Low resistance uniparabolic graded distributed Bragg reflectors using digital alloy

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Abstract We investigated the influence of uniparabolic graded distributed Bragg reflector (DBR) using digital alloy on vertical series resistance and reflectivity of DBRs. Measured specific DBR series resistance was reduced to about $8.787\times10^{-6}\Omega\cdot cm^2$/period for digital alloy uniparabolic graded DBR. This was better than various graded DBRs, especially biparabolic graded DBR. Reflectivity of 42 pair uniparabolic graded DBR was found to be comparable to that of biparabolic graded DBRs.

Introduction

The distributed Bragg reflectors (DBRs), which form mirrors of vertical cavity surface emitting lasers (VCSELs), determine some of the important optical and electrical characteristics of devices. DBRs require high reflectivity and low electrical resistance simultaneously. The high reflectivity is usually realized with a higher index difference of DBR layers and a sufficient number of quarter-wave layers. However, this leads to the large energy band offsets, which impede the carrier flowing in the DBR structures and result in large series resistance especially in the p-type doping case due to their large effective hole mass.

In this work, to reduce series resistance of DBRs without degradation of reflectivity, we introduce uniparabolic graded DBRs using digital alloy. This technique provides the ability to vary the effective alloy composition using a minimum number of cells simply by varying the duty cycle of the digital alloy (1). Therefore, at the heterointerfaces of DBR, effective-continuous compositional grading can be easily achieved by digital alloy structure in MBE system.

Experiments and Results

It is clear that the parabolic graded structure is the most attractive in reducing the series resistance of DBR. Generally, there are two types of parabolic graded structure (2). The one is biparabolic with two concatenated parabolic segments of opposite curvature. The other is uniparabolic with a single negative curvature parabolic segment. The uniparabolic graded DBR approach is simultaneously to reduce electrical resistance and to minimize degradation of reflectivity in comparison to biparabolic graded DBR.

To facilitate the series resistance measurements, the series resistance measurements were performed on samples grown with the following sequence. At first, a buffer layer of p-GaAs layer with 0.4um thick was grown on semi-insulataed GaAs substrate before the growth of p-DBRs. p-DBRs consist of 9 period $Al_{0.83}Ga_{0.17}As$/ $Al_{0.19}Ga_{0.81}As$ with different grading layers incorporating within a 200 Å grading region and 1-pair $Al_{0.83}Ga_{0.17}As$/GaAs for ohmic contact. The p-DBR DBRs were uniformly Be doped at 3×10^{18} cm^{-3}. The cap ohmic contact layer was Be doped at 9×10^{18} cm^{-3}. These samples were fabricated into square elements by inductively coupled plasma (ICP). Alloyed electrodes were formed to lower contact resistance. The series resistances were measured from standard transmission line measurement (TLM) (3) as shown in Fig. 1.

All the resistances values were obtained form the slope of I-V curve measured by semiconductor parameter analyzer. As TLM performed before and after etching away all the DBR, we can obtain the DBR series resistance accurately as seen in Table 1. In the TLM, straight lines in the resistance versus contact pad separation plot were obtained in all cases. The specific resistance value of one pair $Al_{0.83}Ga_{0.17}As/Al_{0.19}Ga_{0.81}As$ with abrupt and 4-step graded DBR was 2.836×10^{-3} $\Omega\cdot cm^2$/period, 2.428×10^{-4} $\Omega\cdot cm^2$/period, respectively. For the linear graded DBR, the specific resistance value was 2.885×10^{-5} $\Omega\cdot cm^2$/period. Using digital alloy uniparabolic graded DBR as our method, the specific series resistance reduced to 8.878×10^{-6} $\Omega\cdot cm^2$/period. Specific resistance of uniparabolic graded DBR was slightly smaller than that of biparabolic graded DBR to 1.6756×10^{-5} $\Omega\cdot cm^2$/period. Therefore, digital alloy uniparabolic graded DBRs were effective in reducing the DBR series resistance. We also measured reflectivity of DBRs with both two types of parabolic-graded DBR at 42 pair. Fig. 2(a) shows the reflection spectra for the biparabolic(solid line) and the uniparabolic-graded DBR(dashed line). The measured peak optical reflectivity of the DBR with uniparabolic graded and biparabolic

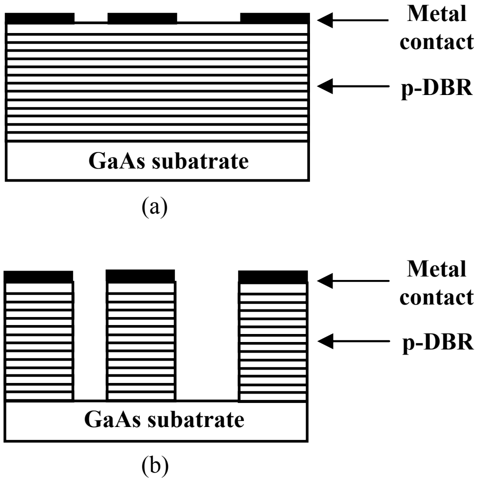
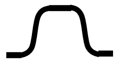


Fig. 1. Sample structure (a) before etching DBRs, (b) after etching DBRs for TLM measurement

graded interface were 99.979%, 99.878%, respectively. This shows a small difference (<0.1%) in the measured peak reflectivity. The stopband width of the biparabolic graded DBR and the uniparabolic graded DBR were 68.7nm and 66nm, respectively. We estimated that this difference in the stopband widths was less than 3 nm. From these results, it is found that the uniparabolic-graded DBR was highly effective in reducing the series resistance of p-DBRs without the degradation of reflectivity and stopband width. Our experimental results on both are in good agreement with the theoretical calculation as shown in Fig. 2(b), (c).

Table 1. List of transmission line measurement results for the different graded mirror.

DBR structures Measured results	 **Abrupt**	 **4-step**	 **D.A.-Linear**	 **D.A.-Biparabolic**	 **D.A.-Uniparabolic**
Specific contact Resistance ($\Omega \cdot cm^2$) (TLM without DBR etching)	**1.15×10^{-2}**	**5.349×10^{-3}**	**1.855×10^{-3}**	**2.1298×10^{-3}**	**1.1132×10^{-3}**
Specific contact Resistance ($\Omega \cdot cm^2$) (TLM with DBR etching)	**3.986×10^{-2}**	**7.766×10^{-3}**	**2.134×10^{-3}**	**2.2973×10^{-3}**	**1.201×10^{-3}**
Specific contact Resistance per 1 pair ($\Omega \cdot cm^2$/period) (ρ_C (*DBR*))	**2.836×10^{-3}**	**2.428×10^{-4}**	**2.885×10^{-5}**	**1.6756×10^{-5}**	**8.787×10^{-6}**

*D.A. stands for digital alloy

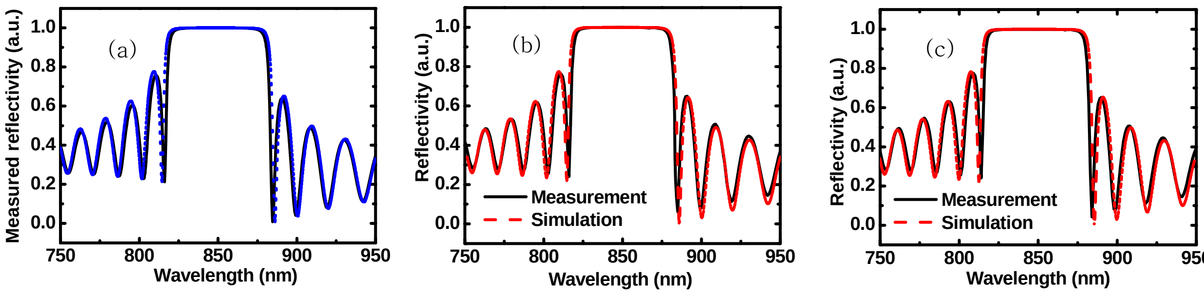


Fig. 2. (a)Reflectivity spectra of uniparabolic graded mirror (dashed line) and biparabolic graded mirror (solid line), Measured and simulated reflectivity spectra of (b) uniparabolic and (c) biparabolic digital alloy graded mirror

Conclusion

We have shown that resistance reduction to 8.878×10^{-6} $\Omega \cdot cm^2$/period was achieved with uniparabolic digital alloy graded DBR. Moreover, the optical reflectivity measurement on this DBR is consistent with the theoretical calculation and peak reflectivity difference between biparabolic and uniparabolic graded DBR was estimated to be less than 0.1% for 42 pair DBR. Thus, the use of a uniparabolic grading reduces series resistance more effectively than biparabolic grading without any degradation of reflectivity

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