way that have a mean of 0 and a standard deviation of 1. The pre-processing steps increased the model accuracy by 10%. Then, the dataset was divided into two subsets, one for training the ML model (75% of the samples) and the rest for testing.

3 Random Forest Model Building

Random Forest (RF) is the ML algorithm used in this work, which consists of multiple Decision Trees (DT) [4]. However, the hyper-parameters, such as the number of the DT in the forest and the criterion for nodes splitting, need to be tuned to achieve high accuracy. Therefore, GridSearchCV algorithm was used [5], which process a

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set of parameters and uses cross-validation technique to find the best combination of hyper-parameters. The accuracy obtained is 99% using R^2 metric.

4 Numerical Results and Discussion

Fig.2 illustrates the influence of different features on the SM property, while the black line represents the mean decrease in impurity. The results shows that the Etching-depth has the highest effect on the modes, followed by the waveguide total height. The polarization of the incident light has a negligible effect on the waveguide modes.

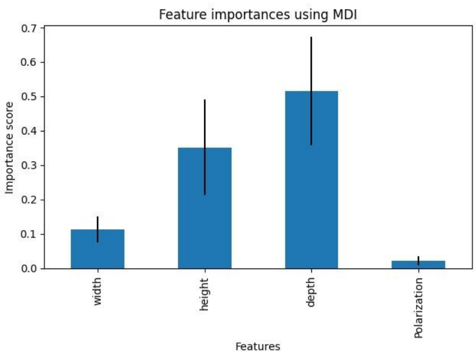

Fig. 2. Importance score of the features

To attempt explaining these findings, we provide an analyses of some SM samples using Lime explainer. The results are shown in Fig. 3, which can be interpreted as follow: an etch depth higher than 1.4μm, has high importance (30%) to produce Multi-Mode (MM) waveguide, which is reasonable because the thinner the slab, the more the waveguide behaves as a ridge one, which has much less ability for showing a SM compared to the rib waveguide [6]. A rib width larger than 1.7 μm also leads to MM waveguide. Interestingly, a thicker waveguide (>1.6 μm) is preferable for SM (29% importance), along with the small etch-depth, as seen before. We can conclude that the etch dept should be smaller than 1.4 μm and the overall thickness should be higher than 1.6 μm.

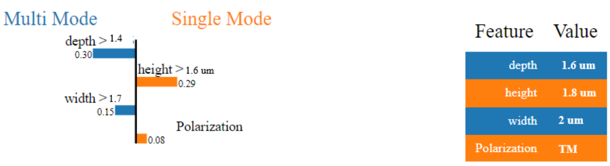

Fig. 3. Explanation of a sample prediction, with parameters and probabilities of getting SM or MM behaviour, and a sample combination of the same for a SM waveguide.

Depending on these results, we fixed the waveguide thickness and varied the width and the etch-depth while predicting the classes of the obtained waveguide geometry. The results are illustrated in Fig. 4, which provides a wide options of width and etch-depth values for obtaining a SM waveguides. Such results were confirmed by means of numerical simulations.

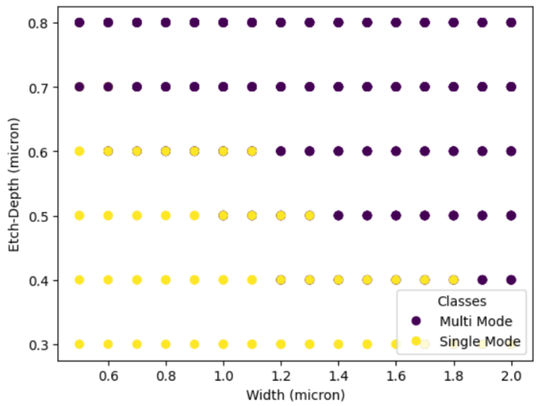

Fig. 4. Mode classification of rib waveguide

5 Conclusion

In this work, we provide a simple and effective method for determining single mode condition for a rib waveguide by using ML techniques based on Random Forest algorithm. Additionally, we explain the importance of the different geometry values of the waveguide. This work highlight the promising potential of using ML techniques for predicting photonic components properties, which is our main focus in future works.

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