A Coupled Cavity Laser based on a Multimode Interference Reflector

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Abstract: We demonstrate the first tunable Coupled Cavity Laser fabricated in an InP based generic foundry process. This is achieved by coupling two Fabry-Perot laser cavities with different length via a 2-Port Multimode Interference Reflector. The coupling coefficients of the reflector are designed to enhance the Side Mode Suppression Ratio. The reflector is realized in a deep-etched waveguide process with vertical sidewalls. We measured Side Mode Suppression Ratio close to 40 dB and tuning range of 4.7 nm for 1.2 mm long cavities with a length difference of five percent.

1. Introduction

Coupled Cavity Lasers (CCLs) have been of interest since the beginning of laser integration and are extensively described in literature. A simple and conventional method to create a CCL is by introducing an air gap[1] into a Semiconductor Optical Amplifier (SOA). The yield of this laser is strongly dependent on accurate control of the gap dimension, which ultimately limits the application of CCLs. Recently, new attempts were made to create CCLs using Multimode Interference Devices (MMIs) without imaging properties[2,3]. Although enabling high Side Mode Suppression Ratio (SMSR), these devices suffer from significant loss. In this work we present a novel Multimode Interference Reflector (MIR) with optimal coupling characteristics for CCLs derived from a 3x3 general interference MMI. Combined with existing MIRs[4], the laser can be fully integrated in generic processes[5] that support vertically etched sidewalls. We fabricated a CCL with cavities of approximately 1.2 mm in length, and a difference of five percent. Our first laser shows a SMSR close to 40 dB at 2 mW output power and 4.7 nm tuning range via the integrated phase sections.

2. Laser Design

A schematic of the CCL is given in Fig. 1(a) below. Two cavities, each containing a SOA and a phase control section, are coupled together via a 2-Port MIR with reflectivity R_2 and symmetric amplitude coupling coefficients C_x and C_{bar}. The opposite output mirrors are formed by cleaved facets with reflectivity R_1. The lengths of the cavities are chosen to differ by 5%. The laser is fabricated in the COBRA generic process[5]. As indicated in Fig. 1(b), the mode selection is based on the Vernier-Effect established between the two cavities of different length. Consequently, the laser can be discretely tuned over the combined Free Spectral Range (FSR) by variation of one of the optical cavity lengths. This can be accomplished by biasing one phase control section. Continuous tuning can be achieved by biasing both phase sections with a similar current. Analogous to previously reported CCLs, it is of momentous importance that the phase difference between C_x and C_{bar} is fixed to multiples of 180° [1-3,6]. Light that is cross coupled, amplified and partially added to the originating cavity can thus interfere constructively with the directly reflected components C_{bar}. This can be obtained using directional couplers with three waveguides[7], which adds the condition $|C_x| + |C_{bar}| = 1$ to our coupling element R_2. It was previously theoretically[2] and experimentally[3] demonstrated that SMSR in the 40 dB range can be expected for the case of $C_{bar} \approx 0.85$ and $C_x \approx 0.15e^{j\pi}$.

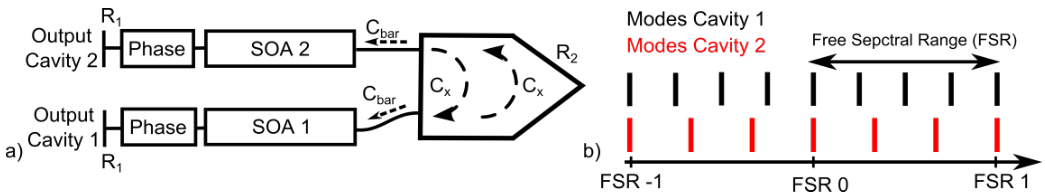

Fig. 1: Schematic of the Coupled Cavity Laser (CCL) (a) with indication of the tuning mechanism (b)

3. MIR Design

The coupling coefficients of a three waveguide coupler are strongly dependent on the accurate control of the gap distances. Previous lasers based on the proposed approach, approximated the right coupling coefficients with a MMI, at the expense of non-ideal imaging properties[2,3,7]. Here we employ a design which shows both ideal imaging and coupling behaviour. We start from a 3x3 general interference MMI in transmission as depicted in Fig. 2(a) and will derive a related reflector at the end of this section. The 3x3 geometry produces images of equal intensity at the beat length L_π. In Fig. 2(b), we show a numerical example of the propagation inside the multimode section where L_π is indicated. Here it is seen that at $L_\pi/2$ three images are present with unequal intensities such that $C_{bar} \approx 0.21$, $C_{cen} \approx 0.57e^{j\pi/3}$ and $C_x \approx 0.78e^{j\pi}$. By realizing that the condition $|C_x| + |C_{bar}| \approx 1$ is fulfilled, we recognize a potential 2x2 coupler for the laser in Fig. 1(a), if the central waveguide is excluded. Although this implies a significant imaging loss in general, the loss of light is minimized if the two outer inputs are simultaneously excited with almost equal intensities and a phase difference of 180°. In that case, destructive interference occurs in the central output at multiples of $L_\pi/2$, as can bee seen in Fig. 2(c). So far the MMI in transmission. A fully reflective device is obtained by placing a corner mirror at $L_\pi/4$, as indicated in Fig. 2(d). Due to the corner reflection, the coupling coefficients are interchanged. Consequently, the reflector coefficients now read $C_{bar} \approx 0.79$, $C_x \approx 0.21e^{j\pi}$ and $C_{cen} = 0$, which is close to ideal for our laser geometry. Note that these ideal values only occur when the two input intensities are equal and their phase difference is 180°. This property will automatically lead to optimization of the laser operation.

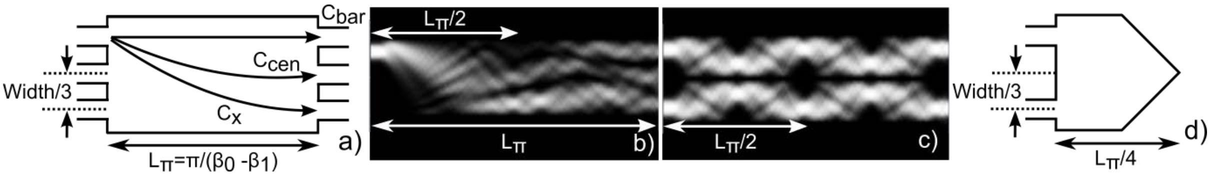

Fig. 2: (a) 2x2 MMI geometry. BPM simulation of (b) Single input excitation of MMI,(c) Anti-resonant excitation of MMI. (d) Related MIR geometry.

4. Measurements

We have fabricated the laser in Fig. 1 (a) with cavities of 1.2 mm length and a length difference of five percent. The MIR is designed 6 µm wide and 25 µm long. The device reaches threshold when 18 mA are injected into SOAs of 500 µm length. Typical spectra of the laser are displayed in Fig. 3, with SMSR close to 40 dB. When a current is injected into the phase control sections, the laser is tuned by 4.7 nm in discrete steps. The inset in Fig. 3 shows a typical L-I curve. The light was collected by a lensed fibre, while injecting current into both SOAs.

5. Conclusion

We have fabricated a Coupled Cavity Laser based on a 2-port Multimode Interference Reflector with optimized coupling characteristics. The laser demonstrates a SMSR close to 40 dB and can deliver several mW output power, when coupled to a lensed fibre. The tuning range of a first, design was 4.7 nm. The fabrication of the device is fully compatible with high-yield waveguide lithography and thus promising for large-scale photonic integrated circuits.

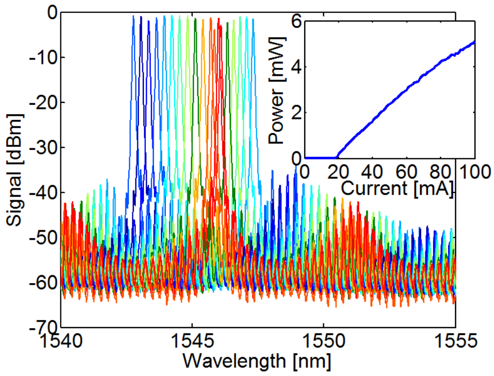

Fig.3: Typical spectrum when 40 mA are injected in both cavities. The phase sections are tuned by current injection. Inset shows a L-I curve obtained with a lensed fiber

6. Acknowledgements

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7. References

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