Packaging multi-wavelength DFB laser array using REC technology

Yi Ni (倪 屹)[1*], Xuan Kong (孔 轩)[1], Xiaofeng Gu (顾晓峰)[1], Xiangfei Chen (陈向飞)[2], Guanghui Zheng (郑光辉)[3], and Jia Luan (栾 佳)[3]

[1]*Shenzhen Key Laboratory of Laser Engineering, Jiangnan University, Wuxi 214132, China*
[2]*Microwave-Photonics Technology Laboratory, National Laboratory of Microstructures, Nanjing University, Nanjing 210093, China*
[3]*Wuhan Oudi Electronic Technology Ltd, Wuhan 430070, China*
**Corresponding author: niy2011 @163. com*

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Packaging of Distributed feedback (DFB) laser array based on reconstruction-equivalent-chirp (REC) technology is a bridge from chip to system, and influences the practical process of REC chip. In this letter, DFB laser arrays of 4 channel @1 310 nm and 8 channel @1 550 nm are packaged. Experimental results show that both 4 channel @1 310 nm and 8 channel @1 550 nm have uniform wavelength spacing and average side mode suppression ratio (SMSR)>35 dB. When I=35 mA, we get the total output power 1 mW of 4 channel @1 310 nm, and 227 μW of 8 channel @1 550 nm, respectively. The high frequency characteristic of the packaged chips is also demonstrated, and the requirements of 4×10 G or even 8×10 G system can be reached. we demonstrate the practical and low cost performance of REC technology and indicates its potential application in the future fiber-to-the-home (FTTH).

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Access network, as the end part of optical fiber communications, makes ordinary users enjoy the real broadband by fiber-to-the-home (FTTH) based on wavelength division multiplexing passive optical network (WDM-PON) system. WDM-PON system takes the potential advantages of wavelength so that it can meet the increasing needs of bandwidth. However, the main hindrance is concentrated in the optical transmitter module of optical line terminal (OLT) and optical network unit (ONU) which needs specific multi-wavelength and high enough laser power with tunable wavelength. At present, method of electron beam lithography (EBL) is used in the preparation of multi-wavelength lasers (MWLs) through monolithic integrated technology[1]. Although EBL can achieve tunable laser diode that conforms to the ITU-T standard, these methods need specific working temperature by thermal micro-resistance[2], in addition, their production process is complex and cost is high. Therefore, EBL is not suitable for large-scale low-cost commercial production[3].

Facing the great market demands from WDM-PON, we urgently need a way of simple and cheap production process with precise wavelength spacing for MWL. Reconstruction-equivalent-chirp (REC) technology took full advantage of existing mature integration technology to realize a low cost MWL array[4]. This letter shows that REC technology can get 4 or 8 channel laser array with 2-nm wavelength spacing and without extra thermal resistance as in EBL. The more remarkable one is packaging of REC laser array really orients to practical application through offering input interface for circuit and output interface for fiber.

In this letter, we packaged the MWL array with 4 or 8 channels based on REC technology. The packaging of MWL array got one fiber output through combining multi-channels with a programmable logic controller (PLC) multimode interferometer (MMI). Experimental results showed the potential applications of REC laser array in the WDM-PON.

REC[4] technology is based on sampled Bragg grating (SBG). Actually, the REC technology stems from a fiber Bragg grating (FBG) regarded as a kind of cascade reflection model, and the light phase difference φ for the two adjacent surfaces is

$$\phi = 2\beta\Lambda, \tag{1}$$

where Λ is the grating cycle, $\beta = 2\eta_{\text{eff}}\pi/\lambda$, λ is the the incident wavelength, η_{eff} is the effective-index of the medium; when the difference of the phase is zero, we get the Bragg conditions:

$$\beta = m\pi/\Lambda, \tag{2}$$

where m is a positive integer.

When the structure is complex with multiple phase shifts and chirps, the complex Bragg gratings must be fabricated in nanometer level. However, REC technology pulls down the fence of FBG through putting forward the thought of ‘equivalent phase shift (EPS)’ that uses SBG sampling function instead of FBG to get equivalent chirp, and the SBG sampling period is in millimeters magnitude. Therefore, technology level of millimeter by REC can achieve submicron effect, and REC operation only adds a second exposure on the traditional holographic one (producing uniform grating) to get the pattern sampling, thus REC technology greatly reduces the manufacturing cost. 8 channel array laser with $\lambda/4$ EPS based on REC technology made by Nanjing University showed good waveform with uniform distribution, and conformed to the ITU-T standard for WDM[5].

For the lasers used in WDM-PON system, low cost and low power consumption is essentially needed. Compared with coupling lasers by mirrors and lens[6], the direct coupling method[7] may not get the optimizing coupling condition, but it is the best total solution for testing, detecting, and analyzing. Therefore, the direct coupling method is easy to be operated, and the schematic arrangement is shown in Fig. 1. This coupling method is to adjust free-space position between the DFB laser array and optical waveguide array channels to achieve even optical output power for each channel. The end part has single channel output through optical coupler which can get multi-channels coupling to a single-mode fiber (SMF).

In the above procedure, the manual adjusting equipment from the newport is shown in Fig. 2. The number of the laser's output is equal to optical waveguide array's input. Experiments show that the total coupling efficiency can reach 3% for each channel by this simple and rapid way. If lens array is used, mode matching between lasers and waveguide can be achieved, and the coupling efficiency will be increased greatly.

Optical fiber communication mainly uses two windows of 1 310 and 1 550 nm, respectively. Therefore, we focus on the packaging of 1 310- and 1 550-nm laser arrays, which have 4 channels @1 310 nm and 8 channels @1 550 nm, respectively. There are coaxial and butterfly typed two kinds packaging, we choose the classical butterfly typed or associate butterfly typed packaging for two reasons: one is that the butterfly one has additive thermo-electric cooler (TEC) to control the working temperature to assure stable output, the other is that the butterfly one uses ceramic metalizing technique to meet high frequency. Packaged 4 channel laser @1 310 nm is shown in Fig. 3.

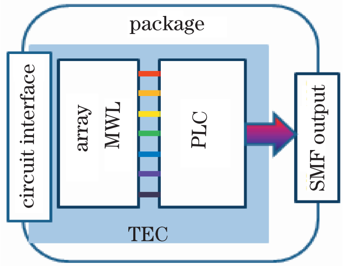

Fig. 1. Schematic arrangement of packaged MWL array.

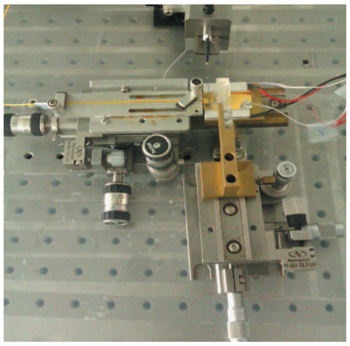

Fig. 2. Adjusting equipment of laser array in packaging.

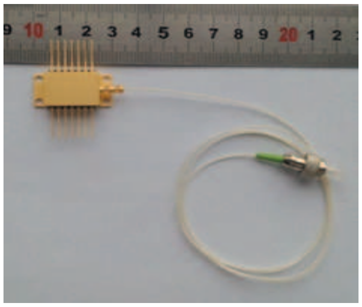

Fig. 3. Photograph of the packaged 4 channel laser @1 310 nm.

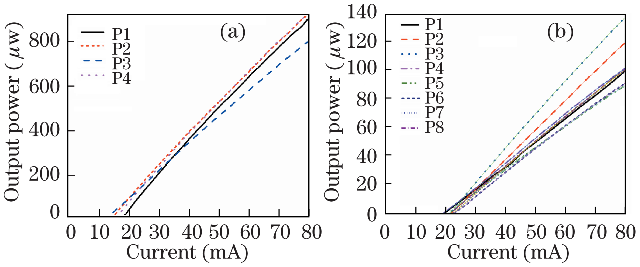

Fig. 4. $P-I$ curves of (a) 4 channels @1 310 nm and (b) 8 channels @1 550 nm.

After packaging, the laser array is tested with optical power meter, spectrum analyzer and vector network analyzer (VNA).

Figure 4 shows the $P-I$ curves of the packaged laser array at room temperature, and the threshold currents are from 15 to 20 mA. As shown in Fig. 4, 4 channels laser array @1 310 nm has good consistent slope about 16 mW/A. When I=35 mA, power of each channel is about 250 μW, and the total power can reach 1 mW. When I=50 mA, power of each channel is about 500 μW, and the total power can reach 2 mW, which can meet the requirement of ONU.

For 8 channels laser array @1 550 nm, when I=35 mA, the power of single channel is from 26.3 μW (–15.8 dBm) to 37.1 μW (–14.3 dBm) and the total value is 227 μW (–6.4 dBm). As the current increases, the diversity becomes obvious due to the different bar lengths at different channels and the mismatch of waveguide in assembly process. For both arrays @1 310 nm and @1 550 nm, coupling efficiencies are about 3%.

Figure 5 shows the side mode suppression ratio (SMSR) of the two packaged modules, for 4 channel laser array @1 310 nm average SMSR is larger than 35 dB; and for 8 channel laser array @1 550 nm average SMSR is larger than 40 dB, which can meet the requirement of laser sensor for gas monitoring, like CH_4, CO, etc. When I=35 mA, we can get uniform output light power in 8 channel array as shown in Fig. 5. However, the $P-I$ curves of 8 channels in Fig. 4 shows that each channel's output power becomes divergent with increasing current, which is unavoidable for chips with long laser bar. The output power divergence can be solved through adjusting the current in application.

S21 is often used as gain of S parameter for measuring upper limit of transport communication. Figure 6 shows the transmission factor S21 of 4 channel laser array @1 310 nm and 8 channel laser array @1 550 nm.

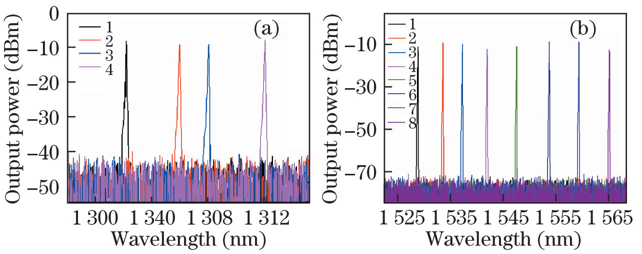

Fig. 5. Test results based on spectrum analyzer of (a) 4 channels laser array @1 310 nm and (b) 8 channels laser array @1 550 nm.

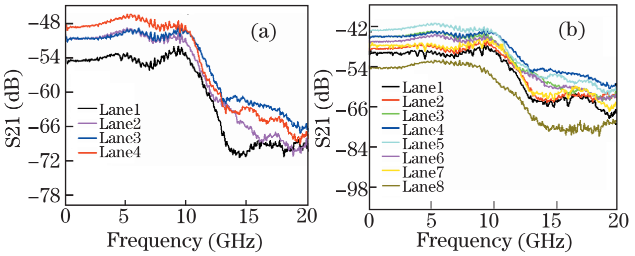

Fig. 6. I=25°, I=50 mA, the frequency characteristic of (a) 1 310-nm laser array with 4 channels and (b) 1 550-nm laser array with 8 channels.

It shows that the 3-dB point of each channel is larger than 10 G, which means that 4 channel (or 8 channel) array can meet the requirement of 40 G (or 80 G) high-speed transmission.

We conclude from Fig. 6 that S21 is influenced by the length of gold bonding wire, and longer gold bonding wire would introduce more parasitic inductance. In 8 channel array, the middle channel like channel 4 or 5 has shorter gold bonding wire, hence its S21 is larger than that in channel 1 or 8.

Experiment results show that the packaging of 4 channel laser array @1 310 nm and 8 channel laser array @1 550 nm has been successfully achieved with uniform light power output in each channel. In future work, we will try to improve the coupling of 8 channels laser array, focusing on the consistency of 8 channel optical output power by changing coupling facility and optimizing optical design.

Experimental results confirm the feasibility of laser array packaging, which can even reach the ITU-T standard without temperature control. Moreover, direct modulation in laser array can reduce the cost compared with the external modulation.

In conclusion, we package the MWL array chip based on REC technology to carry out the important transition from chip to system application. The average SMSR of 4 channel laser array @1 310 nm and 8 channel laser array @1 550 nm are both above 35 dB, uniform wavelength spacing and good frequency characteristic are also demonstrated. In future work, we will try to improve the coupling of 8 channels laser array both @1 310 nm and @1 550 nm, and focus on the consistency of 8 channels optical output power. In general, DFB laser array based on REC technology can basically conform to the ITU-T standard of communication at room temperature. Therefore, this letter provides the potential application of REC technology in future.

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