Novel tuning algorithm for continuous and widely tunable integrated lasers

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We present a novel tuning algorithm to drive and realize a continuously and widely tunable (CWT) laser filter, without jumps in peak wavelength. The filter is realized as an intra-cavity Mach-Zehnder Interferometer (MZI) based wavelength-selective tunable filter, with linearly increasing arm length difference and electro-optic phase modulators (EOPMs) in each arm. Our algorithm to drive the EOPMs ensures that during a 2π phase reset of the EOPMs, the CWT filter tunes over the free spectral range (FSR) with no jumps in peak wavelength. The performance of the CWT filter is investigated with a theoretical model of the filter for parameters such as continuous tunability, side-to-main-mode transmission ratio (SMTR) and full width of half maximum (FWHM). The tuning range of the filter is 30 nm with a centre wavelength of 1550 nm.

Introduction

Continuously and widely tunable lasers are of immense importance in many fields such as dense wavelength division multiplexing [1], gas sensing [2], biomedical sensing [3] and LIDAR [4]. Wide tunability of more than 35 nm has been demonstrated with an array of distributed feedback (DFB) lasers [5], commercially available monolithic widely tunable lasers are digital supermode distributed Bragg reflector (DSDBR) lasers [6] and sampled grating DBR (SGDBR) lasers) [7], demonstrated for tuning ranges of 45 nm with output powers up to 16 dBm. However, the fabrication of complex gratings needs high-resolution lithography technology like electron beam lithography (EBL). Additionally, tuning is slow for these lasers as the mechanisms are typically thermal effects or carrier injection as opposed to faster means of tuning such as electro-optic effect. Apart from grating-based lasers, asymmetric Mach Zehnder interferometer (AMZI) based ring resonator lasers are also promising means of achieving wide tuning range as demonstrated in the works of Latkowski *et al* with a monolithically integrated laser design reaching tuning ranges of 74 nm [8]. By including EOPMs on the arms of the AMZI and making use of Vernier based tuning, fast tuning can be attained over a wide range. In that case, each filter requires a phase shift of 2π to cover the whole spectrum. MZI based feed-forward structures also make use of EOPMs on individual arms as demonstrated in the work of Quanan Chen *et al* [9] and Hänsel *et al* [10]. In both cases, the phase reset of the EOPMs result in mode-hops and hinder continuous tuning. However, the state of the art of fully integrated widely tunable lasers to the best knowledge of the authors, are not capable of demonstrating mode-hop free continuous tuning more than a few nanometers. The tuning schemes for these lasers are at best discreet or quasi-continuous.

In order to realize a CWT laser that tunes the wavelength without mode-hops for the entire FSR while still suppressing side modes, the tunable filter inside the cavity must be able to tune continuously. We present a tuning method for a CWT filter of MZI feedforward configuration, that shows continuous tuning without jumps in peak wavelength. In the first part, we will talk about the theoretical understanding of MZI filters and physical limitations to achieve continuous tunability. In the second part, we elaborate on the implementation and discuss the performance of the filter in terms of important filter characteristics.

Filter structure and tuning mechanism

The CWT filter consists of N arms as shown in Figure 1a. A splitter of 1:N configuration or a cascaded MMI tree is used to connect the N arms. Each arm has individual phase control through EOPMs with length L_{EOPM}. The mirrors have reflectivity R and transmittivity T. The mirror on the left of the splitter is two-port and is where we collect the output light. The structure can be termed a folded MZI, as the round trip phase is doubled due to the light passing through the cavity twice after being reflected by the mirrors.

The length of the arms is increasing linearly with the index of the arm by ΔL, which results in a wavelength-dependent sinc shaped filter. If lengths of the mirrors, splitter, waveguides and EOPM (L_{EOPM}) amount to L_{common},, the length of each arm can be calculated from:

$$L_i = L_{common} + i\Delta L \tag{1}$$

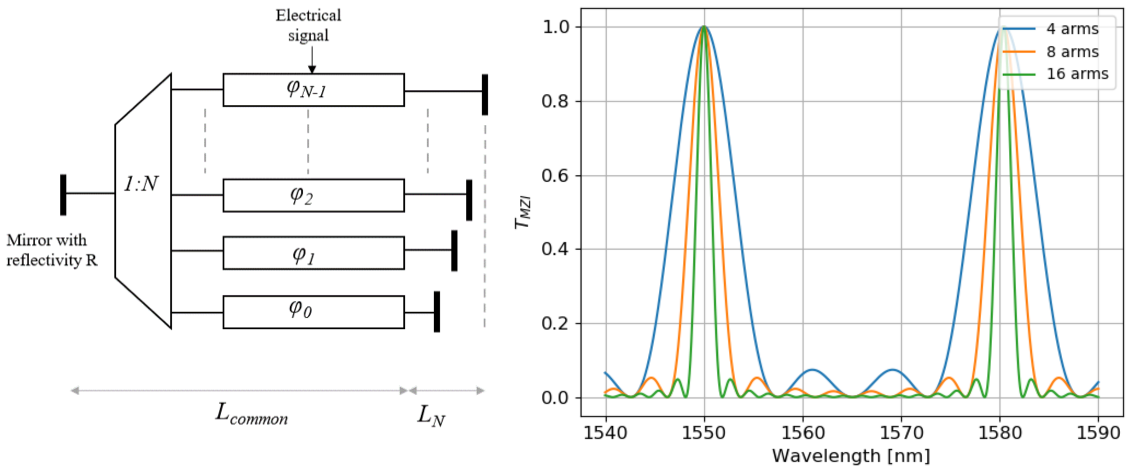

Figure 1: (a) The schematic of CWT filter for N arms configuration. (b) Transmission of CWT filter resulting in a wavelength dependent sinc function, for varying arm numbers.

The incremental arm length difference that results in the sinc shaped filter determines the free spectral range (FSR) and the number of arms determines the FWHM and SMTR of the filter respectively as illustrated in Figure 1b. The target tuning range of the CWT filter is determined to be 30 nm as this almost covers the C band of telecommunication. For group index n_g, a central wavelength of λ_c and an FSR of 30 nm the arm length difference of the filter is given by:

$$\Delta L = \frac{{\lambda_c}^2}{2n_g\lambda_{FSR}} \tag{2}$$

In order to tune the position of the sinc filter along the entire FSR *continuously*, the individual EOPMs will have to tune 2π times the index of the arm within the same time frame. As a result, the slope of the phase applied to each arm is linearly increasing with the arm number. This poses a problem for two reasons. Firstly, the phase modulators have a physical limit of voltage that can be applied. This can be solved by resetting the EOPMs to 0 and by this way emulating a phase shift of more than 2π. But this results in another problem, which is the bandwidth limitation of the EOPMs. A phase reset on the EOPMs does not happen instantaneously. The electrical signal that can be applied to the EOPMs is also bandwidth limited. The bandwidth limited 2π drop will result in an error in filter transmission. In combination with a Fabry-Perot (FP) cavity and lasing modes, this can lead to phase errors. As the slopes of the applied phases are linearly increasing, the phase resets can also overlap in time, which increases the error further. With our tuning scheme, we want to avoid the jumps in peak wavelength and ideally achieve constant peak output power.

We propose a tuning algorithm solution where not more than one arm is in the error domain. This is done by offsetting the resets of the signals in time. Increasing the number of arms reduces the impact of one arm on the overall filter performance. A larger number of arms also enhance the SMTR and reduce the FWHM of the filter. This is the main premise of the work.

Implementation

We developed a model to simulate the transmission of the CWT filter in MATLAB. The phase profiles for a 6 arm structure for bandwidth-limited signals are illustrated in Figure 2. The phase on the arm with index 0 is kept unchanged while the others are increased linearly. The effect of the finite reset of EOPMs is simulated with a lowpass filter with 100 Hz bandwidth. The performance of the CWT filter is determined by investigating the filter parameters: peak transmission, SMTR and FWHM.

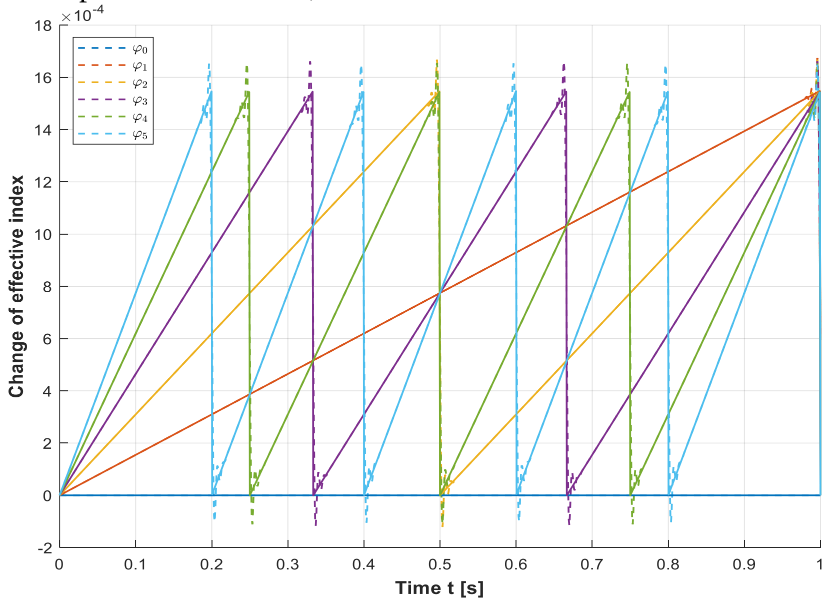

Figure 2: The sawtooth signals ideal in dashed and bandwidth limited in solid lines. The overlap of simultaneous resets of φ_4 and φ_2 can be observed at t=0.5 s.

Results and discussion

Figures 3a and b show results of new offset signals applied. In Figure 3a, the dashed lines illustrate the maximum values of peak transmission, maximum SMTR and FWHM. The solid lines show the minimum values these parameters drop to when there is a phase reset. As the number of arms in the filter increases, the dashed and the solid line converge. This means that as the full wavelength range is tuned, the filter maintains full fidelity and continuous tuning is possible. With a configuration of 13 arms, the peak power drops by only 20%, SMTR by 70% and FWHM by 0.3 nm. Jumps in peak wavelength occur below 12 arm configuration, so at least 12 arms are necessary to attain jump free tuning. The spectrogram in Figure 3b shows continuous tuning without peak wavelength shifts for 30 nm taken for a 12 arm configuration.

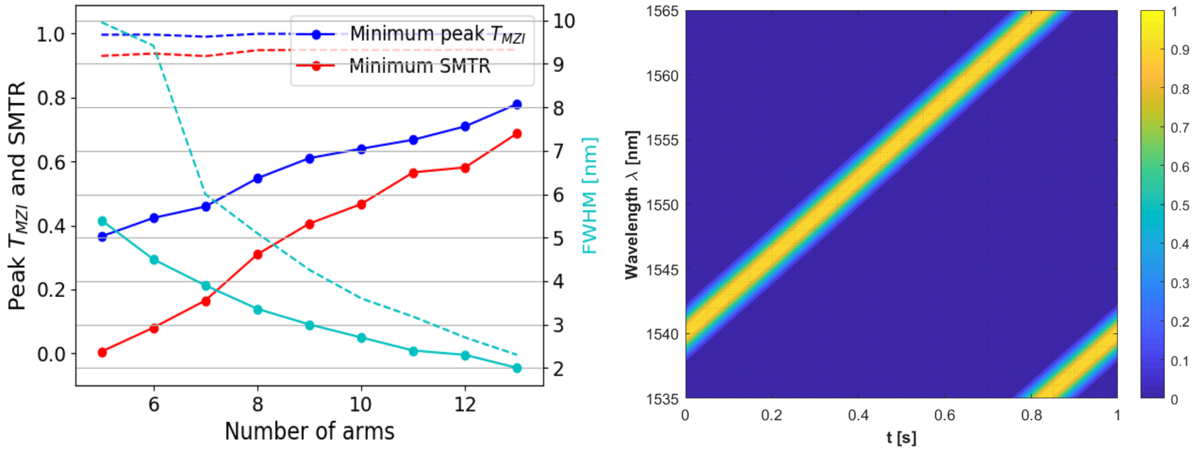

Figure 3: (a) Minimum peak transmission, SMTR and FWHM in solid and maximum corresponding values in dashed lines, with increasing number of arms. (b) Transmission of CWT filter in time tuned for 30 nm.

Conclusion

We have presented a tuning mechanism for continuous tuning using an algorithm where the phase resets of the EOPMs at the same time are avoided and we have shown a design that can support this algorithm. In future work we plan to test this algorithm experimentally on CWT filters we have realized on the SMART photonics platform.

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