1.8-µm DBR Lasers With Over 11-nm Continous Wavelength Tuning Range for Multi-Species Gas Detection

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Abstract: We report a 1.8 µm widely tunable distributed Bragg reflector (DBR) laser with an over 11 nm continuous tuning range. Simultaneous detection of methane and water is successfully demonstrated utilizing this laser.
OCIS codes: (040.4200) Multiple quantum well; (140.3600) Lasers, tunable; (230.3120) Integrated optics devices; (280.3420) Laser sensors

1. Introduction

In recent years, the importance of multi-gas detection is increasing in many fields such as environment control, energy production and health diagnosis [1]. Among different techniques, tunable diode laser absorption spectroscopy (TDLAS) is competitive due to its rapid, reliable, low spectral interference, and non-contact features [2]. Distributed feedback (DFB) laser is commonly used as the light sources in TDLAS system due to its narrow linewidth and simple fabrication process. Since the DFB lasers are limited by their relatively small tuning range (of a few wavenumbers), several lasers are needed in multiple gases detection [3], thus resulting the TDLAS system becomes complex. However, rapid measurement, cost-effective monitoring and system miniaturization is crucial for a powerful gas sensing system, therefore tunable semiconductor lasers highlight their significance when applying in such system [4]. At present, due to the rapid development of telecommunications, 1.3 µm and 1.5 µm DBR lasers have been widely reported [5]. However, 1.6–2.0 µm monolithic tunable DBR QW lasers for gas sensing systems have yet to be explored. The near-infrared range from 1.6 µm to 2.0 µm is important for remote sensing and spectroscopic applications. And this spectral range coincides with the overtone/combination absorption region of many gased species of industrial and environmental interest [6]. A monolithically integrated DBR laser is an ideal source for multiple-gas sensing in this wavelength range. While overtone and combination band absorption features are significantly weaker (2 to 3 orders of magnitude) than the features in the fundamental absorption region (2~20 µm), they are nevertheless of sufficient magnitude to achieve sub ppm detection sensitivity when near infrared laser diode based optical absorption gas sensing is used in conjunction with wavelength modulation spectroscopy (WMS) detection schemes [7].

In general, the tuning bandwidth of DBR lasers directly depends on the difference of refractive index between gain materials and DBR waveguide materials. In order to get a large refractive index difference, we adopt an InGaAsP quaternary with a bandgap of 1.4 µm as the butt-joint material for DBR section. A 11 nm wavelength tuning range is obtained. The lasing spectra cover the absorption lines of several gases. In addition, we extend this work by showing its application in measurements of two spectral features of molecular gases (methane and water). It demonstrates the DBR laser is capable for accurate scanning of the wavelength and is applicable for gas sensing. As far as we know, this is the first demonstration of the monolithic DBR quantum-well laser at 1.8 µm for multispecies gas detection.

2. Device structure and Fabrication

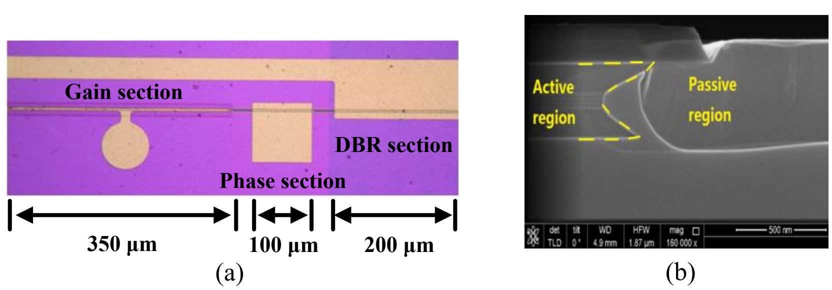

Fig. 1 (a) Photograph of the fabricated DBR laser. (b) SEM image of the butt-joint cross-sectional profile

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The photograph of the fabricated DBR laser is shown in Fig. 1(a). The device structure was grown by a three-step metal organic chemical vapor deposition (MOCVD) procedure. In the first step, a strained separate confinement heterostructure (SCH) multiquantum-well (MQW) was grown on a n-type InP substrate. The active region consisted of four 1.2% compressively strained InGaAs quantum wells (7 nm for each well) and five –0.25% tensilely strained InGaAsP barriers (12 nm for each barrier), exhibiting room temperature (RT) photoluminescence (PL) peak at 1.78 µm. Then, a 150 nm SiO_2 film was deposited as the protection layer, InGaAsP SCH layers and the MQW layer in the DBR and phase sections were selectively removed by wet chemical etchings (H_2SO_4:H_2O_2:H_2O=2：1：5). After that, SiO_2 was deposited to cover the gain sections, and a 340 nm thick undoped InGaAsP (λ_{PL}=1.44 µm) waveguide core layer with lattice-matching to InP was butt-jointed with the active layer of the gain sections by a second step MOCVD growth. A typical scanning electron microscpe (SEM) image of the butt-joint interface is shown in Fig. 1(b) and there are no voids can be seen. A good quality interface ensures a high coupling efficiency when light propagates from gain section to the waveguide.

Gratings were created in the 1.44Q layer of the DBR section. Then, a p-type InP cladding layer and a p+-type InGaAs contact layer were grown in the third step MOCVD growth. When the material growth was finished, a 3 µm width ridge waveguide was fabricated. A 50 µm wide separation areas located between grain section and phase section and between phase section and DBR section were fabricated by etching away the p^+-InGaAs layer and He^+ implantation. A SiO_2 insulation layer was deposited. Electric injection window was opened on top of the ridge waveguide. Finally, Ti-Au was deposited for P-contact metal and AuGeNi/Au was deposited for N-contact metal after substrate thinning and polishing. The chip was cleaved into a 350 µm length in gain section, 100 µm length in phase section and 200 µm length in DBR section (Fig. 1(a)). The devices were mounted on Cu heat sink. Both facets of the devices were uncoated.

3. Results and Discussion

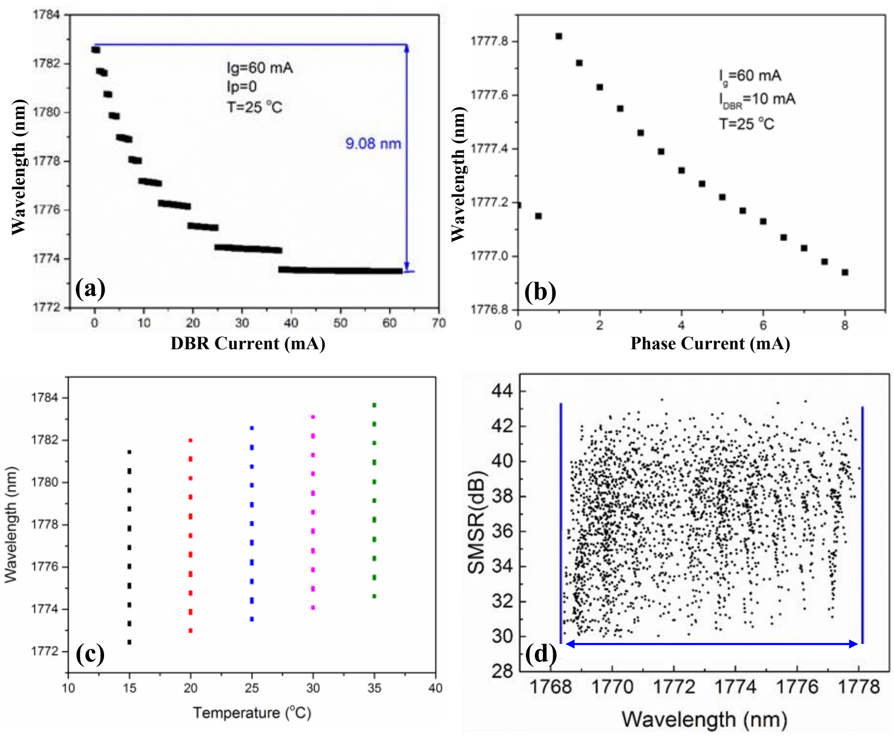

Fig. 2 (a) Emission wavelength as a function of DBR current. (b) Emission wavelength as a function of Phase current. (c) Emission wavelength varies with DBR current and work temperature. (d) The side mode suppression ratio (SMSR) of DBR laser over the entire wavelength range.

we investigate the wavelength tuning range by changing the DBR and phase section current. Fig. 2(a) shows the lasing wavelength as a function of the DBR current. The gain current is fixed at 60 mA and the working temperature is kept at 25 ˚C. It can be seen, when the DBR current increases from 0 mA to 100 mA, the emission wavelength can be quasi-continuously tuned for about 9 nm and shows a decrement trend, which indicates the tuning mechanism is dominated by the carrier injection effect. But, with further increasing the DBR current, a tuning saturation occurs

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because of the self-heating effect which counteracts the effect of injected current on the refractive index. The longer the PL wavelength of the grating material, the more rapidly the index of the material changes with the density of the injected carrier. If we adopt a longer PL wavelength of the DBR section material, a larger tuning range can be realized. The laser shows a continuous tuning feature in a single channel by just varying the DBR current. By adjusting the phase current, the wavelength tuning range can also cover the regions where mode jump happens between two channels, thus achieving a continuous tuning, as shown in Fig. 2(b). When the phase current increases from 1 mA to 8 mA, the lasing wavelength continuously sweeps 0.88 nm, which is larger than the 0.8 nm mode-spacing.

The tuning range of the DBR laser can be expanded effectively by varying the temperature of the heat sink. Combining these thermal tuning mechanism with the methods mentioned previously, the total wavelength tuning range can be increased from 9 nm to 11 nm, as shown in Fig. 2(c). For the application of multi gas species detection, in addition to pursuing a larger wavelength tuning range, the SMSR is also an important parameter for DBR laser. Fig. 2(d) shows the SMSR of the device and it is higher than 30 dB in the whole tuning range.

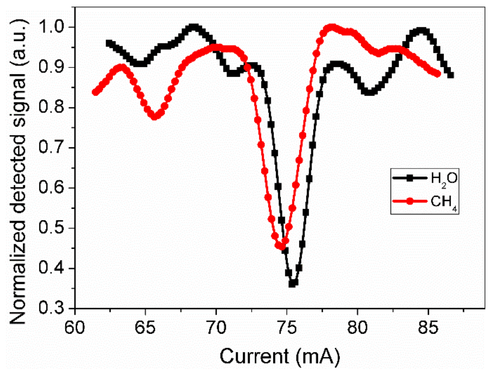

Fig. 3 The second harmonic signal from the lock-in amplifier (methane-red curve, water-black curve)

Fig. 3 shows the second harmonic curve (the “2f” curve) of CH_4 and H_2O. The trough current in the “2f” curve is the same as the driving current of the DBR laser whose emitting wavelength at such current just matches the absorption line of the sample gas. In other words, the sample gas absorption line which corresponds to the lasing wavelength is able to be figured out as long as getting the laser driving current, thus achieving sample gas determination.

4. Conclusions

In this work, we have fabricated a widely tunable three-section DBR laser with butt-jointed InGaAsP (λ=1.4 μm) as DBR material. A tuning range of 11 nm with a SMSR higher than 30 dB is obtained. Simultaneously, detections of methane and water gases have been successfully demonstrated utilizing this DBR laser. It illustrates the potential of such DBR laser as a widely tunable light source for multispecies gas detection.

5. References

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