Regrowth-Free 1.3μm Directly Modulated DBR Lasers Based on Inverted Trapezoid High-Order Surface-Gratings

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Abstract: We demonstrate 1.3 μm regrowth-free directly-modulated DBR lasers based on Inverted-Trapezoid high-order slotted surface-gratings. The laser fabricated by standard photolithography exhibited a threshold current ~10 mA, SMSR ~50 dB, 3-dB bandwidth ~14 GHz, and RIN<-140dB/Hz.

1. Introduction

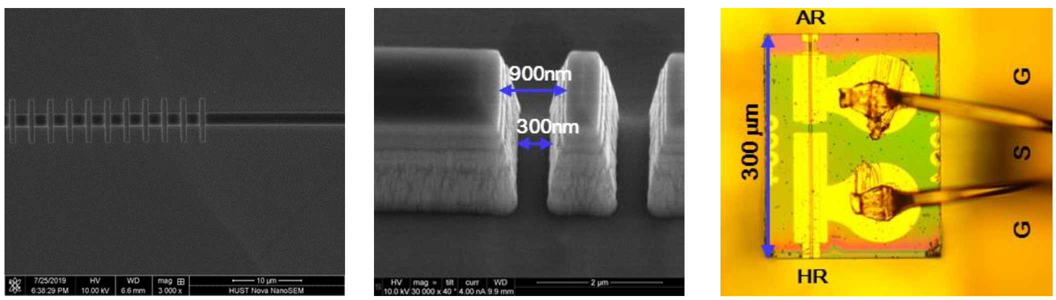
The explosive increase of Internet data, especially the abruptly increased data traffic in local area networks (LANs) pose major challenges for short-distance communications. Directly modulated semiconductor lasers (DMLs) using on-off keying have advantages such as simple operation, small footprint, low cost, high output power and high energy efficiency compared to those of external modulators, and thus are more attractive to work as laser sources for data communication systems [1]. As the typical DMLs, distributed feedback (DFB) lasers have been developed over many years. The bandwidth of DMLs has become wider and wider to operate at relatively higher speed. Recently, II-VI Incorporated has reported the high speed InP DMLs with wide bandwidths of 65~75 GHz by implementing three bandwidth enhancement effects including detuned loading, photon-photon resonance and in-cavity frequency modulation-amplitude modulation conversion [2]. The bandwidth even reaches 100 GHz as demonstrated in [3]. However, these typical DMLs are generally used the buried distributed feedback gratings, which requires both complex re-growth steps and also high resolution lithography, and thus increases the cost and lowers the yield.

To avoid these problems, the lasers have been realized based on surface gratings. Since the surface gratings are implemented after the whole epitaxial growth is completed, such lasers are of only a single growth step and thus can be easily fabricated. Such laser with laterally coupled grating suffers from a weak overlap of the optical mode with the low-order grating located on both sides of the ridge [4]. An implementation of a low-order surface grating within the ridge allows a better overlap but complicates the p-contacting [5]. In addition, lasers based on high-order slotted surface grating have also attracted great interest [6, 7]. Such a slotted laser array with 12 channels has been developed with a threshold current between 19 to 21 mA and a quasi-continuous wavelength tuning range of around 36 nm over the temperature range from 10 ˚C to 45 ˚C [7]. However, slots with a wide width of about 1μm are generally used for the easy fabrication [6, 7]. These wide slots suffer from relative large radiation loss which as a result will increase the threshold current, decrease the output power and the modulation bandwidth [8]. In this paper by carefully optimization of slotted surface grating both theoretically and experimentally, we experimentally demonstrate the 1.3 μm regrowth free directly modulated DBR lasers based on inverted trapezoid high order surface grating with low scattering loss. The fabricated laser exhibited good single mode operation with a threshold current of around 10 mA and the side-mode suppression-ratio of around 50 dB within current and temperature variations. The 3-dB bandwidth reached 14 GHz at the current injection of 80 mA. The relative intensity noise (RIN) was also measured below <-140 dB/Hz.

2. Design and fabrication

The proposed DBR laser based on high order slotted surface-gratings is based on a typical surface ridge waveguide structure. Considering the InGaAlAs material can provide a larger peak differential gain due to a better electron confinement compared with InGaAsP, the InGaAlAs compressively strained multiple-quantum wells (MQWs) are employed for the active region of the laser. The MQWs consisting of five wells and six barriers has a photoluminescence peak of around 1300 nm. To greatly reduce the scattering loss, the grating structure has been optimized using the FDTD method. The inverted trapezoid etching profile of the slots is then chosen for the trade-off between the low loss and easy fabrication by standard photolithography. Simulations show that, for the 100 μm long inverted trapezoid grating with grating period of about 2.6 μm, the slot width on the bottom of around 300 nm predicts a relatively high power reflection when the etched angle is around 11 degree. Due to the lag-effect during the fabrication, in this case the etching depth is of around 1.65 μm and the slot width on the top is about 900 nm corresponds to an original width in advance of lithography of about 600 nm. Therefore the proposed DBR laser can be fabricated by standard photolithography even the bottom slot width is as narrow as 300 nm.

The whole fabrication is quite simple. Firstly a 400nm-thick SiO_2 mask layer was deposited by the plasma enhanced chemical vapor deposition (PECVD) and then 50nm-thick Cr was deposited by the electron beam evaporation. The photolithography using Nikon i-line stepper was performed to define gratings. These grating patterns were transferred into the silicon dioxide hard masks. After ridge waveguide patterns were transferred to SiO_2, both the ridge waveguide and inverted trapezoid shaped surface gratings were etched into wafer with $CH_4/H_2/Ar$ ICP in the same procedure. Fig. 1 (a) and (b) show the SEM images of the slotted gratings during the fabrication. After Pt/Ti/Pt/Au p-electrode was deposited, the epiwafer was thinned to ~100 μm for backside electrode deposition. The wafer was then cleaved into laser chips with a cavity length of about 300 μm, and the HR/AR coating were applied to the both facets of laser chips to improve their performance. Finally the chips were soldered onto the AlN carrier for characterization as shown in the microscope picture of the fabricated DML of Fig. 1 (c). The device is electrically divided into two sections isolated by the slot: the 200 μm-long rear gain section without gratings and the 100 μm-long front section with inverted trapezoid shaped slotted gratings which provide sufficient feedback for lasing.

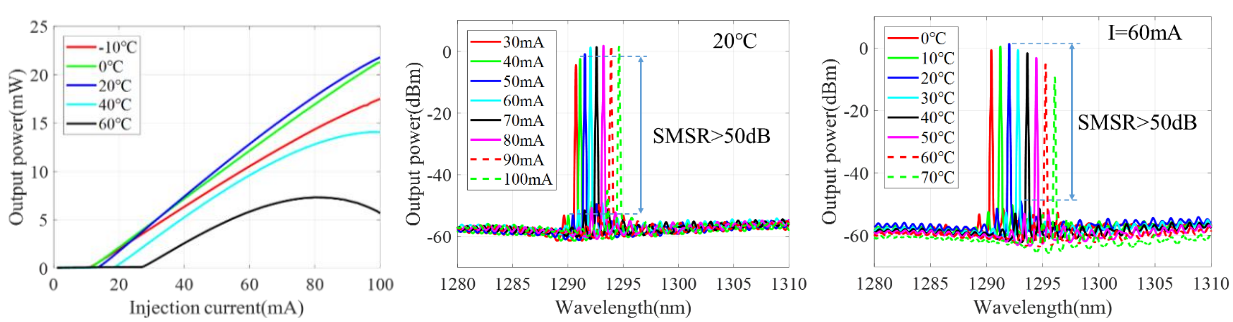


(a) (b) (c)

Fig. 1 (a) SEM picture of etched slotted gratings, (b) SEM picture of etched grating with inverted trapezoid profile, and (c) Microscope image of the fabricated 300 μm-long DML with HR/AR coating soldered onto an AlN carrier.

3. Experimental results

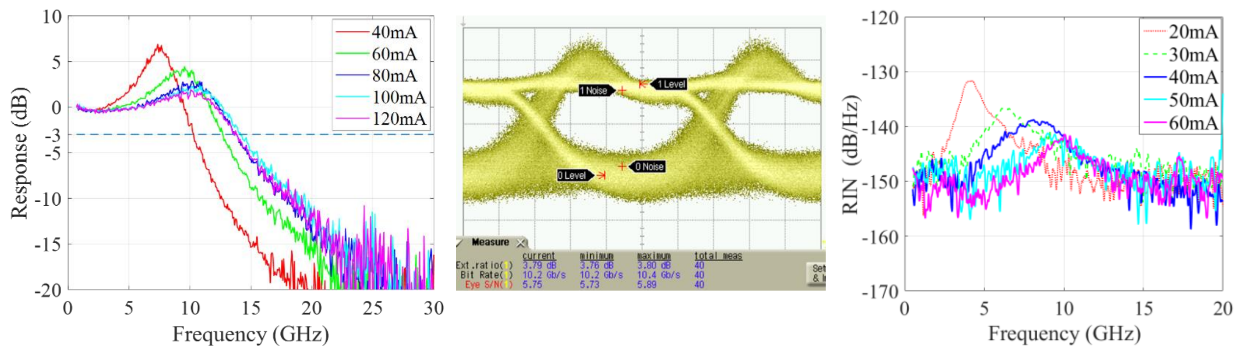
To control the chip temperature, the fabricated DML was placed on a copper heat sink which was mounted on a thermoelectric cooler (TEC). First we measured the light current curves of the laser. Fig. 2(a) shows the measured LI curves of the DML at the stage temperatures changed from -10 ℃ to 60 ℃. It is seen that the threshold current increases from 10 to 27 mA when increasing the working temperature. At room temperature, the threshold current is about 13 mA and the slope efficiency reaches 0.28 mW/mA which is about twice the laser with wide slots. Secondly we measured the output spectrum of the laser. It is observed the laser worked at stable single mode operation within the temperature and current variations. Fig. 2(b) shows the measured output spectrum of the laser versus the current. The SMSR reaches 50 dB when the injected current is 60 mA. Fig. 2(c) shows the output spectrum of the laser at the stage temperatures from -10 ℃ to 60 ℃ when the bias current was 60 mA. The SMSR is about 50 dB over the temperature change of 50 ℃. The variation of emission wavelength with working temperature is about 0.08 nm/℃ during temperature tuning.



(a) (b) (c)

Fig. 2 Measured the performance of the fabricated DBR laser (a) output power versus temperature, output spectrum versus injected current (b) and temperature (c).

Then we measured the small signal E/O response of the DML at different injection currents through a 40-G vector network analyzer, and the results are shown in Fig. 3 (a). It is clearly that the laser has a 3-dB response bandwidth about 14 GHz when the current injection is 80 mA. To measure the eye diagrams for back-to-back (BTB) SMF transmissions, a 10-Gb/s electrical signal with a non-returnto-zero (NRZ) pseudorandom binary sequence was input into the fabricated DML. Fig. 3 (b) shows 10-Gb/s eye diagrams for BTB SMF transmissions. It is seen that the eye openings were clear with a dynamic extinction ratio (DER) of above 3.7 dB. Finally the relative intensity noise (RIN) of the fabricated DML was measured. Fig. 3 (c) plots the measured RIN curves versus frequency. It is shown that the RIN was at the level below -140dB/Hz for the demonstrated DML.



(a) (b) (c)

Fig. 3 Measured (a) E/O frequency response, (b) eye diagram and (c) RIN at room temperature for the fabricated DBR laser.

4. Conclusion

We demonstrated 1.3 μm regrowth-free DMLs based on low-loss high-order slotted surface gratings. The grating consists of inverted trapezoid shaped etched slots with bottom slot-width of about 300 nm which greatly reduced the scattering loss and can be fabricated by standard photolithography. The fabricated DML exhibited good single mode operation with a threshold current of around 10 mA and the side-mode suppression-ratio of around 50 dB within current and temperature variations. The output slope efficiency reached 0.28 mW/mA which is about twice the laser with wide slots. The 3-dB bandwidth reached 14 GHz at the current injection of 80 mA. The relative intensity noise (RIN) was measured below -140 dB/Hz. This laser structure potentially has low scattering loss and can be fabricated by standard photolithography without any regrowth. It thus has strong potential as a robust laser platform for short distance communications applications.

5. Acknowledgements

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6. References

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