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High reflectivity distributed Bragg reflectors for 1.55 μm VCSELs using InP/airgap

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Abstract

A high reflecting InP/airgap distributed Bragg reflector (DBR) using InGaAs as sacrificial layers is demonstrated. The 3-pair InP/airgap DBR is formed by etching the InGaAs layers of the MOCVD grown InP/InGaAs structure using H_2SO_4 solution. A rigid and stable InP/airgap DBR with a peak reflectivity of 99.9% at 1.54 μm and a stopband width of about 200 nm is achieved.

Keywords: DBR; VCSEL; Reflectivity

1. Introduction

Long wavelength (1.3–1.5 μm) vertical cavity surface emitting lasers (VCSELs) are attractive for fiber-optic communication system. The excellent characteristics of VCSELs include single longitudinal mode output, small divergence circular emission beam profile, low power consumption and possible mass productions. However, the absence of high refractive index contrast in InP-lattice-matched materials impedes the progress of the development of 1.3–1.5 μm VCSELs compared to the short wavelength (0.78–0.98 μm) VCSELs.

Recently, there are several reports using various approaches to realize long-wavelength VCSELs. These approaches can be divided into three categories. First, the wafer fusion technique that bonds the InP-based active layers with the GaAs-based distributed Bragg reflectors (DBRs) was reported [1,2]. Second is the GaAs-based VCSELs using various types of active layers for 1.3 μm, such as InGaAsN [3] or GaAsSb [4] quantum wells (QWs), or InAs quantum dots [5], and GaAs/AlAs DBR. However, it is rather difficult to extend the emission wavelength to 1.55 μm range. Third category is the InP-based VCSELs utilizing high-quality InAlGaAs–InP [6] or InGaAsP–InP [7] as the active regions for 1.3–1.5 μm. But the availability of the lattice-matched material combinations with a large index of refraction difference for growth of highly reflecting DBRs is limited. For instance, the refraction index differences of InP-lattice-matched InP/InGaAsP [8] with $\Delta n = 0.27$, InAlAs/InGaAlAs [9] with $\Delta n = 0.4$, and Sb-based AlGaAsSb/GaAsSb [10] with $\Delta n = 0.44$ DBR are only 0.27, 0.4 and 0.44 respectively. As a result, using these material combination DBRs require larger number of the pairs of about 48, 35 and 32 pairs respectively to obtain 99.9% reflectivity. In addition, using these DBRs, the field penetration depth tends to increase causing more absorption, and the heat dissipation could also be a problem. Recently, using InP/airgap structure as DBR for 1.55 μm VCSELs with using InGaAs as sacrificial layer was reported [11,12]. This structure has largest refractive index contrast of $\Delta n = 2.16$ [13] and small optical loss than the conventional InP/InGaAsP and InAlAs/InGaAlAs material systems. The InP/airgap structure only requires 3-pairs to achieve high reflectivity of ∼99.9%. However in the reported InP/airgap DBR structures, the wet etching solution of $FeCl_3$ was used to etch the sacrificial InGaAs layer. The $FeCl_3$ solution has

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relatively low selectivity between InGaAs and InP layers which could cause the decrease in the reflectivity and shifting the stop bandwidth center of the DBR. These reports also did not measure the actual reflectivity of InP/airgap DBRs. In this paper, we report the fabrication and realization of a high reflectivity and rigid 1.55 μm InP/airgap DBR using a new etching technique based on the superior etching selectivity and high etching rate of H_2SO_4 solution for airgap fabrication.

2. Design and fabrication

For a rigid InP/airgap DBR with high reflectivity, a thicker InP layer is preferable. Our 3-pair InP/airgap DBR structure has a $\lambda/4$ thick InGaAs sacrificial layer and a $5\lambda/4$ thick InP layer based on the simulation results. Fig. 1 showed the calculated reflectivity of a 3-pair InP/airgap DBR structure with three different InP layer thickness of $\lambda/4$, $3\lambda/4$, and $5\lambda/4$ for a fixed thickness of $\lambda/4$ for the InGaAs layer. The result showed the peak reflectivity of three DBR structures has nearly the same high reflectivity value of 99.9% around 1.55 μm while the stopband width gradually decreased with increasing InP layer thickness. For the $5\lambda/4$ thick InP layer of DBR, the stopband still had a wide width of about 350 nm.

The 3-pair InP/InGaAs DBR structure with 615 nm ($5\lambda/4$) thick of InP layer and 387 nm ($\lambda/4$) thick of InGaAs layer was grown in a vertical type low pressure MOCVD system with a rotating disk. The disk rotated at 900 revolutions per minute to maintain the laminant gas flow. The growth pressure was 70 Torr. The growth runs were carried out at a temperature of 625 °C. V/III

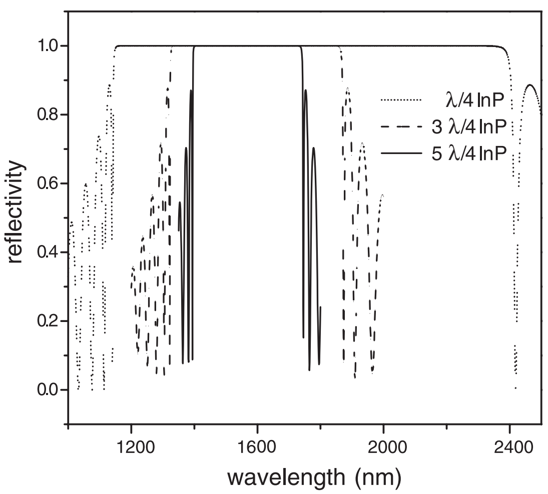

Fig. 1. The reflectivity of 3-pair of InP/airgap DBR structure with a fixed $\lambda/4$ InGaAs layer and different InP layer.

ratio was 160 for InP and 75 for InGaAs. The growth rate was about 34 and 36 nm/min for InP and InGaAs, respectively. The alkyl sources were trimethylindium (TMIn), trimethylgallium (TMGa), and trimethylaluminum (TMAl), and the group V gases were AsH_3 and PH_3. Hydrogen was used as the carrier gas. The epitaxial layers were all grown on n-type (1 0 0) InP substrates. For growth of the InP and sacrificial InGaAs layers of DBR, the growth interruption time technique with an interruption time of 0.4 min based on our previous results [14] was used by switching gas flow between different group V sources. The double crystal X-ray measurement of the grown InP/InGaAs DBR structure showed clear satellite peaks indicating excellent crystal quality of the grown DBR structure.

The basic processing procedures of the fabrication of InP/airgap DBR were shown in Fig. 2(a) and (b). The MOCVD grown InP/InGaAs DBR structure was deposited with SiO_2 as dry etching mask by using plasma enhanced chemical vapor deposition. Conventional photolithography was employed to define a 40 μm width of square mesas for supporting the InP/airgap structure with a 10 μm spacing openings. The openings were then dry etched by reactive ion beam etching (RIE). The etching conditions were set at 300 W total power under a 20 mT pressure with 10 sccm CH_4/40 sccm H_2/15 sccm Ar gas mixtures. The corresponding etching rates of InP and InGaAs were about 45 and 7 nm/min respectively under these conditions. The time required for etching the whole DBR structure of about 4 μm depth was about 200 min. To prevent the cumulation of polymer during the RIE dry etching which has a deposition rate of about 3 nm/min, a 10-min clean-etching step is conducted using O_2 plasma between every 30 min of the $CH_4/H_2/Ar$ RIE process. The procedure is important for maintaining the constant RIE dry etching rate [15,16] for making the mesa with vertical sidewall. A vertical sidewall mesa is critical for uniform etching of the sacrificial InGaAs layers later and the formation of uniform airgap width to prevent any change in the reflectivity of InP/airgap DBR. After the mesa dry etching, the SiO_2 mask was removed by wet etching using HF solution.

The etching of InGaAs layers to form the airgap was conducted by wet chemical selective etching using a $H_2SO_4:H_2O_2:H_2O = 1:1:2$ solution. The solution has a good etching selectivity for InP and InGaAs and three times higher etching rate than the $FeCl_3$ solution. We used a spinning roller in the solution to increase wet etching uniformity and take away the reactant between the InGaAs layers. The airgap created by the wet etching process had a width of about 12.5 μm. The InP/airgap DBR structure was rinsed in D.I water and dried on the hot plate to clean up the residual water left in the airgap. Fig. 3 depicts the SEM picture of the fabricated InP/airgap DBR structure. The DBR structure has a rigid and stable structure with uniform airgaps.

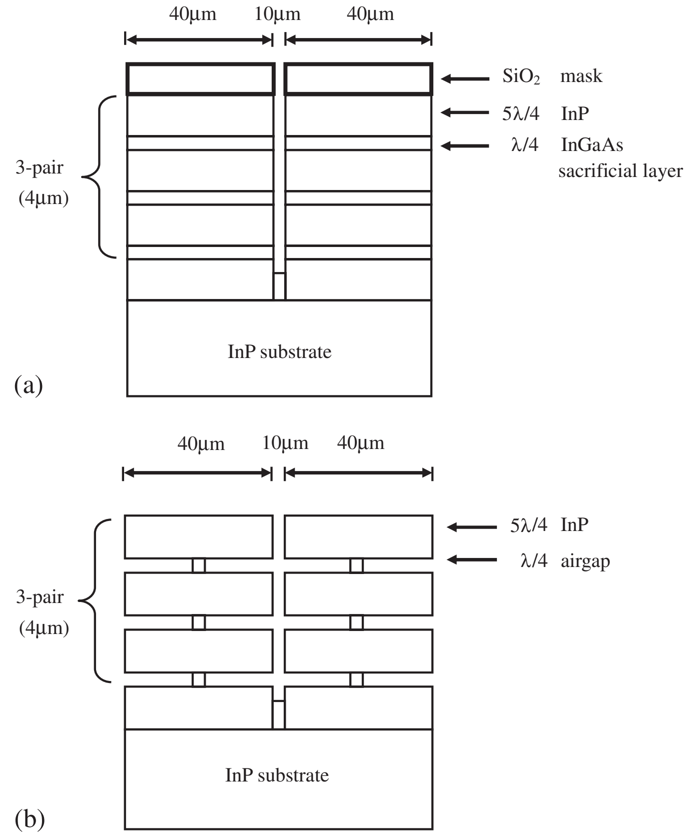

Fig. 2. (a) Schematic diagram of the dry etched mesas. (b) Schematic cross-section of the InP/airgap DBRs.

Fig. 3. The cross-section of the stable suspended InP/airgap DBRs captured by SEM.

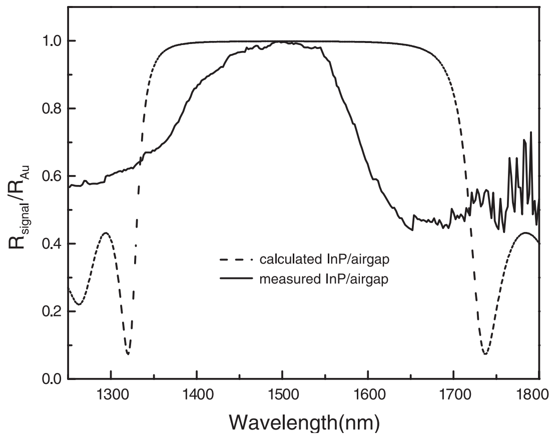

Fig. 4. The calculated and measured reflectivity curves of the InP/airgap DBRs. Peak reflectivity is 99.9% at 1.54 μm.

3. Optical characterization

The reflectivity of the fabricated DBR structures was measured by the spectrometer using the reflectivity of the Au film as the reference. Since the Au film had a reflectivity of 95% at 1.55 μm wavelength, all of the reflectivity of DBR was normalized to the reflectivity of the Au film. Fig. 4 shows the reflectivity spectrum of the InP/airgap DBR structure. The dash line was the calculated curve and the solid line was the measured result.

The peak reflectivity of 99.9% at the wavelength of 1540 nm with a stopband width of about 200 nm was obtained. The peak reflectivity was very close to the simulated value. The measured stopband width was narrower than the calculated width which could be due to the limited etched airgap regions.

4. Summary

In summary, we have designed, fabricated, and demonstrated a rigid InP/airgap structure with high reflectivity at 1.54 μm using InGaAs as the sacrificial layer. The 3-pair InP/airgap DBR structure with $5\lambda/4$ thick InP layer was fabricated from the MOCVD grown InP/InGaAs structure using H_2SO_4 solution as etching agent. The InP/airgap DBR has a peak reflectivity of 99.9% at 1.54 μm with a stopband width of about 200 nm. The InP/airgap DBR structure was rigid and stable and should be applicable for 1.5 μm VCSELs.

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