Design of Single Anti-Reflection Film for High Power Semiconductor Laser Facet

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Abstract: The catastrophic optical damage (COD) threshold of high power semiconductor laser chip is very important in its application. In this paper, based on the transfer matrix calculation method, a coating model is established to explain the relationship between the design parameters and COD threshold. The influence of the refractive index of the film in the whole range between Air and GaAs medium is analyzed. The influence of the refractive index in the range of 1.1 ~ 3.3 on the reflectivity of the film and on the COD threshold are theoretically simulated. The simulation results show that in the design of actual coating parameters, not only the reasonable PC value, but also the requirement of reducing reflectivity and the trade-off between reflectivity and PC value should be considered. In addition, the possible refractive index parameters of the film, the reflectivity of the corresponding film and the corresponding PC value are reflected in the simulation diagram. This paper provides ideas for the improvement of COD threshold and the reliability of chip facet.

1 Introduction

Laser is a kind of strong light source with high power density. If a laser beam converges on a very small facet, the structure of the facet may be destroyed. Therefore, with the continuous improvement of the output power of high-power semiconductor lasers, the requirement of catastrophic optical damage threshold on the facet becomes higher and higher. The edge emitting semiconductor laser is studied in this paper. The cleavage surface of the semiconductor chip is used as the resonant cavity, and anti-reflective film and high reflection film are respectively coated on the resonant facet. The main function of anti-reflection film is to realize light output, improve the reliability and slope efficiency of laser, and effectively improve the output power. At the same time, the film can protect the facet of the laser, prevent the occurrence of COD phenomenon, effectively improve the anti damage ability of the facet of the laser, and enhance the service life of the laser [1-4,6].

At present, the optional films are SiO2, TiO2, sin, Tao, Al2O3, ZnSe and so on. Generally, the refractive index is between 1.55 ~ 2.58. In this paper, the simulation design of single-layer laser film will be carried out, aiming at all the film design within the optional refractive index range, and the trend and phenomenon within this range will be deeply analyzed, and the relationship between the film thickness, refractive index, COD threshold and other parameters will be explained [5,6,8].
2 Theory

The refractive index of anti-reflective film is a very important parameter of optical materials, and its value mainly depends on three factors [1,6-11].

As shown in Fig. 1, inside the GaAs chip, the left traveling wave is $E_{3L}$ and the right traveling wave is $E_{3R}$; inside the coating layer, the left traveling wave is $E_{2L}$ and the right traveling wave is $E_{2R}$; in the external space, the left traveling wave is $E_{1L}$ and the right traveling wave is $E_{1R}$; The output light amplitude of the semiconductor laser is normalized to 1 and the incident light intensity from the facet as zero. That is $E_{1R} = 1$ and $E_{1R} = 0$.

According to the transfer matrix method, the transfer relation is as follows:

$$ R = \left| \frac{E_{jL}^R}{E_{jL}^L} \right| $$  \hspace{1cm} (1)

The intensity of each position of the light field is as follows:

$$ P_j = n_j \cdot \left| E_{jL}^R + E_{jR}^L \right|^2 $$  \hspace{1cm} (2)

$P_C$ is the threshold ratio of COD with and without coating, which can be expressed as follows:

$$ P_C \equiv \frac{P_{coated}}{P_{uncoated}} $$  \hspace{1cm} (3)

In the above formula, the $P_j$ at the facet is the key of our design. In the coating design, we need to reduce the index as much as possible, so that the facet is near the valley of standing wave intensity; in the film design, we mainly focus on the $P_C$ index, which needs to be improved.

3 Simulation and Results

3.1 Simulation

By analyzing the transmission matrix of the light field, the effects of six different refractive indexes are simulated. The refractive indices from low to high are 1.1, 1.5, 2.0, 2.5, 3.0 and 3.3 respectively. In addition, the wavelength of the laser chip is 808nm, which is one of the most widely used wavelengths of high-power semiconductor lasers. The relationship between the thickness of the anti-reflection coating and the reflectivity of the coating with $n_2 = 1.1$ is shown on the left of Fig. 2, and the relationship between the reflectivity and the relative $P_C$ data is shown on the right of Fig. 2. From the simulation results, it can be seen that the reflectivity increases monotonously with the increase of the film thickness in the range of 183.6nm ~ 366.6nm, and the corresponding reflectivity increases monotonously in the range of 0.23 ~ 0.30; with the increase of the reflectivity in the above range, the corresponding $P_C$ value will decrease monotonously from 1.21 ~ 1.0.
In Fig. 3, the relationship between the thickness of single anti-reflection coating with $n_2 = 1.5$ and the reflectivity of the coating is shown on the left, and in Fig. 2, the relationship between the reflectivity and the relative $P_C$ data is shown on the right. From the simulation results, it can be seen that the reflectivity increases monotonously with the increase of the film thickness in the range of 134.7nm ~ 266.7nm, and the corresponding reflectivity increases monotonously in the range of 0.04 ~ 0.30; with the increase of the reflectivity in the above range, the corresponding $P_C$ value will decrease monotonously from 2.25 ~ 1.0.

In Fig. 4, the relationship between the thickness of single anti-reflection coating with $n_2 = 2.0$ and the reflectivity of the coating is shown on the left, and in Fig. 2, the relationship between the reflectivity and the relative $P_C$ data is shown on the right. From the simulation results, it can be seen that the reflectivity increases monotonously with the increase of the film thickness in the range of 101nm ~ 200nm, and the corresponding reflectivity increases monotonously in the range of 0.0066 ~ 0.30; with the increase of the reflectivity in the above range, the corresponding $P_C$ value will decrease monotonously from 4.0 ~ 1.0.

Fig. 2 $n_2 = 1.1$ relationship between film thickness and reflectivity and $P_C$

Fig. 3 $n_2 = 1.5$ relationship between film thickness and reflectivity and $P_C$

Fig. 4 $n_2 = 2.0$ relationship between film thickness and reflectivity and $P_C$
Fig. 5 shows the relationship between the thickness of the anti-reflection coating and the reflectivity of the coating with $n_2 = 2.5$ on the left, and Fig. 2 shows the relationship between the reflectivity and the relative $P_C$ data on the right. From the simulation results, it can be seen that the reflectivity increases monotonously with the increase of the film thickness in the range of 80.8nm ~ 158nm, and the corresponding reflectivity increases monotonously in the range of 0.087 ~ 0.30; with the increase of the reflectivity in the above range, the corresponding $P_C$ value will decrease monotonously from 6.25 ~ 1.0.

Fig. 5 $n_2 = 2.5$ relationship between film thickness and reflectivity and $P_C$

In Fig. 6, the relationship between the thickness of single anti-reflection film with $n_2 = 3.0$ and the reflectivity of the film is shown on the left, and in Fig. 2, the relationship between the reflectivity and the relative $P_C$ data is shown on the right. From the simulation results, it can be seen that the reflectivity increases monotonously with the increase of the film thickness in the range of 67.3nm ~ 133nm, and the corresponding reflectivity increases monotonously in the range of 0.20 ~ 0.30; with the increase of the reflectivity in the above range, the corresponding $P_C$ value will decrease monotonously from 9.0 ~ 1.0.

Fig. 6 $n_2 = 3.0$ relationship between film thickness and reflectivity and $P_C$

Fig. 7 shows the relationship between the thickness of a single anti-reflection film with $n_2 = 3.3$ and the reflectivity of the film. Fig. 2 shows the relationship between the reflectivity and the relative $P_C$ data on the right. From the simulation results, it can be seen that the reflectivity increases monotonously with the increase of the film thickness in the range of 61.2nm ~ 121nm, and the corresponding reflectivity increases monotonously in the range of 0.27 ~ 0.30; with the increase of the reflectivity in the above range, the corresponding $P_C$ value will decrease monotonously from 10.89 ~ 1.0.

Fig. 7 $n_2 = 3.3$ relationship between film thickness and reflectivity and $P_C$
3.2 Discussion

Next, this paper will summarize and analyze Fig. 2 ~ Fig. 7, and compare the refractive index of 1.1 ~ 3.3 with the refractive index interval of 0.1. Then, the reflectivity and \( P_C \) value of the film under the overall refractive index are comprehensively analyzed, as shown in Fig. 8. The Fig. summarizes the parameters in the whole range, and clearly shows the change of \( P_C \) value with reflectivity, and the improvement of \( P_C \) index is consistent with the direction in the middle right of Fig. 8.

Fig. 9 is a further analysis on the basis of Fig. 8. Regardless of the thickness of the film, only the relationship between the refractive index \( n_2 \) and the minimum reflectivity of the film is discussed. The diagram is shown on the left side of this Fig.; the relationship between \( n_2 \) and the maximum \( P_C \) is shown on the right side of this Fig.. Fig. 9 shows that the relationship between the minimum reflectivity and the maximum \( P_C \) value and \( n_2 \) no longer presents a simple monotonic function, that is, in the actual selection of coating parameters, it is necessary to consider the need to reduce the reflectivity, which is helpful to improve the maximum output power index; at the same time, it is also necessary to consider, rather than blindly improve the \( P_C \) value; this is the simulation conclusion obtained in this paper. However, the exact relationship between the most reasonable reflectivity value and \( P_C \) needs to be further verified by experiments.
4 Conclusion

In this paper, aiming at the main failure mode of AR surface COD, the catastrophic optical damage threshold of facet of high-power semiconductor laser chip is very important in application. In this paper, a chip coating model is established to explain the relationship between the design parameters of the film and the COD threshold. The influence of the refractive index of the film in the range of 1.1 ~ 3.3 on its reflectivity and COD threshold is theoretically simulated, which provides ideas for the development and use of high refractive index materials.

At the same time, this paper points out: in the selection of actual coating parameters, it is necessary to consider reducing the reflectivity, which is helpful to improve the maximum output power index; at the same time, it is also necessary to consider the rationalization of P_C value, rather than blindly improving the P_C value. The reasonable matching relationship between reflectivity value and P_C also needs to be further verified by experiments. The above is the simulation conclusion obtained in this paper.

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