Design proposal for edX course Silicon Photonics Design, Fabrication and Data Analysis

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I. Introduction

Silicon photonics leverages CMOS-compatible fabrication to integrate low-loss waveguides, modulators, detectors, and passive components on a single chip, enabling compact and scalable photonic systems for communications, sensing, and computing. This high level of integration reduces cost and footprint while improving manufacturability compared to discrete optical assemblies. In this context, interferometric circuits are widely used because they translate small phase changes into measurable intensity variations and therefore provide a practical route to characterize waveguides and devices [1], [2].

The objective of the edX course project "Silicon Photonics Design, Fabrication and Data Analysis" is to design an interferometer circuit (Mach–Zehnder interferometer, MZI) from which the waveguide group index can be extracted. The extracted group index value(s) will then be compared to simulated values obtained from waveguide modeling, providing a closed-loop validation between design, fabrication, and experimental measurement.

II. Theory

A. Waveguide compact model

Circuit-level modeling is performed in *Lumerical INTERCONNECT* using compact models extracted directly from the physical layout in *KLayout* via the SiEPIC framework. In this workflow, the schematic connectivity is inferred from the placed photonic PCells in KLayout, and an INTERCONNECT-ready netlist is generated in which each layout instance is mapped to a corresponding compact model (e.g., parameterized waveguide segments, directional couplers, and Y-branches), with key parameters such as path length and component type taken directly from the drawn geometry. This layout-driven netlisting reduces manual transcription errors and enables rapid iteration: updates to ΔL or routing in KLayout propagate automatically to the circuit simulation, allowing the predicted MZI transmission spectrum (and the implied FSR and group index) to be compared consistently against the experimentally measured response.

A straight waveguide section of physical length L is commonly modeled by a complex propagation constant

$$\beta(\lambda) = \frac{2\pi}{\lambda} n_{\text{eff}}(\lambda), \tag{1}$$

so that the accumulated phase is $\phi(\lambda) = \beta(\lambda)L$. The waveguide group index is defined as

$$n_g(\lambda) = \frac{c}{v_g} = n_{\text{eff}}(\lambda) - \lambda \frac{dn_{\text{eff}}}{d\lambda}, \tag{2}$$

and governs how quickly optical phase changes with wavelength, which is the key quantity extracted from an interferometric spectrum.

B. MZI transfer function and group-index extraction

An MZI splits the input field into two arms and recombines them to produce wavelength-dependent interference. For a lossless 50/50 MZI with arm length difference ΔL, the normalized output intensity can be written as

$$T(\lambda) = \frac{1}{2}\left[1 + \cos\big(\Delta\phi(\lambda)\big)\right], \tag{3}$$

where $\Delta\phi(\lambda) = \beta(\lambda)\,\Delta L$. Adjacent maxima (or minima) occur when $\Delta\phi$ changes by 2π, leading to the free spectral range (FSR) approximation

$$\text{FSR} \triangleq \Delta\lambda \approx \frac{\lambda^2}{n_g\,\Delta L}. \tag{4}$$

Thus, measuring the FSR of the fabricated MZI spectrum and using the known path-length difference ΔL provides an experimental estimate of $n_g(\lambda)$, which can be directly compared against simulated waveguide group index.

C. Choice of path-length difference ΔL

The interferometer path-length difference ΔL controls the fringe spacing through the FSR relation above: larger ΔL produces a smaller FSR and therefore more densely spaced fringes. Since the laser wavelength sweep in this project uses a step size of $1\,\text{pm}$, using relatively long ΔL values helps ensure each fringe period is sampled by many wavelength points, which improves the robustness of peak/trough detection and reduces uncertainty in the extracted FSR. In practice, one can estimate the number of samples per fringe as $N \approx \text{FSR}/\delta\lambda_{\text{step}}$.

To balance spectral resolution, footprint, and sensitivity, multiple MZIs are implemented with $\Delta L \in \{200, 300, 400, 500\}\,\mu\text{m}$. This provides a set of FSRs that are small enough to be well resolved with a $1\,\text{pm}$ step size, while also allowing cross-checking of the extracted n_g values across several devices (and identifying potential systematic errors such as fabrication bias, excess loss imbalance between arms, or fringe distortion).

III. Modelling and simulation

Figure 1 shows the simulated transmission spectrum of the designed Mach–Zehnder interferometer obtained from *Lumerical INTERCONNECT*. The periodic fringes arise from interference between the two arms, and the free spectral range (FSR)

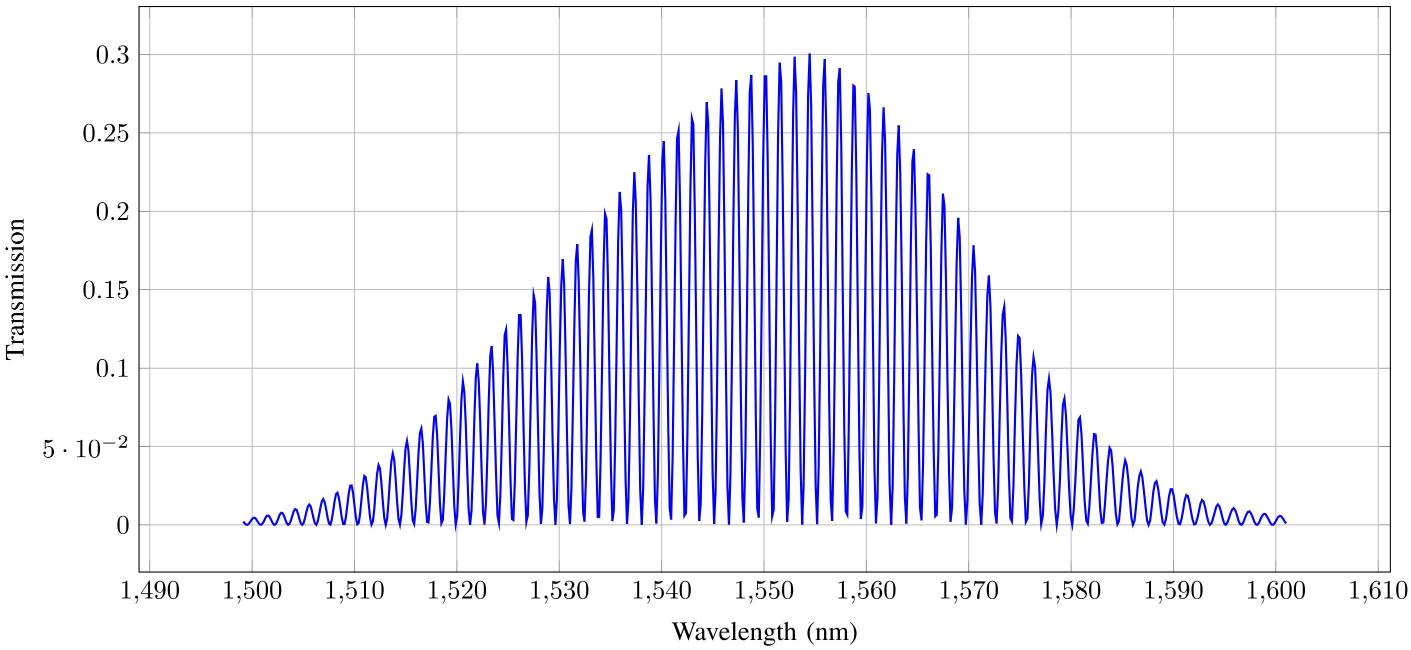

Fig. 1. Simulated transmission spectrum versus wavelength from *Lumerical INTERCONNECT* for $\Delta L = 400\ \mu m$.

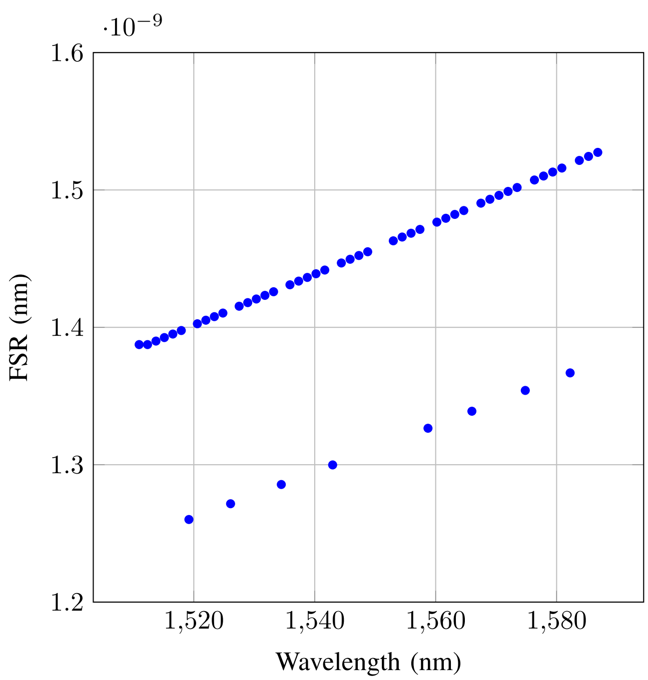

Fig. 2. Simulated free spectral range (FSR) versus wavelength from *Lumerical INTERCONNECT*.

TABLE I
SIMULATED FSR AT $\lambda = 1550\,\mathrm{nm}$ FOR DIFFERENT MZI PATH-LENGTH DIFFERENCES.

ΔL (μm)	FSR at 1550 nm (nm)
200	2.85
300	1.92
400	1.42
500	1.14

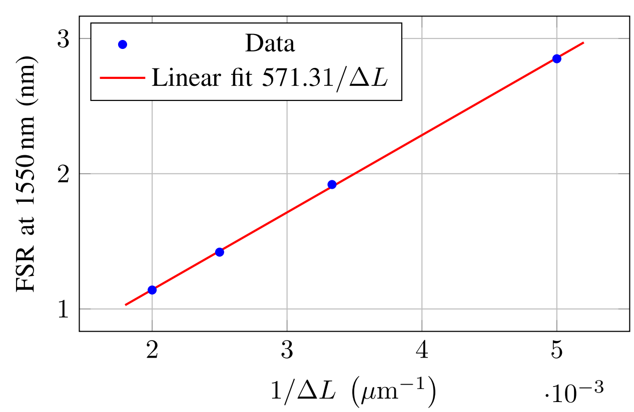

Fig. 3. FSR at $\lambda = 1550\,\mathrm{nm}$ versus inverse path-length difference $1/\Delta L$, with a linear fit.

can be measured from adjacent maxima/minima to extract the waveguide group index via the relation in Section II.

Figure 2 summarizes the extracted free spectral range as a function of wavelength, based on the same *Lumerical INTERCONNECT* simulation results. This curve provides the key input for computing the wavelength-dependent group index using $n_g(\lambda) \approx \lambda^2/(\mathrm{FSR}(\lambda)\,\Delta L)$.

Figure 3 plots the same FSR@1550 nm values as a function of inverse path-length difference $1/\Delta L$, together with a linear fit.

From FSR $\approx \lambda^2/(n_g\,\Delta L)$, a plot of FSR versus $1/\Delta L$ should be linear with slope

$$m \approx \frac{\lambda^2}{1000\,n_g}, \tag{5}$$

where the factor 1000 converts ΔL from μm to nm. Therefore, the group index can be extracted directly from the fitted slope as

$$n_g \approx \frac{\lambda^2}{1000\,m}. \tag{6}$$

Using $\lambda = 1550\,\mathrm{nm}$ and the fitted slope $m \approx 571.3\,\mathrm{nm} \cdot \mu\mathrm{m}$ from Fig. 3 gives $n_g \approx 4.21$.

IV. CONCLUSION

Summarize your findings.

REFERENCES

[1] L. Chrostowski and M. Hochberg, *Silicon Photonics Design: From Devices to Systems*. Cambridge, U.K.: Cambridge Univ. Press, 2015.

[2] D. J. Thomson *et al.*, "Roadmap on silicon photonics," *J. Opt.*, vol. 18, no. 7, p. 073003, 2016.