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Optical microwave generation using two parallel DFB lasers integrated with Y-branch waveguide coupler*

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A new device of two parallel distributed feedback (DFB) lasers integrated monolithically with Y-branch waveguide coupler was fabricated by means of quantum well intermixing. Optical microwave signal was generated in the Y-branch waveguide coupler through frequency beating of the two laser modes coming from two DFB laser in parallel, which had a small difference in frequency. Continuous rapid tuning of optical microwave signal from 13 to 42 GHz were realized by adjusting independently the driving currents injected into the two DFB lasers.

Keywords: optical microwave generation, distributed feedback laser, Y-branch, beat-frequency
PACC: 7820, 4265K, 4260B, 4280S

1. Introduction

Microwave signal is widely used in optical fibre communication systems, such as signal source modulation, optical sub-carrier multiplexing, photonic link signal mixing, all-optical clock recovery and generation of high bit-rate soliton-like sources.[1−4] But design and fabrication of electrical microwave devices is complex and the highest frequency of electrical microwave signal is limited by the parasitical parameters of those devices. Then the electrical-optical conversion in the nodes of the optical communications system makes the system complex and the system cost correspondingly high. So generation and transmission of microwave signals by optical means is of special interest for future broad-band optical fibre communications systems, especially for the systems operating at higher frequency. Prerequisites for the implementation of this technology are reliable low-cost components and sound technological principles. There are many reports on the generation of optical microwave signal by frequency beating of self-pulsation in multiple section DFB laser cascaded in series.[5−9] The highest frequency of 200GHz has been achieved in Ref.[10].

In this paper, we report a new device of two parallel DFB lasers monolithically integrated with Y-branch waveguide coupler to generate optical microwave. The mechanism for generation of microwave signal is, instead of the frequency beating of self-pulsation, the frequency beating of two laser modes coming from the two parallel DFB lasers, which have a small difference in frequency. By adjusting independently the driving currents injected into the two DFB lasers, continuous tuning of optical microwave signal from 13 to 42 GHz were achieved. The Y-branch based microwave generation device has better electrical and optical separation between different sections compared with traditional cascaded DFB laser. It can be a promising method for optical generation of microwave signal, for use in optical fibre communications system.

2. Device design and fabrication

The integration of active materials for the two DFB lasers and the passive material for Y-branch waveguide coupler was realized by quantum well intermixing (QWI). The species implanting the passive

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Y-branch waveguide coupler was chosen to be phosphorous and implanted at energy of 50 keV and dose of $5 \times 10^{13}/\mathrm{cm}^2$ with 4500Å SiO_2 as the mask of the active region of the DFB lasers. Then, the sample was processed by rapid thermal annealing (RTA) at 700 °C for 120 s. A blue-shift of 130 nm in band-gap wavelength between the passive material and the active material was achieved after RTA, as seen in Fig.1, which shows the peak wavelengths of photoluminescence (PL) spectra of the two integrated materials of the sample. The photoluminescence intensity of the two regions are almost equal, which shows that the material quality is maintained at a uniform high level before and after QWI process. The material structures of the active region and the passive region after RTA process are shown in Fig.2. The band-gap wavelengths of the MQWs layer are about 1.55 μm and 1.4 μm for active and passive region, respectively, which ensures minimal absorption loss in the Y-branch waveguide coupler and meets the requirement of 'transparent transmission'.

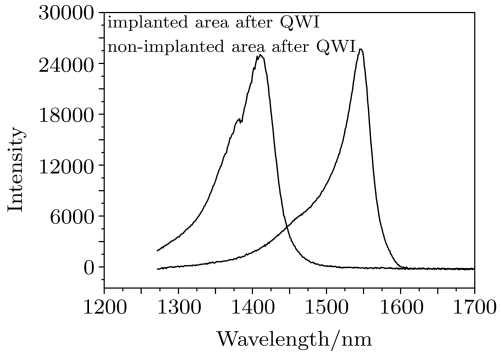


Fig.1. PL spectrum of the active and passive material before and after QWI.

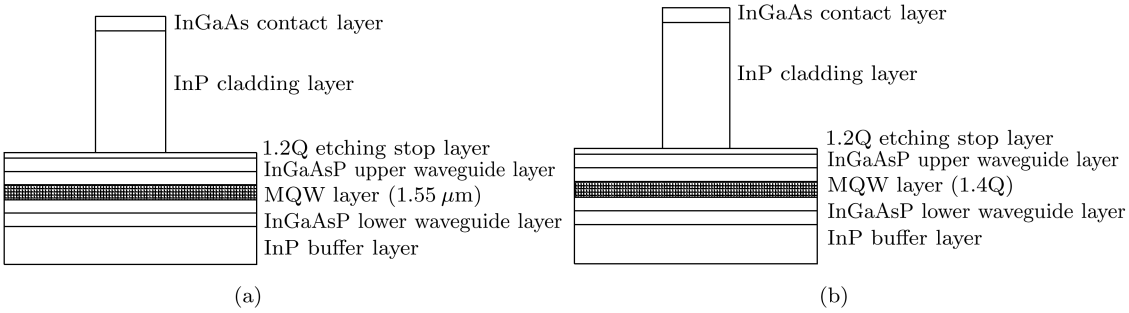


Fig.2. Material structures of the active and passive region. (a) active region, (b) passive region.

The transmission loss of the Y-branch waveguide coupler is another important parameter for the integrated device.[11,12] Figure 3 gives the sketch of the Y-branch waveguide coupler consisting of two S-band waveguides connected with a straight waveguide.

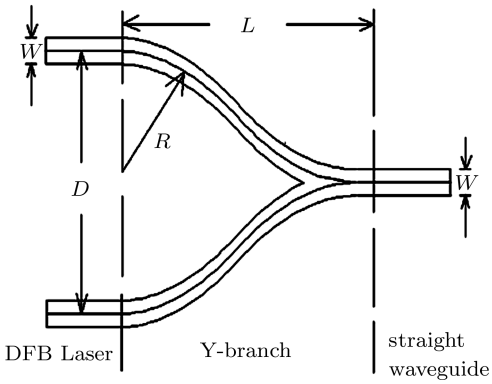


Fig.3. Sketch of the Y-type waveguide coupler.

The transmission loss mainly comes from the winding loss of the S-band waveguides and the scattering loss of the whole waveguide. So the waveguide width (W), separation width (D) between the two branches and the radius (R) of the S-bend all have serious influence on the transmission loss. Beam propagation method (BPM), we believe, is a good choice to simulate the transmission loss of passive waveguides with different structure parameters. Considering the single mode transmission in the waveguide and the practical technological process, the waveguide width was chosen as 2 μm. In simulation, we firstly obtain the fundamental mode of the laser diode based on the material structure of the active region. After launch of the fundamental mode into the Y-branch waveguide coupler, we simulate the light transmission of the waveguide by BPM at different values of the D and R. The results are shown in Fig.4(a), which gives the transmission power in the waveguide with different values of D when R was fixed at 4002.5 μm. The result shows that when D is small the transmission power in the waveguide is small compared with the total power. The reason may be the interaction between the two

branches. So the D should be big enough to ensure good light separation and reduce the loss in waveguides. Considering the adequacy of device size, we choose the separation width D as about 20 μm. Figure 4(b) shows the simulated result of scanning over several values of R when D was fixed at 20 μm. It shows that when R is larger than 4000 μm, the normalized waveguide power remains a constant of about 0.3, so we choose R as 4002.5 μm to ensure a smaller transmission loss and a compact device size.

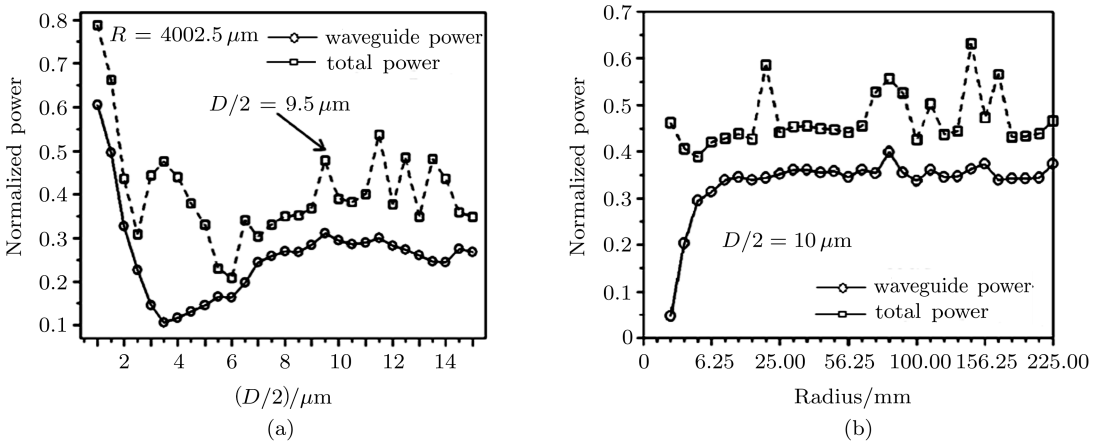


Fig.4. Simulation results of the light transmission on different parameters. (a) power transmission dependence on the separation width D. (b) power transmission dependence on the radius R.

The device was fabricated on n-type InP substrate. The waveguide structure, consisting of the lower waveguide layer, the upper waveguide layer and the MQWs active layer, was grown by low pressure MOCVD at 665 °C. The blue-shift of the band-gap wavelength of the passive region was achieved through QWI process described before. Both Bragg gratings of the two DFB lasers with the same Bragg period were fabricated simultaneously on the upper waveguide in the active region with the InP layer on top the waveguide structure as the mask of the passive region. The p-type InP cladding layer and the p-type InGaAs contact layer were grown in the second epitaxy after etching the InP sacrificial layer. The ridge waveguide of the DFB lasers and the Y-branch waveguide coupler were fabricated by reactive ion etching (RIE) with SiO_2 of 200 μm as the mask. Then the electric isolations between different sections of this device were completed through etching the InGaAs contact layer of the isolation region of the ridge waveguide. Finally, sputtering p-electrode (Ti/Au) and vaporizing n-electrode (Au/Ge/Ni) was completed. Figure 5 shows a sketch of the whole device. The ridge width of the ridge waveguide is about 2 μm. The total device length is about 720 μm, the length of the DFB laser and the Y-branch waveguide are 300 μm and 400 μm respectively, the length of the separation section is about 20 μm. The light power measured from the facet of the DFB laser and the Y-branch coupler are 7mW and 3mW, respectively, showing that the total loss of the Y-branch waveguide coupler is about 57%, which is closed to the value of the ideal Y-branch waveguide.

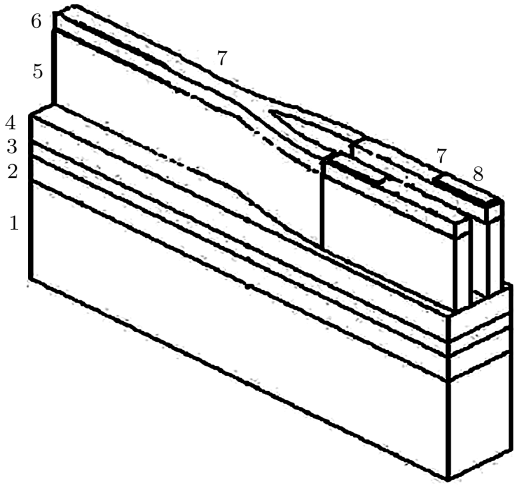


Fig.5. Sketch of the whole device.

The peak wavelength of 1565 nm and side mode suppression ration (SMSR) above 30 dB is realized on the Y-branch side when driving current was injected into DFB lasers separately.

3. Experiment result

Two lasing modes with a small difference in frequency were achieved when injecting independently two currents into the two DFB lasers simultaneously. Both currents are larger than the threshold current of each DFB laser diode and the difference between the two currents should be equal or larger than 20 mA. The reason for the small difference in frequency of lasing modes was believed to be extensive, such as the difference between the injected currents, the mode selection of the stop-band etc. Optical microwave signal can be achieved by beating those two lasing modes coming from the two DFB lasers. The frequency of the microwave signal was given in equation (1) of Ref.[12]:

$$f = c\Delta\lambda/\lambda^2. \tag{1}$$

Here, c is the light velocity in vacuum, λ is the Bragg wavelength and $\Delta\lambda$ is the difference of the two modes. Figure 6 shows an optical microwave signal of 26.64 GHz generated through beating of the frequencies in the Y-branch coupler, which was tested by ADVAN R3182 Frequency Analyzer from the facet of the Y-branch coupler.

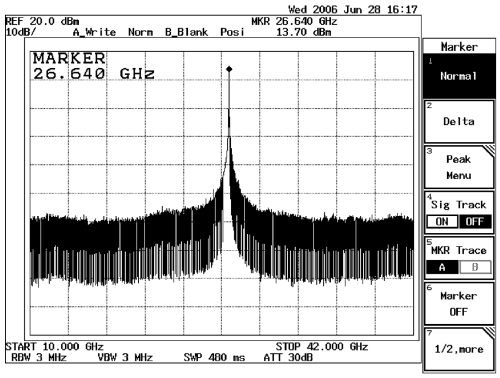


Fig.6. Optical microwave signal of 26.64 GHz generated by beating frequency.

When fixing one of the injected currents at 60 mA and changing the other one from 80 mA to 100mA, the difference of lasing wavelength of two modes $\Delta\lambda$ varied as shown in Fig.7. Continuous tuning optical microwave signal from 13 to 42 GHz were achieved under those working conditions. The measurement results are shown in Fig.8. This device has better optical and electrical isolation to reduce the interaction between two DFB lasers and the Y-branch waveguide coupler, but larger phase noise because of the stochastic phase of the Y-branch waveguide coupler. After optimize the structure parameters, we believe, the performance of this integrated device would be improved.

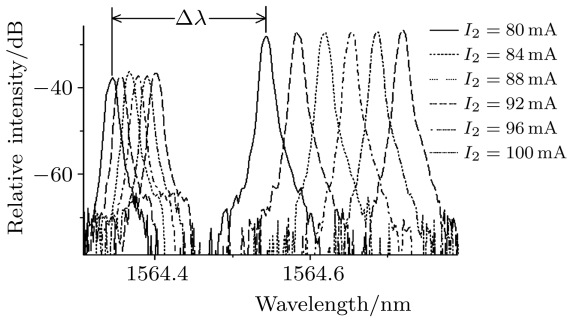


Fig.7. Wavelength difference when fixed one injected current and scan another one.

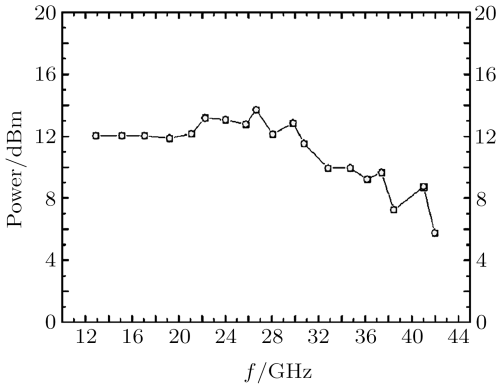


Fig.8. Continuous tuning microwave signal generated through beating frequency.

4. Conclusions

A new device of two parallel DFB lasers integrated monolithically with Y-branch waveguide coupler to generate optical microwave signal was presented in this paper. QWI technology with P^+ ion implanted was adopted to integrate the active material for DFB laser and the passive material for Y-branch waveguide coupler. The optical microwave signal was obtained through beating the two modes coming from the two DFB lasers in the Y-branch waveguide coupler. Continuous tuning optical microwave signal were achieved by independently adjusting the two currents injected in the two DFB lasers, and the tuning range is from 13 GHz to 42 GHz.

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