Study of reflectivity and resistance properties of *p*-type distributed Bragg reflectors with composition graded interfaces

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***Abstract*—In this work, the reflectivity and series resistance of the *p*-type distributed Bragg reflectors (DBRs) in vertical cavity surface emitting lasers (VCSELs) under the different thickness of composition graded interface layers, Al composition of the high Al composition layers, Al composition of the low Al composition layers, and the number of DBR periods are simulated and investigated, respectively. To obtain the optimal parameters for the *p*-type DBRs, the Min-Max normalization method is applied for the comprehensive analysis and comparison of the reflectivity and series resistance. The results show that the series resistance can be effectively reduced by selecting the appropriate parameters of the *p*-type DBRs.**

***Index terms*—distributed Bragg reflectors, vertical cavity surface emitting lasers, reflectivity and resistance properties**

I. INTRODUCTION

Vertical cavity surface emitting lasers (VCSELs) have been widely used as the light source for optical communication and sensing due to their advantages in beam quality, divergence angle, speed modulation, and so on. Although the VCSELs have already been commercialized, lower operating voltage and higher power-conversion efficiency (PCE) is anticipated to be the next generation of laser sources. To reduce the operating voltage and improve the PCE, the most direct and effective technique is to minimize the series resistance of the distributed Bragg reflectors (DBRs), especially the series resistance of the *p*-type DBRs due to the mobility difference between the electrons and holes [1]. Recently, the technology to insert a composition graded interface (CGI) layer between two constitutive layers with a large difference in composition for reducing the DBRs resistance has been wildly employed. However, the insertion of CGI layers will reduce the reflectivity of the DBRs [2,3]. To maintain the required reflectivity, it is inevitable to use more periods of DBR, which in turn will increase its series resistance. Thus, it is important to investigate the interactions between their series resistance and the reflectivity of DBRs with CGI layers.

In this paper, the series resistance and reflectivity of the *p*-type DBRs with CGI layers based on GaAs-based 850 nm VCSELs are systematically analyzed and studied. In addition, the Min-Max normalization method is applied for obtaining the optimal parameters of DBRs with high reflectivity and low series resistance.

II. DBRs STRUCTURE

The structure of the *p*-type DBRs for 850 nm VCSELs used in the simulation is consist of 21 periods C-doped AlGaAs DBRs. Each period of the DBRs is composed of a low Al composition (high refractive index) $Al_xGa_{1-x}As$ layer (x=0.08, doping=3.0 × $10^{18}cm^{-3}$), a CGI layer (doping=3.5×$10^{18}cm^{-3}$) with Al composition from low (0.08) to high (0.88), following a high Al composition (low refractive index) $Al_yGa_{1-y}As$ layer (y=0.88, doping=3.0 × $10^{18}cm^{-3}$), and another CGI layer (doping=3.5×$10^{18}cm^{-3}$) with Al composition form high (0.88) to low (0.08). The thickness of the two CGI layers is equal (25 nm). And the total optical thickness of a low Al composition layer and a CGI layer is a quarter wavelength (λ/4), which is equal to the total optical thickness of a high Al composition layer and a CGI layer. The p-type DBRs geometry in the study is circular with a radius of 20 μm.

III. RESULTS AND DISCUSSIONS

Figure 1(a) shows the peak reflectivity and resistance of the DBRs versus the thickness of CGI layers. It can be observed that the reflectivity and the resistance of the DBRs are decreased together with the increase of the thickness of the CGI layers. However, the rate of the decrease for the reflectivity is gradually increasing while that for the resistance is gradually decreasing with the increase of the thickness.

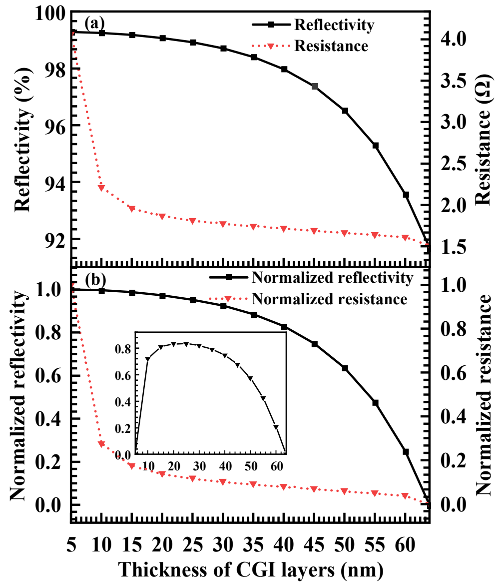

Fig. 1. (a) Peak reflectivity and resistance of the DBRs versus the thickness of CGI layers, and (b) the normalized curves of the reflectivity and resistance. The inset shows the difference curve between normalized reflectivity and normalized resistance.

As for the p-type DBRs used in the VCSELs, the lower resistance and the higher reflectivity are better. To obtain the optimal parameters for the DBRs, the Min-Max normalization (MMN) method is applied for the numerical analysis, which makes the reflectivity and the resistance of the DBRs to be compared in the same dimension, and the normalization formula is $X_{out} = (X_{in} - X_{min})/(X_{max} - X_{min})$, where X_{out} is the normalized value by this formula, X_{in} is the original value, and the X_{max} and X_{min} are the maximum and minimum values of the original values, respectively [4]. Figure 1(b) illustrates the curves of normalized values for the reflectivity and resistance as a function of CGI layers thickness, and the curve of their difference between reflectivity and resistance is shown in the inset. From the inset, it can be found that the difference between reflectivity and resistance is the largest when the thickness of the CGI layers is about 25 nm. Therefore, the optimal thickness of the CGI layers in this study is about 25 nm by comprehensively considering the reflectivity and resistance.

Figure 2(a) demonstrates the curves of peak reflectivity and resistance of DBRs with the change of Al composition in the high Al composition layers; Figure 2(b) are the curves of the normalized reflectivity and resistance by the MMN method, and the inset is the difference curve after normalization. It can be seen from Fig. 2(a) that both reflectivity and resistance increase with the increase of Al composition. From the inset of Fig. 2(b), it can be found that the difference between reflectivity and resistance is the largest when the Al composition of high Al composition layers is about 0.88. Therefore, the optimal Al composition of high Al composition layers is about 0.88.

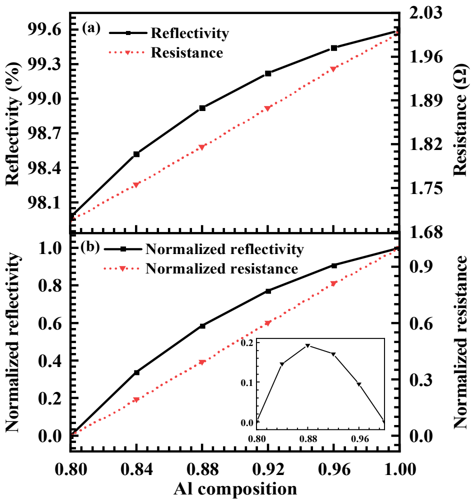

Fig. 2. Reflectivity and resistance of the DBRs versus Al composition of high Al composition layers, and (b) the normalized curves of the reflectivity and resistance. The inset shows the difference curve between normalized reflectivity and normalized resistance.

Figure 3(a) shows the curves of peak reflectivity and resistance of DBRs with the change of Al composition in the low Al composition layers; Fig. 3(b) are the curves of the normalized reflectivity and resistance by the MMN method, and the inset is the difference curve after normalization. It can be seen from Fig. 3(a) that both reflectivity and resistance decrease with the increase of Al composition. From the inset of Fig. 3(b), it can be clearly seen that the difference between reflectivity and resistance is the largest when the Al composition of low Al composition layers is about 0.08. Therefore, the optimal Al composition of low Al composition layers is 0.08 in this work.

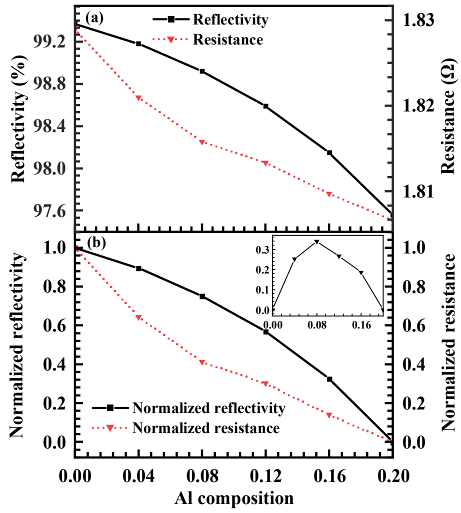

Fig. 3. Reflectivity and resistance of the DBRs versus Al composition of low Al composition layers, and (b) the normalized curves of the reflectivity and resistance. The inset shows the difference curve between normalized reflectivity and normalized resistance.

Figure 4 displays the curves of peak reflectivity and resistance of the DBRs versus the number of periods. It can be found that the reflectivity increases with the increase of the DBR number, however, the rate of the increase is gradually decreasing. As for the resistance, which increases linearly with the increasing number of DBR periods due to the resistance of each DBR period being exactly the same. Thus, the optimal number of the DBR periods is the smallest DBR periods when the reflectivity of DBRs meets the requirement.

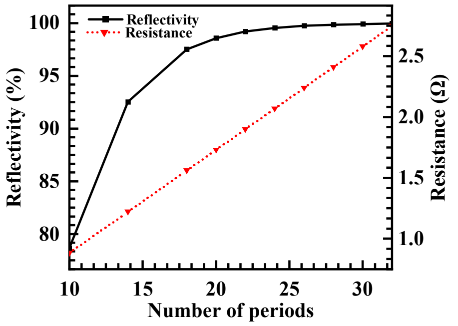

Fig .4. Reflectivity and resistance of the DBRs versus the number of DBR periods

IV. CONCLUSIONS

In this paper, simulation work is made to study the competitive relationship between the reflectivity and resistance of the DBRs with CGIs. Simulation results show that the DBR with CGIs can be optimized to get the lowest possible resistance and the highest possible reflectivity. Its significant advantages may help design VCSELs with better performance.

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