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Room temperature continuous wave low threshold current 850 nm ion implanted vertical cavity surface emitting laser using tungsten wires as mask☆

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Abstract

Vertical cavity surface emitting laser (VCSEL) emitting at 850 nm plays more important role in local fiber communication. Most of the VCSEL products emitting at 850 nm are fabricated by ion implanting. Their threshold current is about 4–6 mA. Using tungsten wires as mask, we developed the parameter of implantation and fabricated 850 nm VCSEL under room temperature CW (continuous wave) operation. The threshold current was 1.4 mA, which was lower than that of most similar devices reported before. The resistance of the device was 206 Ω. The light power was 0.92 mW at 6.74 mA under room temperature CW operation, while the light power did not achieve obvious saturation. The most remarkable advantage was that the fabrication method was simple and the optimization was available to implanting parameter.

Keywords: Vertical cavity surface emitting laser (VCSEL); H^+ implanted; Threshold current

1. Introduction

Compared with traditional edge emitting laser (EEL), vertical cavity surface emitting laser (VCSEL) is a novel device with many remarkable advantages. The light spot emitted from the laser is circular, and the beam angle is very small. That means the light from VCSEL is easy to couple with fiber. The most important character of VCSEL is that its light emits vertically from the wafer so we can test every device on the wafer directly without cleavage, which fits for industrial production. The two-dimension optical integration and large area laser array can also be realized due to this character. VCSEL has been applied widely in optical fiber communication, optical storage [1] and optical interconnection [2]. In the VCSELs emitting at different wavelength, 850 nm VCSEL plays an important role in local fiber communication because of the mature technology in wafer epitaxy and device fabrication. However, most of the VCSEL products emitting at 850 nm are fabricated by using common ion implantation technology, which includes lithography and lift-off step. Optimism in implanting is difficult to realize because it would bring up additional difficulty in lift-off step. The common threshold current of these devices is about 4–6 mA. As far as we know, the best level of the ion implanted VCSEL threshold current reported before is about 1.5–2 mA. Though wet nitrogen oxidation method has been adopted to obtain low threshold current 850 nm VCSEL, it is too expensive to be applied in industry.

In previous reports [3,4], we adopted a simple method to fabricate ion implanted VCSEL. We used the tungsten as mask when the wafer was implanting so that we could avoid the lithography and lift-off step. As a result, the fabrication process was simplified and the performance of the device was easy to be ensured simultaneously. Another advantage of this method was that we could adjust the implanting angle and implantation times neatly.

In this paper, we developed the parameter of the implantation such as implanting angle and the energy to fabricate low threshold current 850 nm VCSEL. We obtained the device with 1.4 mA threshold current and 206 Ω resistance.

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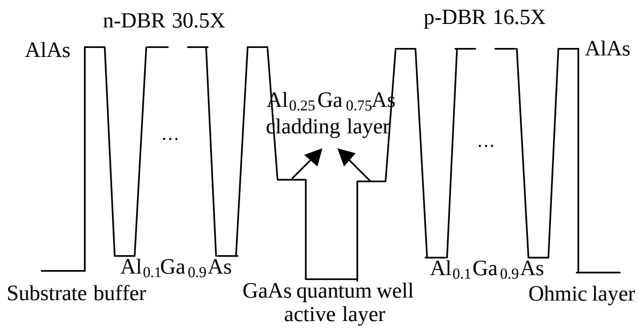

Fig. 1. The schematic of VCSEL epitaxial wafer structure.

Under room temperature CW operation, the light power was 0.92 mW at 6.74 mA while the device did not reach obvious saturation. The device kept in single transverse mode operation state till the current applied to the device was $2.9I_{th}$. The character of this device achieved the best level among similar devices reported before. The most important was that the fabrication method was the simplest technology and suited industry production.

2. Device structure and fabrication

The VCSEL structure, shown in Fig. 1, consisted of a 30.5 pair n-doped quarter-wave $Al_{0.1}Ga_{0.9}As/AlAs$ stack as the bottom distributed Bragg reflector (DBR), three 8 nm GaAs quantum wells in the center of a one-wave $Al_{0.25}Ga_{0.75}As$ spacer and a 16.5 pair p-doped quarter-wave $Al_{0.1}Ga_{0.9}As/AlAs$ stack as the top DBR, all grown by metal oxide chemical vapor deposition (MOCVD) on an n^+-GaAs substrate. Graded layers, with the thickness of 25 nm and formed with variable duty cycle superlattices, are used between each $Al_{0.1}Ga_{0.9}As$ and AlAs heterointerface to reduce the series resistance. A p^+-$Al_{0.1}Ga_{0.9}As$ layer with the thickness of 12 nm was grown subsequently as ohmic contact layer. The DBR reflectivity spectrum and the cavity mode position of our wafer were measured, and are shown in Fig. 2. They indicated that the cavity mode wavelength was about 835.79 nm and mode width was 1.3 nm. The cavity mode located at the center of high reflectivity region of DBR basically. The reflectivity decreased in whole when the wavelength increased, because the photo-multiplier tube responded differently at different wavelengths. In the figure, the high reflectivity spectrum was from 810 to 870 nm.

Tungsten wires, whose diameter was 20 μm and spacing was 300 μm, were adopted to cover on the wafer as mask at first. The tungsten wires were aligned with the wafer cleavage plane. We deposited a Cr–Au with thickness of about 150 nm before the first implantation to avoid the wafer to be dirtied and improve ohmic contact. Subsequently, H^+ implantation inclined at an angle from the normal direction of the wafer surface was performed instead of common implantation vertically to the wafer surface. Our purpose was

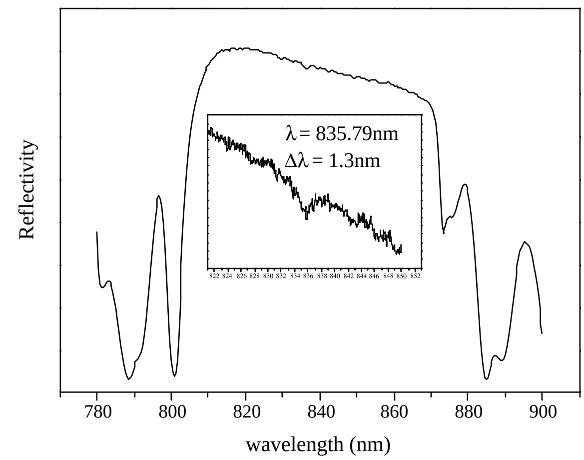

Fig. 2. Measurement result of DBR reflectivity spectrum and cavity mode.

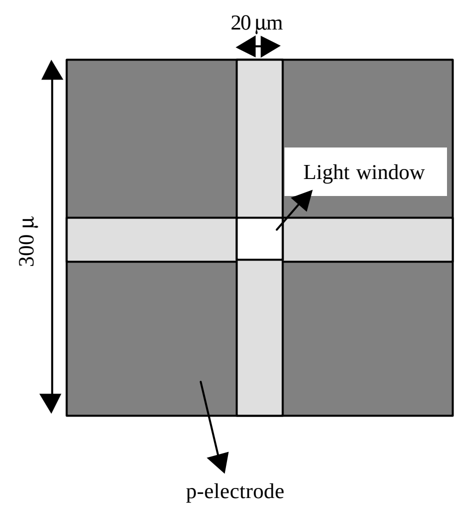

Fig. 3. The schematic of device surface using tungsten wires as mask.

to avoid the tunnel effect and expect the H^+ to distribute perfectly around the active region. The perfect distribution was that a waist shape would be obtained around the active region so that current could inject the active region along the infundibular routeway. In our experiment, the incline angle we used was 10°. The energy of H^+ implantation was 440 keV, and infection dosage was $3 \times 10^{15}\ cm^{-2}$. The wafer was rotated 90° before the second implantation. Then the tungsten was vertical to the trace of it at the first time. In the second implantation, the incline angle was still 10°, the implanting energy was 400 keV, and the dosage was $3 \times 10^{15}\ cm^{-2}$. The decrease of implanting energy was to shape a thick insulation layer around the active region. Finally, we deposited a Cr–Au with the thickness of 150 nm as electrode. The n-electrode was obtained by depositing Au–Ge–Ni layer. The single device surface schedule is shown in Fig. 3. The square, which was shaped by two across rectangular in the center of the device, was light window surrounded by electrode. The rectangular was the trace of tungsten after depositing Cr–Au.

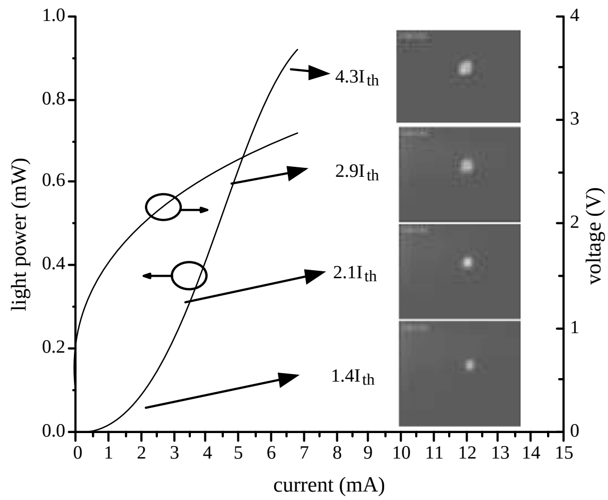

Fig. 4. Measurement result of light power and voltage and current and the near field pattern at different current under CW operation.

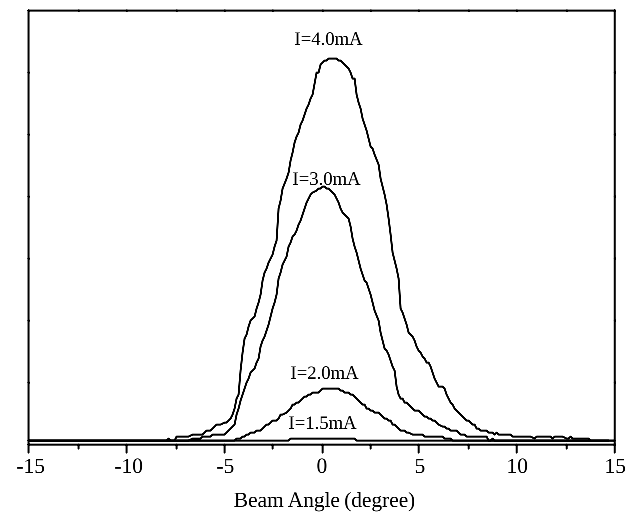

Fig. 5. Far field figure of the device at different currents.

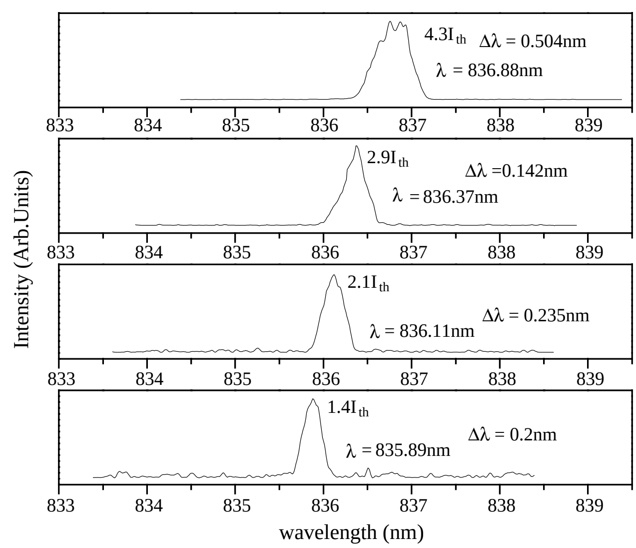

Fig. 6. The spectrum at different currents.

3. Experiment results

Measurement on the VCSEL was performed under room temperature. The light power versus current curve of the device with a heatsink under CW operation was shown in Fig. 4. The voltage and current curve were shown simultaneously. It showed that the threshold current was 1.4 mA while the threshold voltage was 1.6 V. The series resistance calculated from the voltage and current curve was 206 Ω. We also gave the near field pattern at different current in the figure. The device kept emitting single transverse mode when current increased from I_{th} to $2.9I_{th}$. The TEM_{00} mode switched to TEM_{11} at $2.9I_{th}$ current. It was possibly because the heat effect mainly from the center of active region changed the carrier distribution and the refractive index in DBR and active region. There are four symmetrical light spots in the pattern at this moment. When the current increased at $4.3I_{th}$, the intensity of two symmetrical spots increased more than the other two. The total light power at this moment was 0.92 mW. The curve showed that the device began to enter the saturation state but the light power did not decrease obviously with increase in current. The external quantum efficiency was not high, only 8%. Too high implanting energy destroyed the active region that might result in the low light efficiency.

Fig. 5 showed the far field of the device at different current. When the current was 4.0 mA, about $2.9I_{th}$, the light beam angle was 6°. The beam angle would change to 5° when the current decreased to 3 mA. We did not find increase in the beam angle though the high order mode existed. It is noticed that the peak of the light intensity changed the position at emitting light direction under different current. It showed the carrier distribution in active region changed with current because of heat effect.

In Fig. 6, we gave the spectra when the current was $1.4I_{th}$, $2.1I_{th}$, $2.9I_{th}$, and $4.3I_{th}$, respectively. When the current was above the threshold current, at the $1.4I_{th}$, the lasing wavelength was 835.89 nm according to the cavity mode we measured previously. The spectrum width was 0.2 nm. The wavelength changed to 836.11 nm when the current was $2.1I_{th}$, while spectrum width changed to 0.235 nm. The lasing peak transmitted to long wavelength because the increasing carrier and heat affected the gain peak wavelength. Compared with the near field pattern in Fig. 4, we could easily draw the conclusion that the device was lasing single transverse mode TEM_{00}. When the current increased to $2.9I_{th}$, the peak wavelength was 836.37 nm. It proved that the device was emitting high order transverse mode TEM_{11} according to the near field pattern shown in Fig. 4. When the current increased to $4.3I_{th}$, the lasing wavelength was 836.88 nm while the spectrum width changed to 0.504 nm. That the spectrum width expanded showed that the device began to come into saturation while light power had not yet decreased obviously, as shown in P–I curve. At the same time, the spectrum showed that the device began to emit multi-transverse-mode.

4. Conclusion

By developing the parameter of the implantation, a low threshold current 850 nm VCSEL was fabricated by twice H^+ implantation by using tungsten as mask. The threshold current was low up to 1.4 mA. The series resistance of the device was 206 Ω. The output light power was 0.92 mW when the current applied was 6.74 mA under room temperature CW operation while the light power did not decrease obviously. As far as we know, the character of this device achieved the best level among similar devices reported before. The most important is that the fabrication method is the simplest technology and suited industry production. Furthermore, the optimization is available to implanting parameter.

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