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Ultralow Threshold Red Vertical-Cavity Surface-Emitting Lasers*

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Abstract Visible Vertical-cavity Surface-emitting Lasers (VCSELs) have been designed and fabricated by using metalorganic vapor phase epitaxy. Using the 8λ optical cavities with 3 quantum wells in AlGaInP/AlGaAs VCSEL's to reduce the drift leakage current and enhance the model gain, the device can operate continuous wave at wavelength of 670nm. For better performance, a misoriented (100) substrate (6~ 10° to (110)) has been used to reduce the ordering of AlGaInP. However, as the angle of misorientation increased, the symmetry of the structure became worse. This made it difficult to achieve little aperture device. By using 45° rotated selective oxidation method, a little aperture ($1\times1\mu m^2$) device with low threshold of 0.25mA can operate continuous wave at room temperature.

Key Words: Surface Emitting Lasers, Vertical Cavity
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1 Introduction

Red AlGaInP vertical cavity surface emitting lasers (VCSELs) are attractive for a number of application. First, as an element of tricolor, red lasers are very useful for display. And because VCSELs can be easily arrayed, red VCSELs have more advantages than the usual red laser. Besides these features, good performance of the laser beams also makes it be favored at display market. Second, because of the short wavelength and better (smaller) light spot, high memory density can be achieved by using red VCSELs. Furthermore, red VCSELs may be used in some other applications, such as laser printing, plastic

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fiber-based optical communication links and scanning[1].

Electrically injected CW red VCSELs employing AlGaInP active regions and AlGaAs DBRs were first reported in 1993[2~4]. Most devices in the past were fabricated by using H^+ implantation for lateral current confinement and device isolation. However, this method has some disadvantages. It can not be easily controlled, and can not form little aperture to confine the current. Selective oxidation was also used for lateral confinement. However, this method was influenced by the symmetry of the structure. In this paper, some analyses were offered to explain it. Finally, a new method (45° rotated selective oxidation method) was used to solve this problem. By using this method, an aperture of $1\times1\mu m^2$ for lateral current confinement was completed, and it made threshold current very low, near to 0.25mA.

2 Structure and Symmetry of Epitaxy Chip

GaInP has the tendency to order on GaAs substrate under certain growth conditions. Figure 1 illustrates this ordered structure. The figure shows that Ga and In atoms are arranged in (111) plane. A disadvantage of this structure is that the energy gap is too small (1.84eV). For better performance of the GaInP active region, a misoriented substrate has been used[6]. Figure 2 illustrates the PL spectrum of a structure grown on a (100) substrate misoriented by 6° toward the (110) plane.

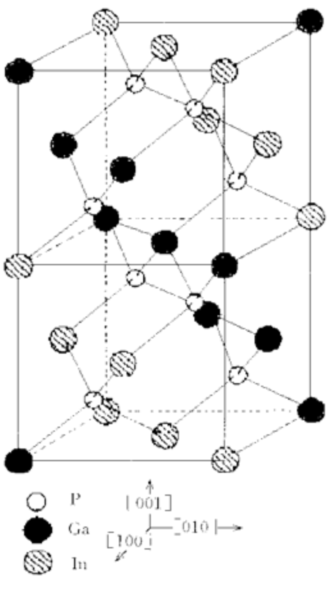

FIG. 1　Ordered GaInP Structure

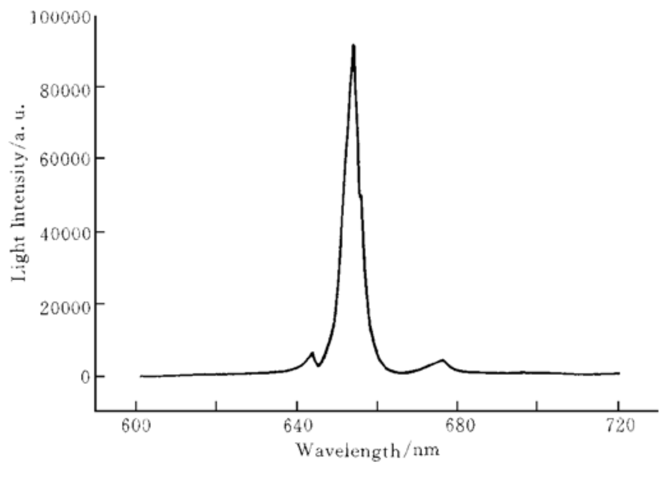

FIG. 2　PL Spectrum of the Misoriented Structure

However, the misorientation results in some difficulty in device processing such as selective oxidation. The selective oxidation of AlGaAs/AlAs is a reaction between the gas and the solid, the reactant vapor exists as molecule.

$$2AlAs + 3H_2O = Al_2O_3 + 2H_3As$$

This reaction can be considered as: 3 H_2O molecules attach to 2 adjacent As atoms, 6 H atoms and 2 As atoms combine to 2 H_3As molecules, the leaving 3 O atoms must react quickly to the adjacent 2 Al atoms. So the oxidation reacts as a reaction between H_2O molecules and AlGaAs/AlAs molecules. In the following analysis, the crystal structure of AlGaAs/AlAs is considered to be cubic system as shown in Fig. 3. In the figure, each black spot represents an As atom and the adjacent Al/Ga atom. The vector S is perpendicular to (001) plane, but S' perpendicular to the surface of the misoriented substrate. In the following, this surface is named as S' face. In Fig. 4, the thin lines show the projection of the (001) square in Fig. 3. Vector S is a C_4^1 axis. S' misoriented a certain angle from S, so the character of each side can not maintain the same if the substrate rotates 90°. In Fig. 3, there are four mirror planes respectively parallel to (010), (100), (110) and ($1\bar{1}0$) plane. Because S' is not parallel to (010), (100) and (110) plane, S' face does not have these mirror planes. There is only one mirror plane (parallel to ($1\bar{1}0$)). In Fig. 3 and Fig. 4, the solid line m_1 represents this mirror. In the surface, the dashed line shown in Fig. 4 can be considered to be another mirror: m_2.

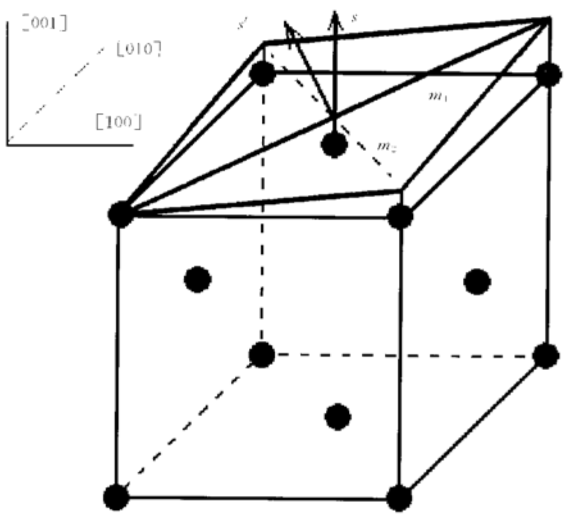

FIG. 3 Symmetry of the Structure

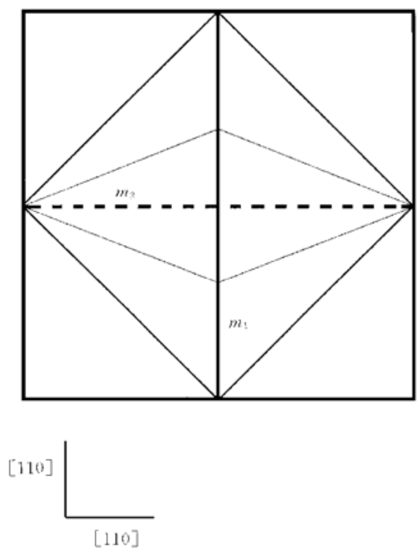

FIG. 4 Symmetry of the Surface after the Substrate Inclined to (111)

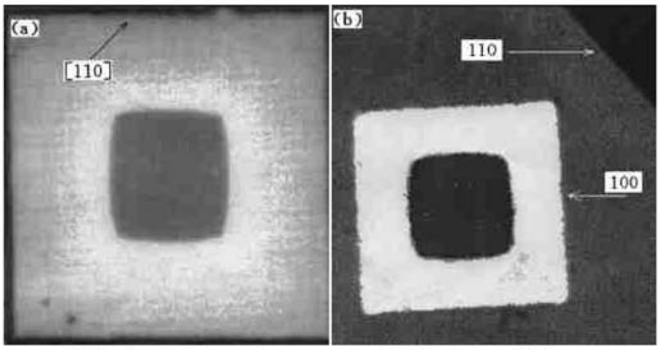

FIG. 5　Relation Between the Oxidation and the Orientation of Mesas

An experiment was designed to analyze the symmetry of AlGaAs/AlAs structure grown on a misoriented substrate. First, by using etching method, a squared mesa was shaped up along the directions [110] or [1$\bar{1}$0] and then selectively oxidized. The result was illustrated in Fig. 5(a). In the photo, the bright part has been oxidized, the dark part has not. Obviously, there are two oxidation speeds in the different orientation, the ratio is 49∶45 (experimental condition: the temperature of substrate is 450℃, the temperature of vapor is 90℃.). This formed a rectangle current confinement window. This is caused by the dissymmetry of the misoriented surface. Considering the mirrors m_1 and m_2 on the surface, a square mesa with its sides parallel to (100) or (010) planes can be oxidized to form a square window. The reason is that such a mesa also has mirror m_1 and m_2. The speeds of each side are the same. Figure 5(b) is an experimental result. As Fig. 5(a), the bright part shows the oxidation result, the dark park has not been oxidized. This experimental result accords with our expectation.

3　Oxidation Experiments and Analyses

The structure of red VCSEL has three parts, two $AlAs/Al_{0.5}Ga_{0.5}As$ DBRs and an AlGaInP active region. Between active layer and DBRs, there is a AlAs layer (300nm). Table 1 shows the structure. To get a low threshold device, the current confinement window must be very small. If the oxidation speeds of the mesa are different, it is hard to make such a window, because it will cause a rectangle window. To solve this problem, a $100\times100\mu m^2$ mesa was used and its sides parallel to (100) or (010) planes, respectively. Figure 5(b) illustrates the result.

Table 1　The Structure of VCSELs

1	GaAs	10nm
36	AlGaAs	λ/4
	AlAs	λ/4
1	AlAs	300nm
1	AlGaInP active layer	8λ
1	AlAs	300nm
55	AlAs	λ/4
	AlGaAs	λ/4
1	AlAs	λ/4
	GaAs	substrate

This result can be explained on the other hand. Figure 6 illustrates the profile of (1$\bar{1}$0). In the figure, solid lines are parallel to the surface of misoriented substrate, dashed lines show the structure of the crystal. The intersect angle θ between the two lines represents the misoriented angle. Here $\theta=6°$. But profiles of the other planes have different θ. For example, in the profile of (110), $\theta=0°$. It is reasonable to consider that the oxidation direction must follow the dashed lines. So the oxidation ratio R can be calculated by the ratio of the different distances, which may be expressed as the following formula.

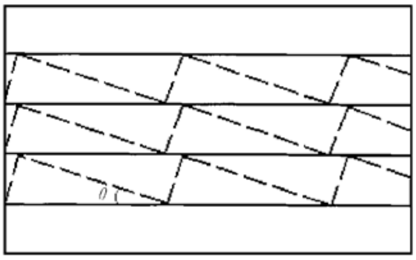
FIG. 6 The Profile of $(1\bar{1}0)$

$$R \equiv \frac{Speed_1}{Speed_2} = \frac{Distance_2}{Distance_1} = \frac{\sin\theta_2 + \cos\theta_2}{\sin\theta_1 + \cos\theta_1}$$

In the case of a square mesa with one side parallel to (110) plane, $\theta_1 = \theta_{(110)} = 0°$ and $\theta_2 = \theta_{(1\bar{1}0)} = 6°$. Therefore, $R = 1.1:1$, which was approved by experiments. In the case of a square mesa with one side parallel to (100), $\theta_1 = \theta_{(100)} = 4.25°$ and $\theta_2 = \theta_{(010)} = 4.25°$. Therefore, $R = 1$. They have the same oxidation speed. In this case, a small square confinement window may be formed by the oxidation. Figure 5(b) approves it.

4 Fabrication and Characteristic of Red VCSELs

By using 45° oxidation method, a small ($1 \times 1\mu m^2$) and square current confinement window was fabricated. So the device can operate continuous wave at room temperature with the threshold current of 0.25mA. Such a low threshold is first reported. Figure 7 is the L-I curve of a device. The maximum light output power is greater than 0.3mW.

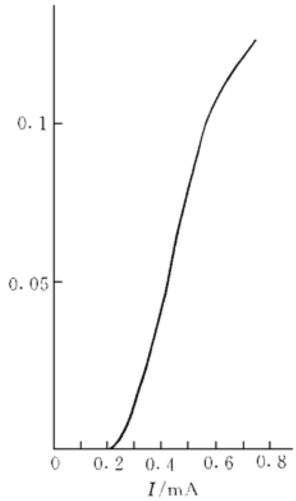

FIG. 7 L-I Curve of the Device

5 Conclusion

By using the misoriented substrate, the energy gap was enlarged and the light characteristic of the epitaxy structure was improved. But it also destroyed the symmetry of the surface, which made it harder to get a small confinement window. For depressing the threshold current, we used a new oxidation method based on reestablishing the symmetry of the surface. Finally, a red VCSEL with a low threshold current was successfully developed.

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