# Ten-Channel High Power DFB Laser Array with High Single Mode Stability and Low RIN

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**Abstract:** A high power 10-channel single-mode DFB laser array with 200-GHz-spacing is demonstrated. Output power over 85mW, SMSR over 55dB and RIN below -155dBc/Hz have been realized for all channels of the fabricated laser array. © 2024 The Author(s)

## 1. Introduction

High power semiconductor laser diodes have been widely used in coherent optical communications, microwave photonics, free space optical communications, cable TV and Light Detection and Ranging (LiDAR) system for its small footprint, high efficiency and easy operation [1-4]. Recently, thin-film lithium niobate (TF-LN) Mach-Zehnder (M-Z) modulators have demonstrated low insertion loss and high modulation bandwidth and shows good potential in dealing with data traffic when co-packaged with a high power continuous wave (CW) DFB laser [1,2]. Furthermore, with the ever-growing demands in higher data traffic speed, another potential option can be provided when an external modulator array is further co-packaged with a high power CW-DFB laser array for higher communication speed. Many high power lasers have been reported to improve the saturation power by reducing photon density, decreasing internal loss and improving injection efficiency [3,4,5]. In these reports, ridge waveguide DFB lasers can be a cost-effective option for its easy fabrication and low material growth cost. To further improve the saturation power, single mode DFB lasers with wide waveguide with have been demonstrated to reduce the saturation photon density [5]. In this work, a C-band DFB laser array with HR-AR coated facets is further demonstrated.

## 2. Laser Design and Fabrication

Optimization is performed to improve both the saturation power and single mode operation stability of this 10-channel HR-AR coated DFB laser array using traveling wave time domain method [6]. On one hand, as the Jour heat and gain saturation at high photon density will limit the output power, a specially design offset-quantum-well epitaxial structure as proposed in our previous work is employed as shown in Fig. 1(a). The epitaxial structure can realize single transverse mode operation with wide ridge waveguide width of 8 μm to reduce both the photon density and serious resistance and thus to achieve higher output power.

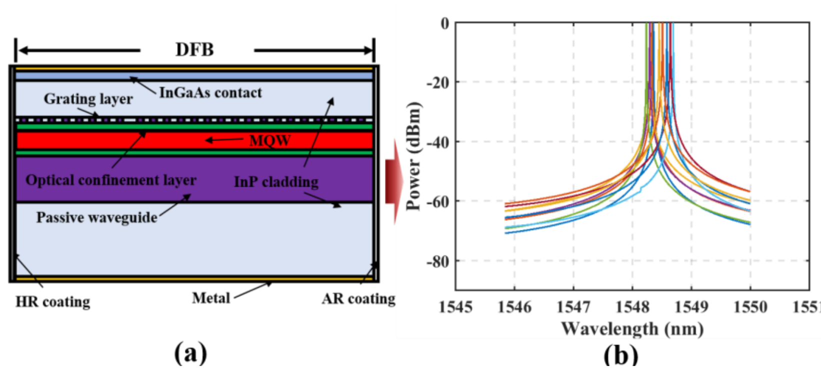


Fig. 1. (a) 2D schematic image of the designed laser; (b) Calculated spectra at different HR coated facet phases from 0 to π;

On the other hand, each channel of the demonstrated laser array has a λ/4 phase shift close to the HR coated facet to ensure single mode operation against random phase of the HR coated facet and the phase shift position is set at 0.35 of the cavity length from the HR facet. Furthermore, to reduce the uncertainty of lasing wavelength, the length of the DFB section in each channel is set at 800 μm with κL~0.8 to reduce longitude mode spacing and reduce the spatial hole burning effect. The calculated output spectra versus different random phases of HR coated facets is shown in Fig. 1(b) which shows that the designed laser can realize single mode operation against different HR facet phase with full Bragg band gap (FWHM) ~0.37 nm which is lower than 50 GHz. Additionally, in each channel, a backup laser is also fabricated beside the main laser with its grating starting position shifted λ/4 to further reduce the uncertainty of the lasing longitude mode to ~0.18 nm.

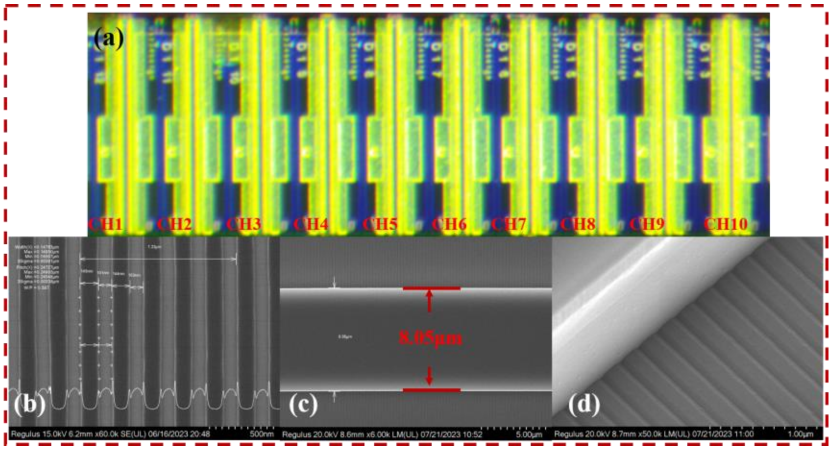


Fig. 2. (a) Microscope image of the fabricated laser array and the SEM images of: (b) the grating pattern after EBL; (c) the ridge waveguide with 8 um width and (d) the side wall of the ridge waveguide after wet etching.

With all these designs, we finally fabricated this laser array and the microscope image of the fabricated 10-channels laser array is shown in Fig. 2(a). The first-order grating is patterned using electron beam lithography (EBL) with a λ/4 phase shift section positioned closer to the HR coated facet for better single mode stability. The grating is then etched using reactive ion etching (RIE) and the Scanning Electron Microscope (SEM) image of the fabricated first-order gratings is shown in Fig.2 (b). The grating period is set at from 241.38 nm to 237.18 nm to realize a 10-channels operation with 200-GHz-spacing. The p-InP cladding layer and p+-InGaAs contact layer are then grown. The surface ridge waveguide is then patterned using i-line photolithography. The ion coupled plasma (ICP) etching using chlorine combined with wet etching using HCl is applied to fabricate the ridge waveguide structure. The SEM image of the fabricated waveguide is shown in Fig.3 (c) and Fig.3 (d) where the width of fabricated device is 8.05 μm which is close to the design value. The p-pad containing Ti/Pt/Au is deposited using electron beam evaporation (EBE). Extra Au plating process is also employed to help improve heat dissipation for better saturation output power.

## 3. Characteristics

The fabricated laser array with 10 channels is placed on a copper heat sink mounted on a thermoelectric cooler (TEC) to measure its static characteristics. The operation temperature of this TEC is set at 20 degrees Celsius and the laser bar is measured p-side up. The output of each channel is then collected as much as possible by a Ge photodiode with an active area of 7.1 $mm^2$. The measured L-I curves of the fabricated laser array is shown in Fig. 2(a) where the saturation output power of each channel is more than 85 mW at the injection current of 500 mA. The measured saturation power of this laser array is varied from 85 mW to 105 mW while its threshold current is varied from 55 mA to 70 mA mainly due to the variation of the material gain of the MQWs at different wavelengths. The output of each channel is then coupled by a 5-μm lensed-fiber into an optical spectrum analyzer (OSA) to measure its spectrum as shown in Fig. 3(b). The fabricated laser array shows good single mode performance with its side mode suppression ratio (SMSR) of each channel is more than 55 dB. By adjusting the operation current of each channel, the channel gap of this array is near 200 GHz with misalignment error lower than 2 GHz as shown in Fig. 3(c). These results prove that this epitaxial structure can realize good single transverse mode operation with an 8-μm wide waveguide and this double-laser design for each channel can also help to achieve stable single longitude mode performance.

Relative intensity noise (RIN) of each channel is then measured using the setup presented in our previous work [5]. The output is coupled into a variable optical attenuator and then received by a high speed photodiode. The RF output of this photodiode is then amplified by a low noise RF amplifier and finally received by an electrical spectrum analyzer to measure the intensity noise. After compensating the thermal noise and the short noise of the RIN testing setup, the RIN of each channel can be extracted and is shown in Fig. 3(d). The injection current of each channel is set at 500 mA and the operation temperature of this TEC is also set at 20 ℃. The measured result shows that all the 10 channels operated with a RIN lower than -155 dBc/Hz and some channel can stably operate with RIN lower than -157 dBc/Hz. This result also proves that this laser array has good single mode operation stability at high injection current.

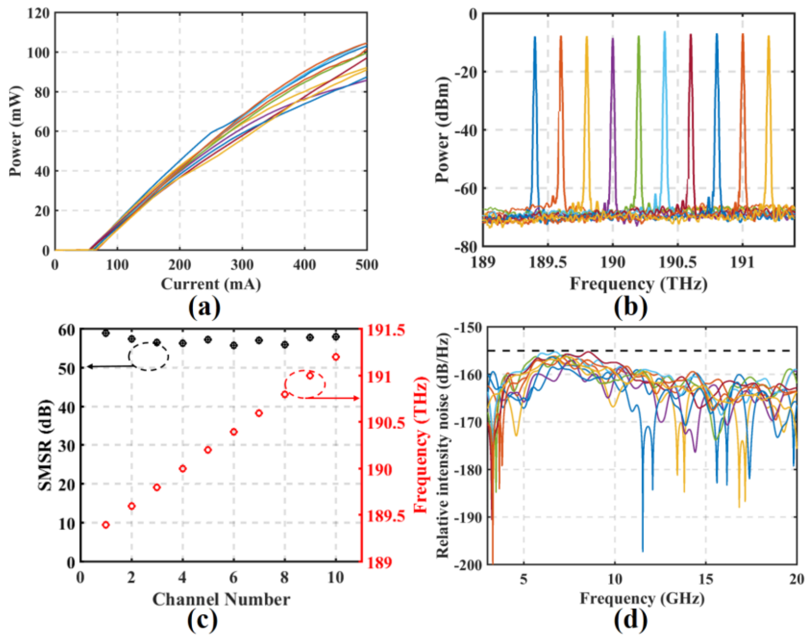


Fig. 3. (a) Measured L-I curves of each channel of the fabricated laser array; (b) Measured spectra of each channel of the fabricated laser array; SMSR and frequency of each channel of the fabricated laser array;( d) Measured RIN curves of each channel of the fabricated laser array.

## 4. Conclusion

In conclusion, we experimentally demonstrated a 10-channel high-power C-band DFB laser array with good single mode stability and low RIN. The optimized phase shift position and longitude spacing help to improve the saturation power of each channel to more than 85 mW at 500 mA injection current with threshold current below 70 mA and slope efficiency over 0.32 W/A. The fabricated laser array also realizes 200-GHz-spacing with SMSR over 55 dB and RIN of each channel lower than -155 dBc/Hz.

## 5. Acknowledgement

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