Design of the optical core of an integrated ratiometric wavelength monitor

A. M. Hatta[1], G. Farrell[1], Q. Wang[2] and J. Zheng[3]
[1]Applied Optoelectronics Centre, School of Electronic and Communications Engineering, Dublin Institute of Technology, Kevin Street, Dublin 8, Ireland
agus.muhamadhatta@student.dit.ie
[2]Data Storage Institute, DSI Building, 5 Engineering Drive 1, 117608 Singapore
[3]College of Electronic Science and Engineering, Jilin University, 2699 Qianjin Street, 130012 Changchun, P.R. China

Abstract. *The optical core of an integrated ratiometric wavelength monitor which consists of a Y-branch and two edge filters, with opposite spectral responses, based on a pair of symmetrical multimode interference (MMI) structures is proposed. The designed ratiometric structure demonstrates a suitable spectral response, with potentially a 20 pm resolution over a 100 nm wavelength range.*

1. Introduction

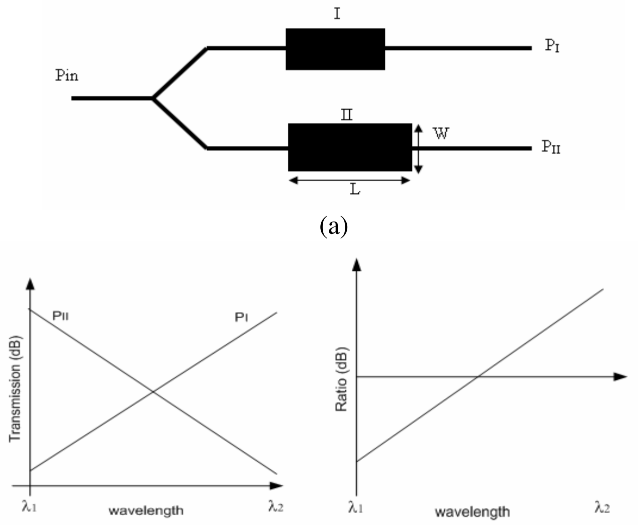
Wavelength monitoring and measurement is required in many optical systems such as multi-channel dense wavelength-division multiplexing optical communication systems and fibre-Bragg-grating-based optical sensing systems. In one wavelength monitoring scheme, the so-called a ratiometric detection scheme, the wavelength of an input signal is determined by the measurement of the ratio of two signal powers. It has a simple configuration and offers the potential for high-speed measurement as compared with wavelength-scanning-based active measurement schemes. A ratiometric wavelength measurement scheme can be implemented with bulk devices, an all-fiber based configuration or integrated optical circuits. Integrated wavelength monitors have a compact size, a fast response, are more robust and have a low fabrication cost compared to bulk optical devices. Examples of the designed and developed integrated wavelength monitors include multimode interference (MMI) couplers, a Y-branch with an S-bend structure and a Y-branch with an MMI structure [1-3].

In [1], the wavelength monitor consists of a central MMI waveguide, two output waveguides, and one input waveguide. For wavelength measurement it offers a 100 nm range and 200 pm resolution. Previously, in [3], we have shown that an MMI structure can be used as an edge filter for a ratiometric wavelength monitor. In [3], the length and width of the multimode section, and the positions of the input and output waveguides are optimised according to a desired spectral response by using the global optimisation algorithm-adaptive simulated annealing. We propose here a further improvement, with a ratiometric scheme which employs two opposite slope edge filters offering a higher resolution compared with the ratiometric scheme with one edge filter and one reference arm [4]. In this paper, two edge filters with opposite slope spectral responses based on a symmetrical MMI are designed and can be used for high resolution wavelength monitoring.

2. Proposed configuration and design method

Fig.1.a shows a schematic configuration of an integrated ratiometric structure. It contains a Y-branch splitter and two edge filter arms, containing symmetrical MMI structures. The desired spectral responses of the two arms are shown in Fig.1.b, while the corresponding ratio of the two outputs over a wavelength range is presented in

Fig.1.c. The wavelength of an input signal can be determined through measuring the power ratio of the output ports at the outputs of the two arms, assuming a suitable calibration has taken place.



(b) (c)

Figure 1 (a) Schematic configuration of ratiometric structure with two edge filter arms with MMI structures (b) Desired spectral response of two edge filter arms and (c) The output ratio between two arms.

The design steps for each MMI structure are identical. To optimise an individual MMI structure for an edge filter application, the width (W) and length (L) of the MMI are adjusted. The transmission response of the MMI is calculated for each W and L of MMI. A modal propagation analysis (MPA) can be used to calculate the transmission response in the multimode waveguide [5]. It is known that the desired edge filter corresponds to either an increasing or decreasing transmission as the wavelength increases over the wavelength range. Therefore it is necessary to calculate the transmission response between the lower and upper limits [λ_1 and λ_2] of the desired wavelength range over a range the W and L values for the MMI. For each W of the each MMI, we scan the length L in increments of 0.01 L_π (where L_π is the beat length) and determine the transmission value at λ_1, λ_2 as $P(\lambda_1)$, $P(\lambda_2)$ and then calculate the corresponding discrimination range $D = |P(\lambda_1) - P(\lambda_2)|$ (thus $P(\lambda_1)$ and $P(\lambda_2)$ should be in dB). A symmetrical MMI produces a self image at a distance $L = \frac{3}{4} L_\pi$, so we can set the scanning range of L as $0 \le L \le 2\frac{3}{4} L_\pi(\lambda_1)$.

After calculating $P(\lambda_1)$ and $P(\lambda_2)$ for each W and L for an MMI we select some structures as possible candidates. We select the structures based on the constraints that the discrimination, *D,* should be better than 10 dB and that the baseline loss (either $P(\lambda_1)$ and $P(\lambda_2)$ depending on whether the slope is negative or positive) should also be less than 8 dB. Then we calculate the spectral response for each selected structures. An ideal response for the edge filter should give a linear dependence for wavelength versus transmission. We can use a linear curve fitting and get a slope (*m*) of linear function

$(T(\lambda) = m\lambda + c)$ and a norm residual (nxr) from a QR decomposition of the Vandermonde matrix [6], as the parameters to choose the best spectral response. The ideal spectral response has high m and low nxr. The optimal edge filter with positive or negative slope is chosen based on a figure of merit:

$$F = \exp\left[-\left(\frac{c_n nxr}{c_m |m|} \right) \right] \qquad (1)$$

where c_n and c_m are weighting coefficients. The best edge filter occurs when $F = 1$ and the worst when $F = 0$.

3. Numerical example and discrimination demonstration

As a numerical example, a buried silica-on-silicon waveguide is chosen where the refractive index of the core and cladding is 1.4553 and 1.4444, respectively. The waveguide cross section is 5.5 μm x 5.5 μm and the multimode section thickness is 5.5 μm. The effective index method is used to simplify the calculation. The wavelength range for this example is taken to be 1500 – 1600 nm. The width of the MMI is chosen to be in the range 30 – 50 μm and the length $0 - 2\frac{3}{4} L_\pi(\lambda_1)$. Based on the above procedure, the optimal edge filters are found to have the dimensions W = 45 μm, L = 3478 μm and W = 46 μm, L = 3250 μm for the positive slope MMI (P_I) and the negative slope MMI (P_{II}), respectively. The spectral responses are plotted in Fig.2.a from which it is clear that the discrimination range (from 1500 to 1600 nm) is 10.97 dB, while the baseline loss is 6.57 dB for the positive slope edge filter. For the negative slope edge filter the discrimination range is 11.39 dB with a baseline loss of 5.96 dB. To calculate the ratio of the whole integrated ratiometric structure, a Pade (1,1) beam propagation method with a GD scheme is used [7]. The ratio of the spectral response is from –10.91 to 11.49 dB and is shown in Fig.3.

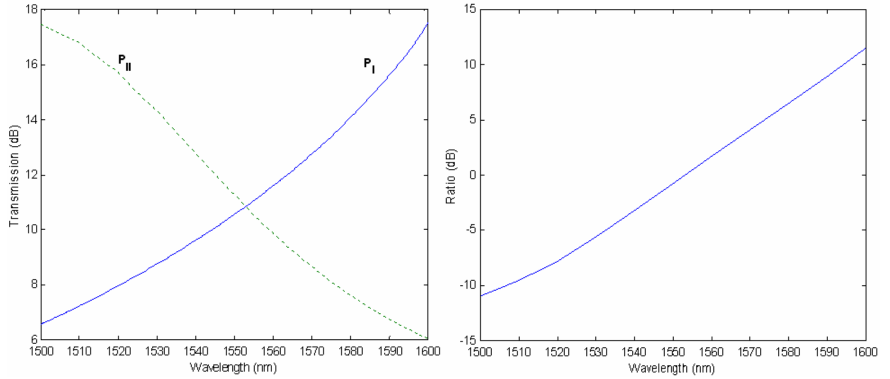


Figure 2 (a) Spectral response of optimised edge filters with opposite slopes (b) Spectral response of the ratiometric

To confirm the wavelength discrimination capability of the designed structure, the ratiometric wavelength measurement process is modelled numerically [8] by taking account of the optical noise of the source signal and the electrical noise of the photodetectors. Assuming the SNR of the input signal is about 55 dB, the best resolution achievable for power measurement is 0.001 dB and the noise generated by photodetectors and electronic circuitry is equivalent to an uncertainty in the ratio measurement of 0.002 dB. The source wavelength is set to 1550 nm. This wavelength is changed by successively increasing increments of 5, 10, 15 and 20 pm. The photodetector outputs are sampled 100 times and the ratio of the photodetectors outputs is calculated for each wavelength. The wavelength is incremented again and the process of sampling is repeated. Fig. 3 shows the complete time series of the calculated ratio values as a function of sample time and the wavelength increments. From Fig. 3, it is clear that the detectable ratio due to the wavelength tuning has a potential resolution at least better than 20 pm.

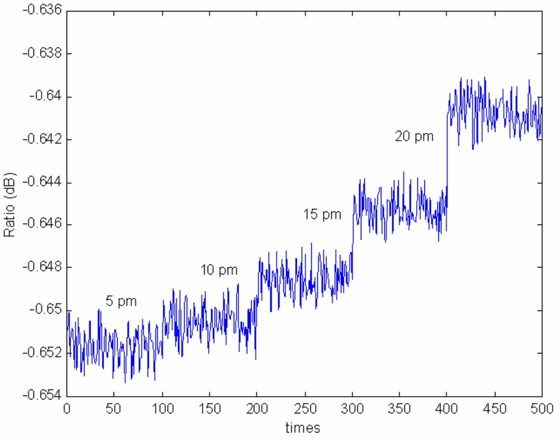


Figure 3 Output ratio as the wavelength is tuned

Conclusion

An integrated ratiometric wavelength monitor based on a pair of MMI structures with symmetrical responses has been presented. The width and length of the two MMI edge filters with opposite slope spectral responses are optimised based on a defined figure of merit. The wavelength discrimination of the designed ratiometric structure has been demonstrated numerically and shows a competitive resolution (20 pm) for wavelength measurement.

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