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Low Ohmic Contact Resistance 980 nm VCSELs Fabricated

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Abstract: 980 nm vertical cavity surface emitting laser (VCSEL) ohmic contact technology is investigated. In order to enhance the output power of VCSEL, and extend its reliability, the contact resistance has to be reduced. Ti/Pt/Au alloy is chosen as the metal contact system for P type high doped GaAs, and Ge/Au/Ni/Au alloy is chosen as the metal contact system for N type GaAs. By chosing the optimum alloying temperature of 440 ℃, the lowest ohmic contact resistance of 0.04Ω is obtained. Comparing output power and conversion efficiency of the device for 440 ℃ and the device for 450℃, the test results show that, the ohmic contact resistance is 0.04Ω, the peak wavelength is 980.1 nm, the FWHM of spectral is 0.8 nm, the lateral divergence angle $\theta_{\parallel}$ is as low as 15.2°, the vertical divergence angle $\theta_{\perp}$ is as low as 13.5°, the output power is 1.4 W, the maximum conversion efficiency is 14.4% for the device of 440 ℃, while the ohmic contact resistance is 0.049 Ω, the output power is 1.3 W, the conversion efficiency is 12.8% for the device of 450 ℃. By optimizing the alloy temperature can effectively reduce ohmic contact resistance of VCSEL 980 nm.

Key words: VCSEL; ohmic contact; Alloying

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0 Introduction

Vertical-Cavity Surface-Emitting Lasers (VCSELs) are a relatively recent type of semiconductor lasers. VCSELs were first invented in the mid-1980's. Very soon, VCSELs gained a reputation as a superior technology for short reach applications such as fiber channel, Ethernet and intra-systems links. Then, within the first two years of commercial availability, VCSELs became the technology of choice for short range datacom and local area networks, laser pumping, medicine and materials processing[1-5] effectively displacing edge-emitter lasers. This success was mainly due to the VCSEL's lower manufacturing costs and higher reliability compared to edge-emitters. Ohmic contact technology, a very complex technology, is one of the important procedures in the fabrication of VCSELs. The contact quality directly affects the out power and reliability of the laser device[6]. As known to all, good contact can be obtained between metals and lightly doped semiconductors. So, in order to realize satisfactory contact between metals and lightly doped semiconductors, it is only necessary to add a highly doped semiconductor film between the metal and the lightly doped semiconductor. For the fabrication of VCSELs, many ohmic contact methods have been adopted, such as evaporation[7], sputtering[8], diffusion[9], laser processing[10], high temperature technology[11] etc. Each method is appropriate to specific applications.

This paper introduces our work on the ohmic contact study for the fabrication of VCSELs. Electronic beam (EB) gun evaporation and alloying technology have been adopted in the experiments. By experimental analysis and comparison for many times, ideal ohmic contact resistance results have been obtained, resulting in relatively high level VCSELs.

1 The structure of VCSELs

The cross-section view of VCSELs structure used in this work is shown in Fig. 1. The multilayer system is grown by metal organic

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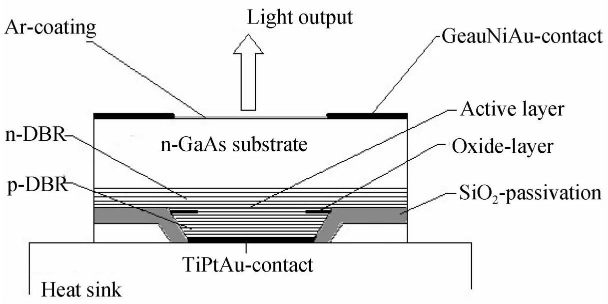

Fig. 1 The cross-section view of VCSELs structure

chemical vapor deposition (MOCVD) epitaxy on an n-GaAs substrate. For emission wavelengths in the 980 nm spectral regions, the inner cavity consists of three 8 nm thick $In_{0.2}Ga_{0.8}As$ quantum wells embedded in 10 nm thick GaAs barriers. Two $Al_xGa_{1-x}As$ cladding layers are introduced on both sides of the active region to improve longitudinal carrier confinement and to make the cavity one wavelength. The high reflective p-type Bragg stack is built of 30 pairs of quarter wavelength thick $Al_{0.9}Ga_{0.1}As$/GaAs with a graded interface, providing a reflectivity of 99.9%. To reduce the series resistance of the thick multilayer stack, carbon as p-type dopant is employed using extra modulated doping near interfaces to decrease the voltage drop without increasing absorption losses. The n-type Si-doped Bragg stack consists of only 28 pairs of the same material composition providing a reflectivity of 99.6%. There is a 30 nm thick AlAs layer located between the active region and the top p-type mirror, which is to be oxidized. The top 40 nm GaAs contact layer is doped to a concentration of $1\times10^9/cm^2$ to achieve a good ohmic contact.

2 The fabrication of VCSELs ohmic contact

In our technology process, we chose Ti/Pt/Au and Ge/Au/Ni/Au systems. In the systems, Au acts as electric conductor, Ti is the acceptor, Ge is the donor, and Ni provides the driving force for the diffusion of Ge to GaAs, so we chose Ti/Pt/Au alloy as the metal contact system for P-GaAs, which structure is shown in Fig. 2, and Ge/Au/Ni/Au alloy as the metal contact system for N-GaAs, which structure is shown in Fig. 3.

100 nm Qu
60 nm Pt
40 nm Ti
Highly doped P-GaAs

Fig. 2 Metal contact system structure for P-GaAs

100 nm Qu
10 nm Ni
120 nm Au
60 nm Ge
N-GaAs

Fig. 3 Metal contact system structure for N-GaAs

First of all, 40 nm Ti 60 nm Pt 100 nm Au alloy was evaporated on highly doped P-GaAs. 60 nm Ge 120 nm Au alloy was first evaporated on N-GaAs. On the basis of these, 10 nm Ni and 100 nm Au was evaporated. After evaporation, the wafer should be alloyed under certain temperatures to obtain high doping near the surface area. For the same type of film, we systematically studied the effects of alloying time and alloying temperatures on the ohmic contact resistance, obtaining optimum technological conditions. Under different alloying temperatures, results have been obtained for the resistance, listed in Table 1.

Table 1 Contact resistance results

Alloying temperature(℃)	First (Ω)	Second (Ω)	Third (Ω)	Average (Ω)
400	0.083	0.084	0.082	0.083
410	0.071	0.073	0.072	0.072
420	0.065	0.062	0.062	0.063
430	0.052	0.052	0.049	0.051
440	0.039	0.042	0.039	0.040
450	0.049	0.048	0.050	0.049
460	0.057	0.059	0.058	0.058
470	0.064	0.065	0.066	0.065
480	0.074	0.072	0.076	0.074

It is shown, from Table 1, the contact resistance is smallest at the alloying temperature of 440 ℃, which is the optimum temperature for our technology with the same method as above, we did some alloying experiments on Ge/Au/Ni/Au film, with the following results: the optimum alloying temperature is 440 ℃, the optimum alloying time is 60 s.

The Au film on the wafers obtained above is very thin, with Ge/Au/Ni/Au alloy formed. In order to form good contact with the electric wire to be formed in the follow-up process, a thicker Au film has to be evaporated on the wafer surface, typically 150 nm thickness.

3 Results and discussion

As Fig. 4 shows, we comparing output power of the device of 440 ℃ and the device of 450 ℃. The output power is 1.4 W for the device of

440℃, and the output power is 1.3 W for the device of 450℃. As Fig. 5 shows, the maximum conversion efficiency is 14.4% and 12.8% for the device of 440 ℃ and 450 ℃. The lateral divergence angle $\theta_{\parallel}$ is as low as 15.2° for the device of 440 ℃, which is shown in Fig. 6 and the vertical divergence angle $\theta_{\perp}$ is as low as 13.5°, which is shown in Fig. 7 for the device of 440 ℃.

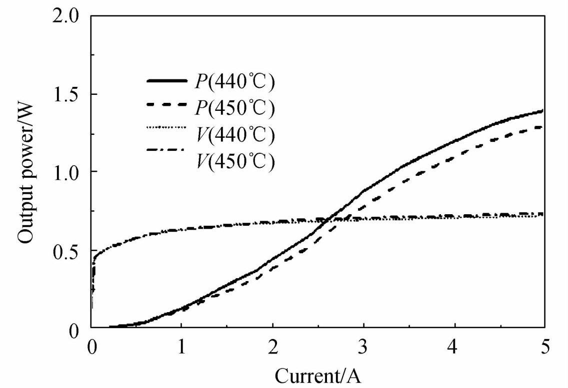

Fig. 4　Dependence of CW light output power and voltage on injection current

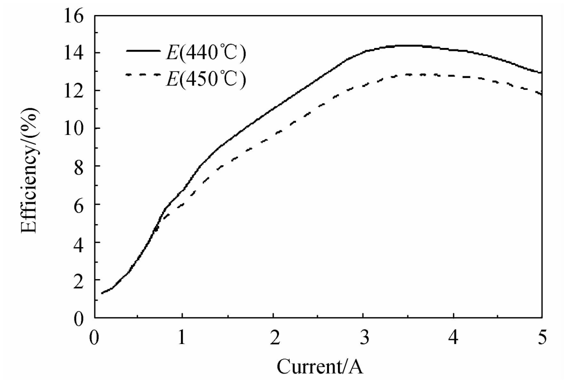

Fig. 5　Dependence of CW light output power and voltage on injection current

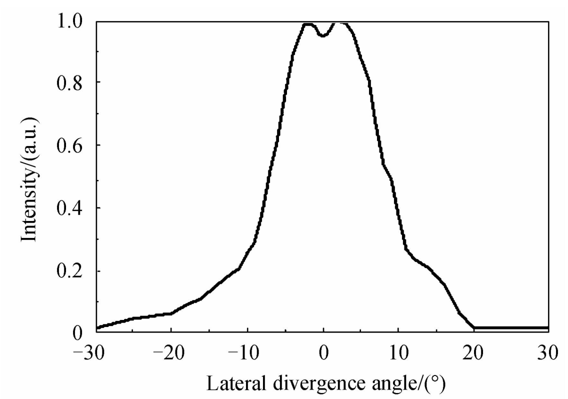

Fig. 6　The measured far-field lateral divergence angle of VCSEL

Since Ti has a relatively high evaporation pressure and a low evaporation temperature, while Pt has a relatively low evaporation pressure and high evaporation temperature, the aim of this is prevent the GaAs was oxide, otherwise resulting in high contact resistance . Because all the

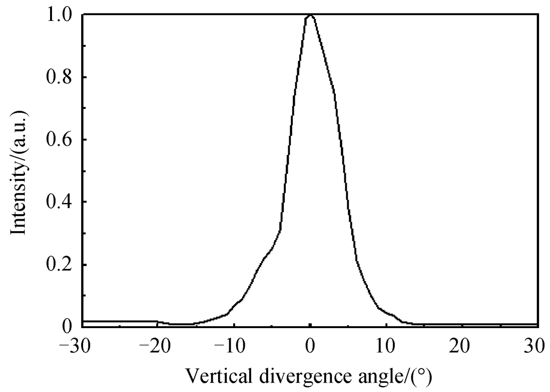

Fig. 7　The measured far-field vertical divergence angle of VCSEL

compositions of Ge/Au/Ni/Au affect the forming and characteristics of ohmic contact, so the components of metal layers are very important. In order to obtain the lowest contact resistance, optimum alloying conditions have to be found, including the temperature increase time, alloying time and the cooling time. In addition to alloy temperature, the thickness of the metal layer has to be controlled to the optimum value.

4　Conclusions

By adopting the appropriate alloy system (Ti/Pt/Au, for highly doped P-GaAs, Ge/Au/Ni/Au for the N-GaAs) and the optimum conditions, the lowest ohmic contact resistance for laser devices can be obtained. The optimum conditions are: The alloying temperature is 440 ℃, Ge/Au/Ni/Au alloying time is 60 s.

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980 nm 垂直腔面发射激光器低欧姆接触电阻制备

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摘　要:研究了 980 nm 的垂直腔面发射激光器(VCSEL)欧姆接触技术.降低 VCSEL 的欧姆接触电阻,可有效地提高 VCSEL 的输出功率和延长其可靠性.P 面采用高掺杂的 P-GaAs/Ti/Pt/Au 系统,N 面采用 N-GaAs/Ge/Au/Ni/Au 系统,通过优化合金温度,得到了最佳优化合金温度为 440 ℃,最低欧姆接触电阻值为 0.04 Ω,同时对比了 440 ℃和 450 ℃器件的输出功率和转换效率之间的对比关系.测试结果表明,440 ℃器件的欧姆接触电阻 0.04 Ω,峰值波长 980.1 nm,光谱的半高宽 0.8 nm,平行发散角 $\theta_{\parallel}$ 15.2°,垂直发散角 $\theta_{\perp}$ 13.5°,输出功率 1.4 W,转换效率最大值为 14.4%,而 450℃的器件欧姆接触电阻为 0.049 Ω,输出功率为 1.3 W,转换效率为 12.8%.通过优化合金温度能有效地降低 980 nm 的 VCSEL 欧姆接触电阻.

关键词:垂直腔面发射激光器;欧姆接触;合金