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Low-linewidth and tunable single frequency 1x2 multimode-interferometer-Fabry-Perot laser

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ABSTRACT

In this paper, we present a novel 1x2 multi-mode-interferometer-Fabry-Perot (MMI-FP) laser diode, which demonstrated tunable single frequency operation with more than 30dB side mode suppression ratio (SMSR) and a tuning range of 25nm in the C and L bands, as well as a 750 kHz linewidth. These lasers do not require material regrowth and high resolution gratings; resulting in a simpler process that can significantly increase the yield and reduce the cost.

Keywords: MMI-FP laser, low linewidth, single frequency, tunable

1. INTRODUCTION

Tunable single frequency semiconductor laser diodes with a narrow linewidth in the C and L bands have diverse applications in optical communication systems, DWDM system, remote sensing and spectroscopy [1-2]. Grating-based distributed feedback (DFB) lasers and distributed Bragg reflector (DBR) lasers have demonstrated robust single longitudinal mode performance and broad wavelength tunability thus gaining wide interest, while the required fabrication complexity of nanometer dimensional gratings and material regrowth limits the yield and increases the cost. In addition, the free-running linewidth reported for DFB and DBR laser devices is typically in the 1-5 MHz range which restricts their applications in coherent optical communications systems and ultra-high resolution spectroscopy applications [3-4].

Alternatively, a slotted Fabry-Perot laser diode has been developed, which demonstrated excellent tunable single longitudinal mode performance and the outstanding narrow linewidth of ~ 100 kHz [5-7]. These lasers were fabricated by etching single or multiple micron dimension reflective slots into the ridge waveguide of FP lasers. The regrowth- free processing and the one micron dimension level slots that can be made with photolithography, ease the fabrication significantly and reduce the cost compared with the grating-based single mode lasers. However, these etched slots result in additional mode loss and the required high optical quality of the slots remains a challenge for the photolithography and etching processes.

In this Letter, we present a widely tunable single mode laser which is designed by introducing a 1x2 MMI into a FP laser cavity and fabricated by simple regrowth-free FP laser processing techniques. The three dimensional configuration of the 1x2 MMI-FP laser is shown in figure 1. An active 1x2 MMI is connected to symmetric twin angled waveguides with spacings of 250μm at the end on the left and a straight waveguide on the right, where each of the twin angled waveguides has a metal contact that is electrically isolated using 7° angled etched slots and then an MMI and straight waveguide share another common metal contact. In principle, each angled waveguide together with the 1x2 MMI and straight waveguide forms a FP cavity and the two cavities overlap via the MMI and straight waveguide. This leads to the mode beating from these two cavity modes. When proper biasing is applied on the three contacts, different amount of index change of the two FP cavities generate phase difference, thus the mode beating creates a single longitudinal mode emission from the composite cavity, and the emission wavelength is then tuned by altering the bias conditions.

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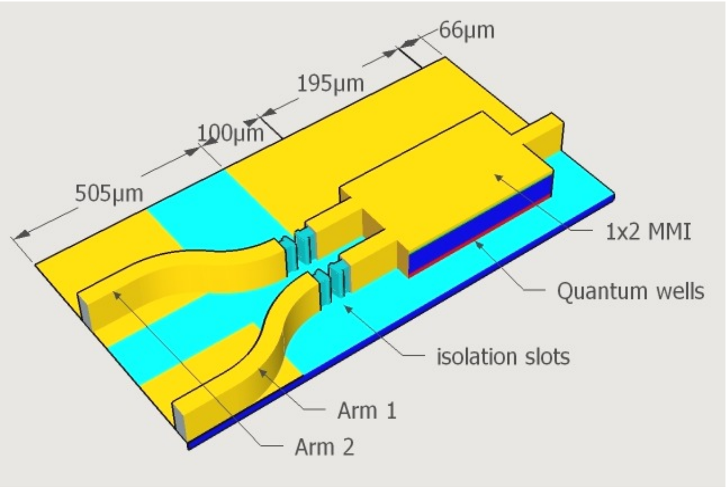


Figure 1. Schematic configuration of the proposed 1x2 MMI-FP laser

2. DESIGN AND FABRICATION

2.1 Design

In this design, the 1x2 MMI plays an important role in joining the two FP cavities by splitting and combing the light, and it also provides additional gain due to the large area compared with the narrow etched waveguides. Thus, the MMI section contributes toward a high power output of the laser diode while benefiting from a lower contact resistance and thus better thermal stability. We used commercial software FIMMWAVE to determine the dimensions of the 1x2 MMI which is 12.5µm wide and 195µm long [8]. The separation of the center of the twin waveguides at the MMI is 7µm, while the radius and angle of the curved waveguides are 250µm and π/4. The etched narrow ridges are 2.5 µm wide. To reduce the coupling loss between all the narrow ridges and MMI, 100 µm long linear waveguide tapers are utilized which are 3.5 µm wide at the MMI and 2.5 µm wide at the connection with the narrow ridges. The simulation of the optical transmission of the 1x2 MMI is shown in figure 2(a) and the mode profile in the twin waveguide is illustrated in figure 2 (b).

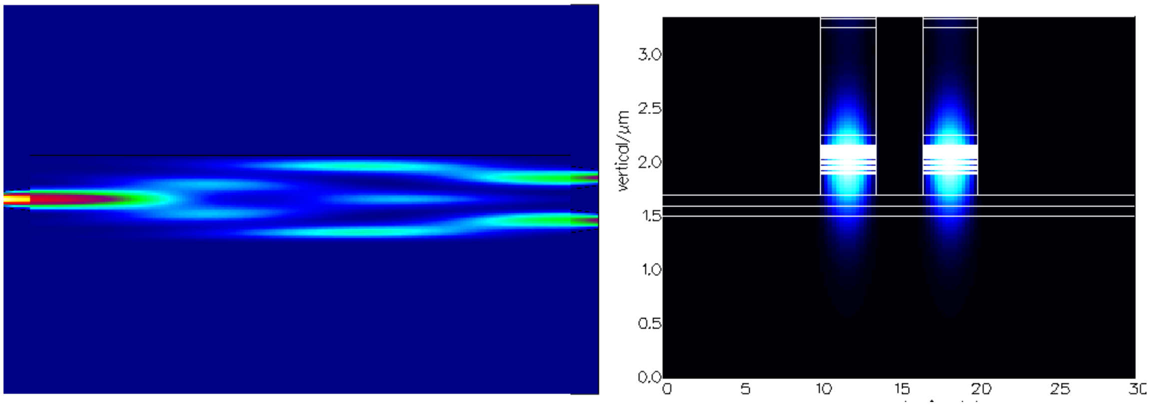


Figure 2. Simulated optical transmission of 1x2 MMI (a) and optical mode profile in the twin waveguide (b) by commercial software FIMMWAVE

2.2 Fabrication

The designed 1x2 MMI-FP lasers were fabricated using 5 pairs of compressively strained AlInGaAs/AlInGaAs quantum wells (+1.2% strain, 6nm thick quantum well and 10nm thick barrier, λ_{PL}= 1.55 µm, where PL stands for photoluminescence) on n-doped InP. The processing is the same as our typical processing for a Fabry-Perot semiconductor laser with common photolithography and etching techniques. First 500nm thick SiO_2 was deposited on top of the wafer by sputtering, followed by standard photolithography which was performed to define the MMI and waveguides. Inductively coupled plasma (ICP) dry etching of the SiO_2 with a CF_4/CHF_3 was then done to transfer the pattern into the SiO_2 mask. After removing the photoresist, room temperature ICP dry etching with $Cl_2/CH_4/H_2$ was used to etch approximately 2.5µm deep through the multiple quantum wells. Following a wafer passivation using 300 nm of SiO_2, a window opening was made in the SiO_2 by ICP dry etching which was followed by a p metal (TiAu) deposition and annealing at 420 degree for 5 minutes under an N_2/H_2 atmosphere. Finally, the samples were thinned to 100 µm and AuGeAuNiAu was deposited on the back of the wafer, followed by annealing at 380 degree for 5 minutes in a nitrogen furnace.

3. CHARACTERIZATION

The fabricated 1x2 MMI-FP lasers were cleaved into devices as dimensioned in Figure1 and the microscopic picture of a gold-wire bonded device is shown in the inset of Figure 3. Measurements on lasing performance of the devices were carried out with DC biasing and room temperature control. The light was collected from the cleaved facet of the output waveguide to the right of MMI.

3.1 Light-Current-Voltage (LIV) curves

In the measurements of the L-I characteristic, the light was collected with an integrating sphere. Lasing was observed when the MMI and either or both of the two angled waveguides were biased above a certain value, while no lasing was detected when only one of the contacts was biased. Figure3 shows the light output power changing with the bias current on MMI (I1) while the bias current on the arm 1 (I2) is constant and the bias on the arm 2 is off (I3=0). The result shows that: when the bias on the arm 1 I2=20mA, the laser does not lase by increasing the current I1 on MMI up to 150mA; when I2=40mA, the laser lases when I1 goes to 40mA and the output power increases with I1. The maximum power in the measurement range is up to 11mW when I1=150mA and I2=100mA. Figure 3 also gives the plot of voltage-current, which shows the low contact resistance on the MMI.

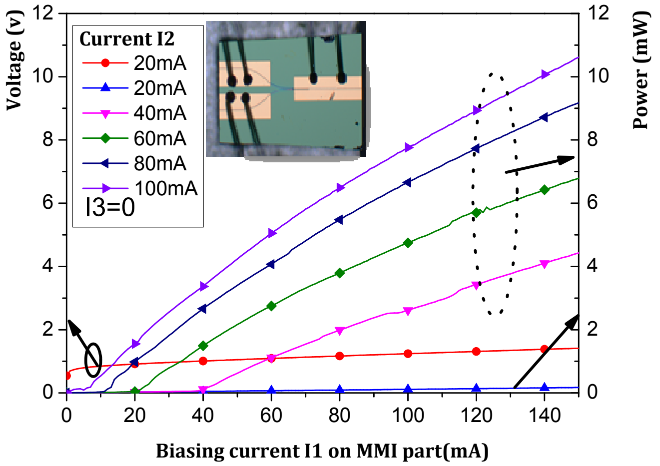


Figure 3. Measured L-I-V curve of the fabricated 1x2 MMI-FP laser

3.2 Spectra analysis

The lasing spectra of the 1x2 MMI-FP lasers were measured with an optical spectrum analyzer (resolution 0.01nm) and fiber coupling under different bias conditions. Figure 4(a) and (b) plot the spectra of the device under different bias conditions as shown in each plot. The measured spectra demonstrate that the 1×2 MMI laser lases in a single longitudinal mode with a SMSR between 30 and 36dB under the specific bias conditions. The lasing wavelength shifts to longer wavelength from 1559.08nm to 1571.7nm when the biasing current on the MMI or the arms increases.

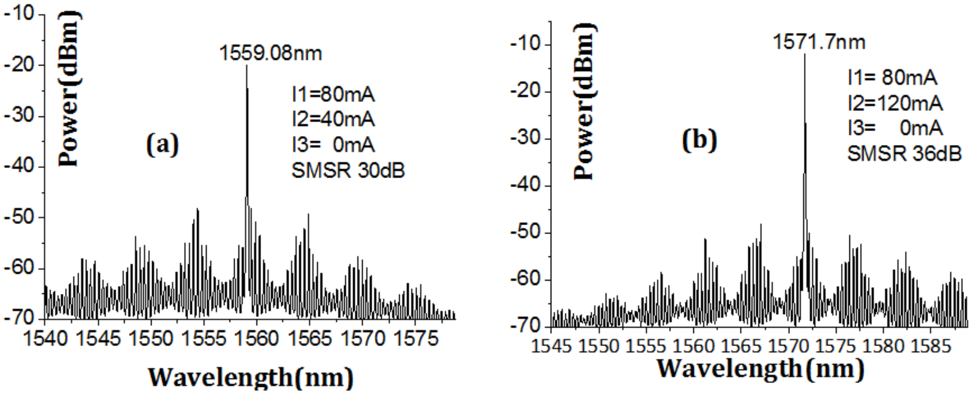
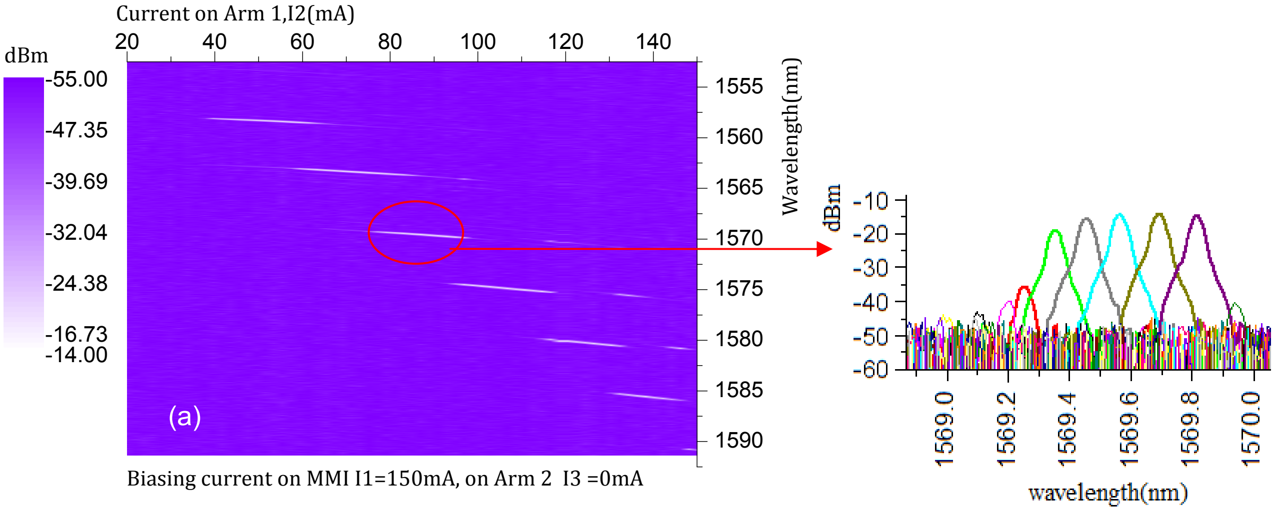


Figure 4. Measured lasing spectra of the 1x2 MMI laser

The tuning features of the 1x2 MMI-FP laser were further investigated and the tuning wavelength mapping with bias current is illustrated in Figure 5. It is observed that the lasing wavelength is tunable by changing the bias current either on the MMI or on the arms. Three isolated contacts provide sufficient flexibility to tune the laser to different wavelengths. Figure 5(a) presents the tuning effect due to changing the bias on one waveguide arm while the MMI bias is constant at 150mA and the bias on second arm is off. The wavelength shifts to longer wavelength continuously with biasing current I2 in a range then it jumps to another range by around 5nm, and it covers from 1558nm to 1585nm with average SMSR around 30dBm. Figure 5(b) shows the tuning effect by changing the bias to the MMI when both arms are biased at a constant of 50mA and 60mA respectively. Similar tuning features as Figure 5(a) are observed while the single mode lasing wavelength range is different. This indicates that more wavelengths are selectable with the different tuning combination on the three contacts. In Figure 5(a) and (b), the light was collected from the output of the waveguide to the right of MMI.



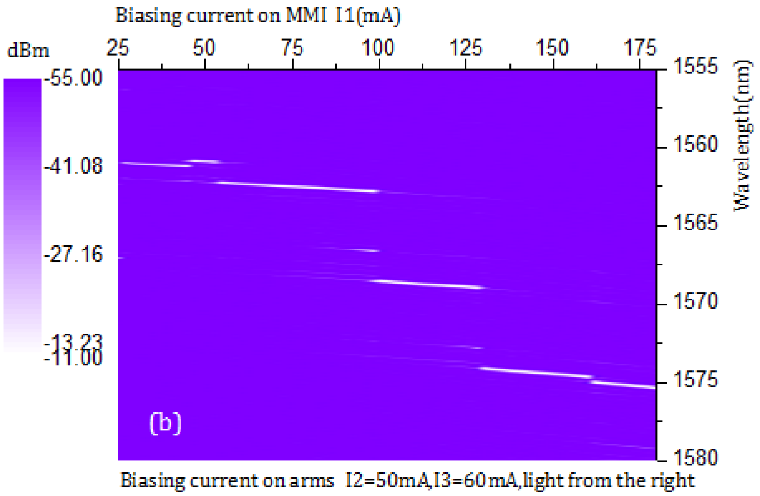


Figure 5. The lasing wavelength tuning map of the 1x2 MMI-FP lasers

3.3 Linewidth measurement

The spectral linewidth of the 1x2 MMI-FP lasers was measured by using the delayed self-heterodyne method and the result is shown in Figure 6. In the measurement, the delay length is 25 km, which corresponds to a minimum measureable linewidth of 2.5 kHz using a Lorentzian line shape. An acoustic-optic modulator (AOM) with a 70-MHz frequency shift was used in the experiment. Beat signals were detected by a photodetector (PD) and then measured by an electrical spectrum analyzer (Agilent PXA-N9030A). Figure 6 shows the measured normalized spectrum and the Lorentzian fit demonstrating a 750 kHz linewidth when the 1X2 MMI-FP laser is biased with I1=62.16mA, I2=60mA and I3=0mA and the SMSR is 30dB.

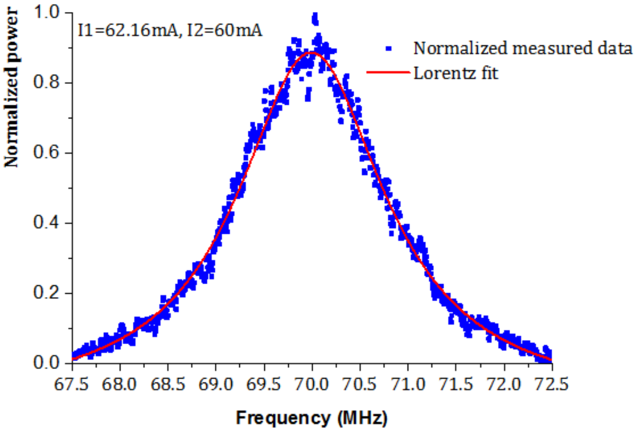


Figure 6. Measured linewidth spectrum and the Lorentzian fit

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4. CONCLUSION

In summary, we present a novel 1x2 MMI-FP composite cavity laser which demonstrates tunable single frequency with SMSR more than 35dB in a range of 25nm in the C and L bands and a narrow linewidth of 750 kHz. The regrowth free and simple FP laser processing enables high yield and low cost.

Acknowledgement

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