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Thermal Characteristic of VCSEL with AlN Film Passivation Layer

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Abstract: In this paper, the internal thermal field and heat flow vector distributions of high power vertical-cavity surface-emitting semiconductor lasers (VCSELs), which is based on AlN film and SiO_2 film passivation layers, were analyzed using ANSYS finite-element software. The simulation results proved that the AlN film passivation layer has better features than the SiO_2 film passivation layers, and can make the device work in a more stable status, which also improves the device characteristics. Through the simulation, it was found that the Rthjc of VCSEL in AlN film was 3.12 K/W and the Rthjc of VCSEL in SiO_2 film was 4.77 K/W. Comparison with the experimental values that the AlN film of 3.59 K/W and the SiO_2 film of 4.82 K/W shows that simulation results are in good agreement with the experimental results. The proposed research works prove that the AlN film passivation layer has better thermal features than SiO_2 film passivation layer.

Key words: Vertical-Cavity Surface-Emitting Lasers(VCSEL); AlN Film; SiO_2 Film; ANSYS

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0 Introduction

Vertical-Cavity Surface-Emitting Lasers (VCSEL) is a new kind of high-performance quantum well lasers. In recent years, the development of high-power VCSEL has become the research focus of scientists internationally. VCSEL with low threshold current, high conversion efficiency, small divergence angle, beam quality and easy-to-fiber coupling can easily be two-dimensional array of high-density power light output[1-2]. In optical communications, optical storage, pumped solid-state lasers, medicine, sensors and other applications have received much attention. VCSEL′s own serious phenomenon of self-heat, since the heat caused by temperature, significantly affects the properties of the laser. Laser thermal effect severely restricts the development of high-power semiconductor lasers[3-4]. To improve the thermal characteristics of high power VCSEL and their output performance, we used the AlN film passivation layer instead of the previous film passivation layer of SiO_2, and we packaged the lasers with Flip technology replace Formal technology. In order to verify that if the use of AlN film passivation layer can improve the laser′s thermal properties or not, ANSYS which is the thermal analysis software was used to simulate temperature rise of VCSEL based on AlN film passivation layer and the SiO_2 film passivation layer structure, and calculate the thermal resistance based on two films structure of VCSEL.

1 VCSEL structure

As a special wavelength of 980 nm semiconductor laser, GaAs substrate of VCSEL on the optical absorption of the this wavelength is very limited, so we used light output of N side instead of light output of P side, light output of N side can effectively avoid the phenomenon of uneven distribution of light which caused by the aggregation effect of carrier of ring electrode current injection with light output of P side, furthermore, P side packaged in copper heat sink can be effective for cooling, since copper heat sink from the active region was only a few micron. VCSEL flip-chart is shown in Fig. 1.

VCSEL can work with N side emitting and P side emitting. P side emitting which Uniforms current distribution will result in uneven spatial distribution of light and damage the Light mode. P side emitting which is active region for form the copper heat sink, influences the laser cooling effect, so we used chip-flip form when package the

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high-power semiconductor laser. We used Molecular Beam Epitaxy (MBE) growth of three quantum well structure $In_{0.2}Ga_{0.8}As$ (8 nm)/GaAs (10 nm) of the active region, 30 pairs of P-type DBR and N-type DBR which doping concentration is 3×10^{18} cm^{-3} can get theoretical reflectivity of 99.9% to 980 nm wavelength. High aluminum structure of the oxide laye $Al_{0.98}Ga_{0.02}As$ is between P-type DBR and active region layer. The relatively high aluminum content can quickly be oxidized and then the formatted the oxide hole (Fig. 1), which Limits the light and the effective current. VCSEL epitaxial layer structure is shown in Table 1.

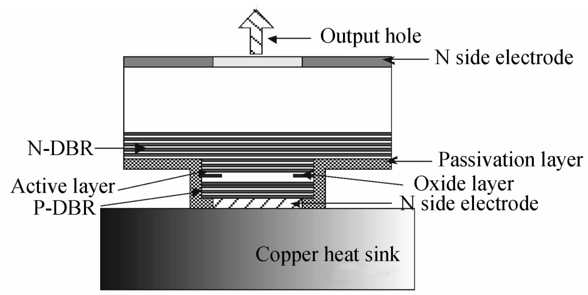

Fig. 1 Schematics of VCSEL in flip package

Table 1 Epitaxial layer structure of the laser

Name of layers	Material	Thickness/μm
Cap layer	GaAs	0.04
P-DBR(30 pairs)	$Al_{0.9}Ga_{0.1}As$(82.7 nm)/ GaAs(68.6 nm)	4.592
Oxide layer	$Al_{0.98}Ga_{0.02}As$	0.004
P-Cover layer	$Al_{0.2}Ga_{0.8}As$	0.0733
Three Quantum well	$In_{0.2}Ga_{0.8}As$(8 nm)/ GaAs(10 nm)	0.064
N- Cover layer	$Al_{0.2}Ga_{0.8}As$	0.0732
N- DBR (30pairs)	$Al_{0.9}Ga_{0.1}As$(82.7 nm)/ GaAs(68.6 nm)	4.593
N-Buffer layer	GaAs	0.4
Substrate	GaAs	160

2 Features of SiO_2 film and the AlN film

The electrode of P-side is Ti-Pt-Au, which is made by evaporation method. Generally speaking, to prevent leakage, we coated with dielectric film on the table which has been corrosion before evaporate Ti-Pt-Au as passivation layer of high-power VCSEL. We first cleaned out the passivation layer of the circular electrode windows, and then we evaporate Ti-Pt-Au. So the passivation layer had been preserved around the electrode windows, and achieve a good isolation between wafer and current, so that current can only be injected through the circular electrode, to achieve a good limit on the current, this ensures that the active region material produce lasing. We often use good insulation dielectric film as a passivation layer of high-power VCSEL. The comparation of SiO_2 dielectric film and the AlN dielectric film are shown in Table 2, the location shown in Fig. 2.

Table 2 Compare AlN film with SiO_2 film on Parameters

Parameter \ Material	AlN	SiO_2
Band gap/eV	6.2	9
Coefficient of thermal expansion(10^{-6} K^{-1})	4.5	0.5
Density(g/cm^{-3})	3.26	2.27
Breakdown field strength(10^6 V/cm)	14	13
Thermal conductivity(W/(cm·℃))	3.0	0.014
Dielectric constant	8.5	3.9
Resistivity (Ω·cm)	$>10^{13}$	$>10^{14}$
Index of refraction	2.15	1.46

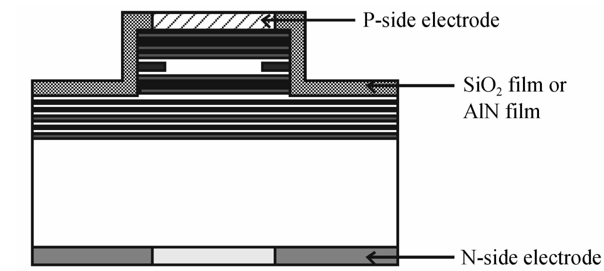

Fig. 2 Position of SiO_2 film or AlN film

Now days, most of the VCSEL devices prepared at home and abroad use SiO_2 dielectric film, since SiO_2 dielectric film has advantages of large band gap and large high resistance, but the thermal properties of SiO_2 film is poor, thermal conductivity is 0.014 W/(cm.℃). And its coefficient of thermal expansion is only 0.5×10^{-6} K^{-1}, GaAs thermal expansion coefficient is 5.9×10^{-6} K^{-1}, there is much difference between SiO_2 film and GaAs substrate. Prone to stress, thus undermining the output characteristics of semiconductor lasers. The AlN film as Ⅲ-nitride wide band-gap insulating material, its thermal conductivity is 3.0 W/(cm.℃). The thermal conductivity is 200 of SiO_2 times. AlN film has good thermal conductivity, resistivity large high breakdown field strength, good chemical and thermal stability. What is the most important is that the thermal expansion coefficient is 4.5×10^{-6} K^{-1}, closed to the thermal expansion coefficient of GaAs . All of these properties determine that the AlN dielectric film is better than SiO_2 dielectric film. Therefore, we used to replace SiO_2 film with the AlN film as passivation layer of devices [5-6].

3 Thermal analysis of VCSEL

We used ANSYS software to simulate the temperature distribution within the chip of AlN film passivation layer and the SiO_2 film passivation layer. The parameters of simulation are shown in Table 3.

Table 3　Parameters of modeling VCSEL with ANSYS

Injection current	2.1 A
Device Voltage	2 V
Output power	1.1 W
Device threshold current	0.5 A
Electro-optical conversion efficiency of the device	26.8%
Round table diameter	350 μm
P-side electrode circle diameter	200 μm
Round table surface height of P	4.73 μm
GaAs substrate height	150 μm
Copper heat sink height	200 μm
Thermal conductivity of AlN film	3 W/(cm·℃)
Thermal conductivity of SiO_2 film	0.014W/(cm·℃)
Thermal conductivity of Copper	3.98W/(cm·℃)
GaAs substrate thermal conductivity	0.55 W/(cm·℃)
P-DBR thermal conductivity	0.65 W/(cm·℃)

The height of P-side round table is only 4.73 μm, the GaAs substrate and the Cu heat sink height of 150 μm and 200 μm, respectively, and the main heat region of VCSEL is active region and P-DBR, so we can take an approximation, putting entire round table as laser heat source. The copper heat sink temperature was set constant temperature 20 ℃ on simulation, and we used air flow. When we used AlN film as a passivation layer, because the thermal conductivity of AlN films was 3 W/(cm·℃) which was closed to Cu heat sink thermal conductivity 3.98 W/(cm·℃), P side electrode is a better heat conductor, the thermal region diameter equal to 350 μm. If we took SiO_2 film as Passivation layer, thermal conductivity was only 0.014 W/(cm·℃), equivalent insulation material, it does not heat, so efficient cooling diameter 200 μm.

Here we simulated temperature distribution and heat flux vector distribution with AlN film passivation layer structure and SiO_2 film passivation layer structure, respectively.

In Fig. 3, we can see temperature rise of VCSEL with AlN dielectric film is 6.243 K, and temperature rise of VCSEL with SiO_2 dielectric film is 9.534 K. The Rthjc of VCSEL with AlN film is 3.12 K/W, and the Rthjc of VCSEL with film SiO_2 is 4.77 K/W. As can be seen from Fig. 4 shows the cooling area in Fig. 4(a) is much smaller than in Fig. 4(b), this proves that there have greater cooling area and better heat dissipation with AlN film passivation layer.

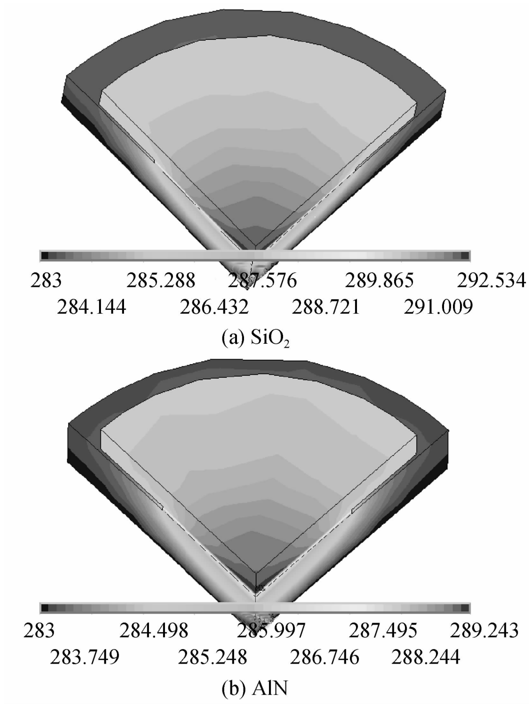

Fig. 3　Distribution of thermal fields in SiO_2 film and AlN film

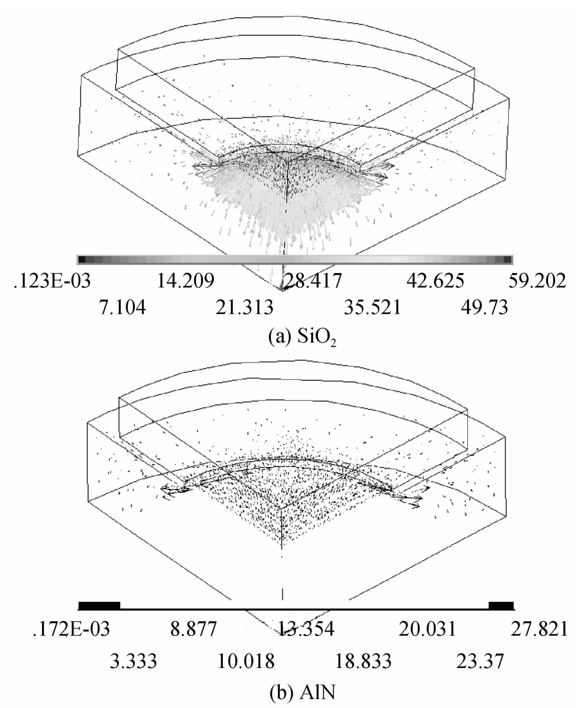

Fig. 4　Heat flow vector distribution in SiO_2 film and AlN film

4　Experiment

Since the peak wavelength of VCSEL will red shift with increased active region temperature, so we used spectroscopy, low duty cycle pulse lasing conditions, and as duty cycle increased, the corresponding average power of laser will increase, the active region temperature will increase too. We measure different duty cycle of the laser peak wavelength, and by comparing, we calculated temperature change of active region, Rthjc obtained by temperature change divide heating power of VCSEL. Laser Rthjc is calculated as[7-8]

$$R=\frac{\Delta T}{\Delta P} \qquad (1)$$

Whrer ΔT is temperature difference on chip, ΔP is Inject electric power difference , and P can be expressed as[9-10]

$$P=UI\frac{\Delta}{M} \qquad (2)$$

Where U is the device Voltage, I represents device operating current, and Δ represents pulse width, M represents pulse cycle. The pulse width of experiment is 10 μs, frequency is 100 Hz, and with 1% duty cycle, we measured the central wavelength of the laser in pulse and continuous lasing with spectrometer, so measuring the wavelength shift in order to calculate junction temperature rise. We got the wavelength shift coefficient was 0. 075 nm/℃, and calculate wavelength red shift was 0. 8nm. Through calculation, we got the Rthjc of VCSEL with AlN film was 3. 54 K/W, and the Rthjc of VCSEL with film SiO_2 was 4. 75 K/W. The experiment measures on the heat sink temperature of 20 ℃, which ensures that the results of experimental measurements and simulation have some comparability.

5 Conclusion

We got the result in which the thermal resistance with AlN film is 3. 123 K/W form simulation, and 3. 54 K/W form experiment, at the same time, we got that the thermal resistance with SiO_2 film is 4. 377 K/W form simulation, and 4. 75 K/W form experiment. The simulation results and experimental results agree well with calculations. Form the Rthjc, we can prove that AlN dielectric film is better than the SiO_2 dielectric film as passivation layer. The cooling effect of the device with AlN film passivation layer is much better than SiO_2 film passivation layer.

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基于 AlN 膜结构 VCSEL 热特性的研究

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摘要:本文用 ANSYS 有限元热分析软件模拟了基于 AlN 膜钝化层和 SiO_2 膜钝化层的高功率垂直腔面发射半导体激光器(VCSEL)器件内部的热场分布和热矢量分布.目的是证明 AlN 膜钝化层要比 SiO_2 膜钝化层有具更好的特性,使器件能更稳定的工作,提高器件的特性,经模拟得到基于 AlN 膜钝化层的 VCSEL 热阻为 3.12 ℃/W,而基于 SiO_2 膜钝化层的 VCSEL 的热阻为 4.77 ℃/W.经实验测得基于 AlN 膜钝化层的 VCSEL 热阻为 3.59 ℃/W 而基于 SiO2 膜钝化层的 VCSEL 的热阻为 4.82 ℃/W,模拟结果和实验结果吻合较好.说明 AlN 膜钝化层要比 SiO_2 膜钝化层具有更好的热特性.

关键词:垂直腔面发射激光器; AlN 膜; SiO_2 膜;ANSYS

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