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Novel semiconductor/superlattice distributed Bragg reflector: Experiment and simulation

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Abstract

We design a novel semiconductor/superlattice AlAs/(GaAs/AlAs) distributed Bragg reflector (DBR), and the reflection spectrum is calculated by employing transfer matrix method. In experiment, this kind of DBR is grown on GaAs (1 0 0) substrate. From the measured reflection spectrum, the central wavelength is about 810 nm with high reflectivity, and the reflection bandwidth is about 100 nm. By adjusting the thickness of AlAs layer and the period of superlattice GaAs/AlAs, the DBR with center wavelength at 1.3 μm is also investigated theoretically. The calculated results show that the central wavelength is about 1.3 μm, and the peak reflectivity is up to 99.5% with 30 pair.

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Keywords: Distributed Bragg reflector; Semiconductor superlattice; Vertical-cavity surface-emitting laser; Micro-cavity device

1. Introduction

Distributed Bragg reflectors (DBRs) have been widely used in micro-cavity device. Especially in the inorganic device, DBRs form vertical-cavity surface-emitting lasers (VCSELs), determining many optical and electrical characteristics of devices. VCSELs have become attractive devices since their planar design and small size offer many advantages in beam characteristics, scalability, fabrication, and array configurations, as opposed to their edge-emitting counter parts [1–3]. For example, VCSELs arrays are attractive for use in wavelength division multiplexing local area networks. The expitaxy technology such as molecular beam epitaxy (MBE), metal–organic chemical vapor deposition (MOCVD), also support the development of VCSEL devices. The DBR, which forms VCSELs, is desirable to use semiconductor DBRs to make the device structure more simple to fabricate [4]. The required properties for DBRs are usually a reflectivity exceeding 99% and good matching to the substrate such as GaAs or InP substrate [5,6]. The high reflectivity is accomplished with a high refractive index contrast (Δn) and sufficient number of quarter wave layers. For the short-wavelength VCSELs, it has been shown that the $Al_xGa_{1-x}As/AlAs$ DBRs can be successfully used for GaAs substrate [7,8]. In the region of 1.3–1.55 μm VCSELs, the semiconductor DBRs lattice-matched on InP substrate such as InGaAsP–InP, AlGaInAs–AlInAs, and AlGaSaSb–AlAsSb, are also designed [9,10]. In either case, the $Al_xGa_{1-x}As/AlAs$ DBR for short wavelength VCSELs or the InGaAsP–InP DBR for long wavelength VCSELs, these semiconductor DBRs all consist of two kinds of semiconductor materials, so we can call them as semiconductor/semiconductor DBRs. Since the semiconductor materials with large differences in refractive indices have large band gap differences, the large band gap differences would cause high electrical resistance and excess power consumption,

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and many kinds of various modified heterointerface structures were designed in order to reduce the electrical resistance of semiconductor DBRs [11,12]. However, these modified heterointerface structures would complicate the design and fabrication of DBRs structure, and influence the characteristics of VCSELs. In this paper, we introduced a new semiconductor/superlattice AlAs/(GaAs/AlAs) DBR. In experiment, semiconductor/superlattice DBR at 810 nm has been grown on GaAs (1 0 0) substrate by V80 H MBE system. From the results of experimental measurement, this kind of DBR can have high reflectivity with small quantity of pairs, and have flexible central wavelength by simply adjusting the period of superlattice. By using transfer matrix method the reflection characteristics of this kind of DBR is also investigated theoretically.

2. DBRs structure and fabrication

The schematic diagram of 1-pair semiconductor/superlattice AlAs/[GaAs/AlAs] Bragg mirror structure is shown in Fig. 1. In the structure, AlAs is 70.1 nm, and the superlattice is 16.5-period GaAs(3 nm)/AlAs(0.7 nm). The DBR is designed with central wavelength of 810 nm. By employing the transfer matrix method, the DBR characteristic is calculated. In experiment, this kind of DBR is grown on GaAs (1 0 0) substrate by V80 H MBE system. A GaAs buffer layer, a 10-pair AlAs(70.1 nm)/(16.5-peiod GaAs(3 nm)/AlAs(0.7 nm)) DBR, and a cap GaAs layer are successively grown. The growth rates of GaAs and AlAs as functions of cell temperatures of Ga and Al are calibrated initially by using reflection high-energy electron diffraction (RHEED) oscillations and from the flux gauge readings before the DBR growth. During the MBE growth, the substrate rotated in order to make the epitaxial layers uniform.

The DBRs with different pairs are also grown in order to study the dependence of peak reflectivity on the number of pairs. Furthermore, by simply adjusting the thickness of AlAs to 73.3 nm, and the superlattice to 18.5-period GaAs(3 nm)/AlAs(0.7 nm), the semiconductor/superlattice DBR with central wavelength at 850 nm is also obtained in experiment.

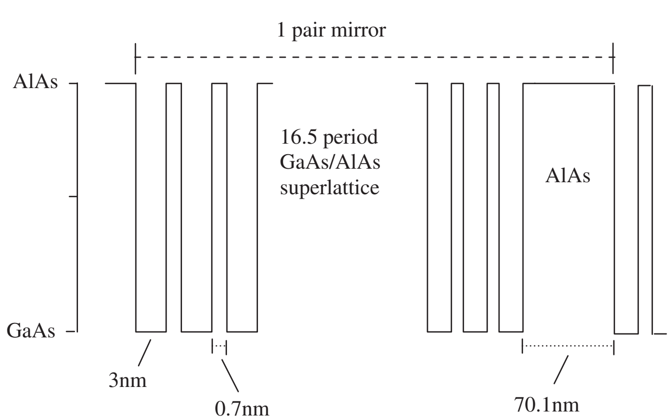

Fig. 1. Schematic diagram of the semiconductor/superlattice 1-pair AlAs/(16.5-period GaAs/AlAs) DBR structure.

3. DBRs characteristics

High-mirror reflectivity is essential for achieving VCSELs with low-threshold current or large optical gain. By using the semiconductor/superlattice type DBR structure, we can obtain high-reflectivity mirror. We fabricated the DBRs on GaAs substrate and calculated the mirror reflectivity.

The reflection spectrum of 15-pair AlAs/(16.5-period GaAs/AlAs) is calculated by using transfer matrix method. For comparison, we also calculated the reflection spectrum of conventional $AlAs/Al_{0.2}Ga_{0.8}As$ DBR with the same pair. From calculated results shown in Fig. 2, we can obtain higher reflectivity and wider stop bandwidth by using the new semiconductor/superlattice DBR. This kind of DBR with smaller quantity of pairs can reach the same reflectivity as conventional semiconductor/semiconductor DBR, therefore the growth time can be reduced. Moreover, wider reflection bandwidth enables a large wavelength tolerance to fabricate VCSEL structure and expands the possible operation wavelength range.

Fig. 3 shows the experimental-measured reflection spectrum (solid line) of 10-period AlAs(70.2 nm)/(16.5-period GaAs(3 nm)/AlAs(0.7 nm)) DBR. From Fig. 3, the central wavelength is 810 nm, the peak reflectivity is up to 97.5%, and the reflection bandwidth is about 100 nm. Fig. 3 also shows a calculated spectrum (dashed line). The experimental-measured result exhibits good agreement with the calculation result. By increasing the pair of DBR, the reflectivity is up to 99.3% at 20 pair. Therefore, such a high reflectivity can meet the requirement of

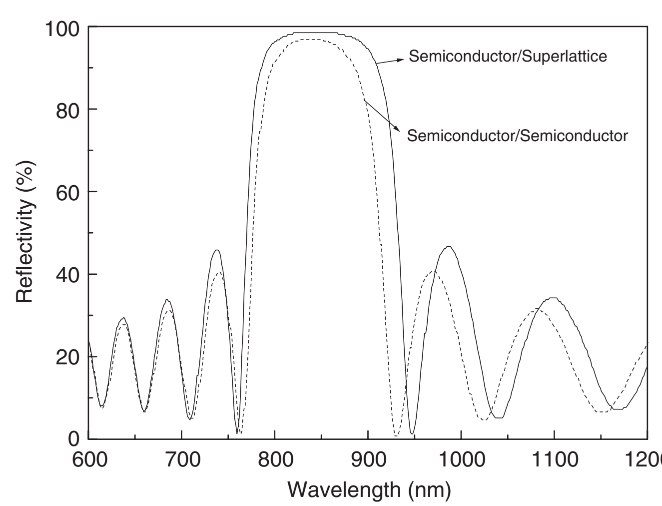

Fig. 2. Comparison of calculated performances between AlAs/(16.5-period GaAs/AlAs) DBR and $AlAs/Al_{0.2}Ga_{0.8}As$ DBR: reflectivity spectrum of 15-pair AlAs/AlGaAs DBR stacks (solid), and reflectivity spectrum of 15-pair AlAs/(16.5-period GaAs/AlAs) DBR.

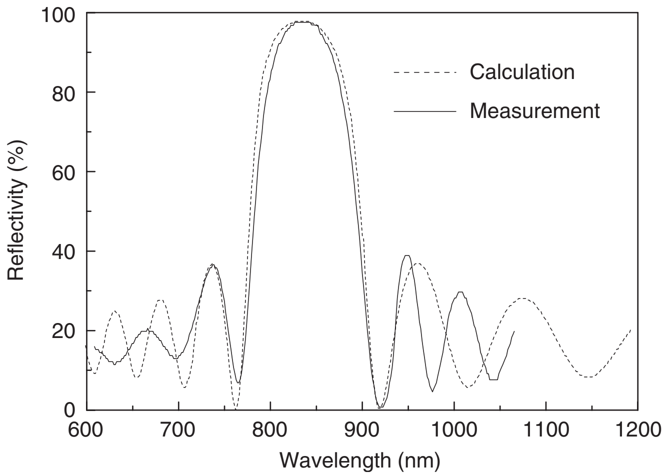

Fig. 3. Mirror characteristics of fabricated 10-pair AlAs/(16.5-period GaAs/AlAs) DBR and comparison with theoretical calculated results: experimental measured reflection spectrum (solid) and calculated reflection spectrum (dashed).

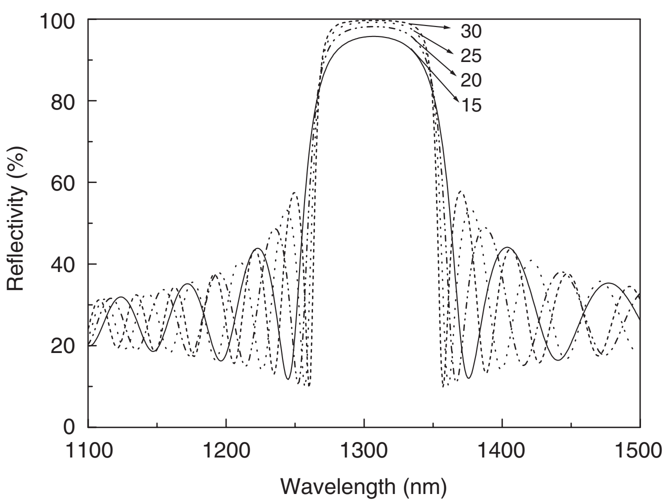

Fig. 4. Theoretically calculated reflection spectrum of the DBR with center wavelength at 1.3 μm.

opto-eletronic devices, which need high optical feedback, such as VCSELs.

By adjusting the thickness of AlAs layer and the period of superlattice GaAs/AlAs, we obtained the DBR with center wavelength at 850 nm. The experimental-measured result of the reflection spectrum of 20-pair AlAs (73.3 nm)/(18.5-period GaAs(3 nm)/AlAs(0.7 nm)) DBR shows that the central wavelength is 850 nm, the peak reflectivity is up to 99.3%, and the reflection bandwidth is about 100 nm.

We also investigated the DBR with center wavelength at 1.3 μm, by adjusting the thickness of AlAs layer and the period of superlattice GaAs/AlAs. The theoretically calculated results are shown in Fig. 4, the central wavelength is about 1.3 μm, and the peak reflectivity is up to 99.5% with 30 pair. Therefore, this kind of DBR structure can also meet the requirement in long wavelength opto-eletronic devices, which need high optical feedback, such as long wavelength VCSELs devices.

4. Conclusion

Novel semiconductor/superlattice AlAs/(GaAs/AlAs) DBRs have been designed, and the reflection spectra are also calculated by transfer matrix method mode. In experiment, the semiconductor/superlattice DBRs with central wavelength at 810 nm have been grown on GaAs (1 0 0) substrate by V80 H MBE system. From the experimental-measured results, this kind of DBR has high reflectivity and wide reflection bandwidth. By adjusting the thickness of AlAs layer and the period of superlattice GaAs/AlAs, we have also investigated the DBR with center wavelength at 1.3 μm. The theoretically calculated peak reflectivity is as high as 99.5% with 30 pair, therefore this kind of DBR structure can also meet the requirement in long wavelength opto-eletronic devices.

Acknowledgments

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