Single-mode ridge – waveguide AlGaAs/GaAs quantum well lasers

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Abstract: Ridged-waveguide AlGaAs/GaAs single-quantum-well lasers with graded-index separate confinement heterostructure were fabricated by molecular beam epitaxy. Fabricated diode lasers exhibited excellent lasing characteristics including a low threshold current of 23mA (CW, 25℃, 5μm stripe). Continuous-wave laser output increases linearly with the drive current up to 15mW in single-mode operation.

Key words: single-mode semiconductor lasers single quantum well ridge-waveguide

单模 AlGaAs/GaAs 脊形波导量子阱半导体激光器

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摘要：本文报道用分子束外延设备研制梯度折射率分别限制式单量子阱 AlGaAs/GaAs 脊形波导半导体激光器。该激光器具有良好的性能，条宽 5μm 器件室温阈值电流 23mA，线性连续输出单模激光功率大于 15mW。

关键词：单模半导体激光器 单量子阱 脊形波导

1. Introduction

In recent years particular attention has been paid to semiconductor quantum well lasers, because they possess several novel characteristics different from conventional the double heterostructure (DH) lasers, among which are extremely low threshold current densities, less temperature dependence of the threshold current, much narrower spectral width, wavelength tailoring, and improved dynamical properties[1~2]. It has already been shown that, by careful optimisation , single-mode semiconductor lasers can be made[3]. Single-mode(i. e., a single transverse mode and single lateral mode) operation is necessary for achieving good speatial coherence of the laser beam. There is an ever-increasing demand for quantum-well lasers with good beam quality, such as solid-state laser pumping, fiber coupling, long-distance high-data-rate optical communications, etc.. In this paper, a well-known GRIN-SCH was adopted for the AlGaAs/GaAs single-quantum-well laser structure and a ridge-waveguide was fabricated to confine the lasing mode. The result of investigating single-mode AlGaAs/GaAs GRIN-SCH SQW ridge-waveguide lasers will be presented.

2. Quantum-well structure and epitaxial growth

The very small thickness of active region in QW laser is reason to greatly reduce the threshold of laser. But, because its small physical dimension results in the insufficient carrier and optical mode confinement, high performance in QW laser can not be readily obtained. This problem can be solved by using graded index separate confinement heterostructure(GRIN-SCH). The AlGaAs/

GaAs single-quantum-well semiconductor laser structure reported in this paper were grown by molecular beam epitaxy (MBE). The strucrure of laser is the GRIN-SCH SQW, in which a single-quantum-well active layer is embedded in a graded-index waveguide layer which is in turn sandwiched between outer cladding layer. The structure was grown on an n-doped GaAs substrate at a substrate temperature of 700℃. First, a Si-doped buffer layer was grown on the substrate to provide a damage-free crystallographic surface for the following layers. An 1.5μm n-$Al_{0.45}Ga_{0.55}As$ cladding layer was then grown. The following layers were a n-doped 0.2μm $Al_xGa_{1-x}As$ graded-index layer with a linearly varying Al concentration between $x = 0.45 - 0.15$, an undoped GaAs well with width $L = 70$Å and 0.2μm p-doped graded index region. The 1.5μm p-doped cladding $Al_{0.45}Ga_{0.55}As$ layer and a 0.1μm p-doped GaAs layer were finally grown. The n-confining layer was doped $5\times10^{17}cm^{-3}$, the p-confining layer at $5\times10^{17}cm^{-3}$, while both graded regions were doped at $2\times10^{17}cm^{-3}$. The doping density of the top GaAs layer is sufficiently high enough for good ohmic contact. Fig. 1 shows a scanning electron microscope (SEM) photograph of a cross section of the actual GRIN-SCH SQW laser epitaxial layers fabricated by MBE.

Because the growth of high-quality quantum well active layer is essential for high-performance operation GRIN-SCH SQW laser, we have measured the optical and physical properties of epitaxial layers before laser devices fabrication. Room temperature photoluminescence was measured to verify the luminescence properties of the well and to estimate the effective well thickness from the energy transition of photon. The peak of luminescence is 841nm, which corresponds to a photon energy $h\nu = 1.474$eV. This photon transition energy is attributed to the 1e-hh transition in a well with $L = 70$Å and $x = 0.15$ Al barriers. This confirms that the well thickness was controlled efficiently by MBE. In addition, the actual thickness of GRIN-SCH SQW layers were measured by transmission electron microscope (TEM). The thickness measure is important for etching the ridge waveguide in mode controlled laser fabrication.

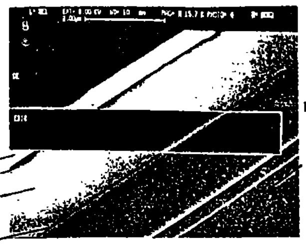

Fig. 1 The SEM photograph of the actual layers of GRIN-SCH SQW laser

3. Ridge waveguide

It is known that the carriers and optical mode confinement in the plane perpendicular to the junction of semiconductor laser is accomplished by the dielectric waveguide formed by the active layer and the four AlGaAs confining layers. The GRIN-SCH SQW structure greatly improves the carrier and optical mode confinement in this direction. Because of small active region, the GRIN-SCH SQW laser inherently exhibits single mode behavior in the transverse direction. The only concern in this direction is to control the thickness of quantum well active layer and the alloy composition of AlGaAs confining layers in epitaxial growth. However, it is necessary to reduce the total threshold current in order to reduce the power consumption and heat dissipation when laser diode is required to CW stable operation at room temperature. It is also important to control the laser spatial mode. The single mode operation is necessary for achieving good spatial coherence of the laser beam. For these purposes, stripe-geometry configurations have been proposed, in which the carriers and optic modes are laterally confined to a narrow stripe in the lasers.

There are different methods which can be used to realize stripe-geometry to achieve lateral confinement of injected carriers and optical mode[4]. One of the simplest structure for this confinement is the ridge waveguide structure[5]. The fundamental structure of the ridge waveguide laser is shown schematically in Fig. 2. In this structure, the electrical confinement is achieved by limiting the current flow to a narrow stripe window opened on the top surface of the device. The lateral optical confinement is provided by etching off part of the material outside the waveguide in order to obtain a sufficient refractive index decrease in the etched region, thus creating an optical waveguide. For achieving a single lateral mode emission, it is necessary to choose the parameters of the ridge waveguide laser, that is the ridge width w and depth t in Fig. 2. The number of propagating modes and the waveguide dimension for single-mode operation in ridge waveguide can be deduced approximately in theory. The maximum ridge waveguide width w for single-mode operation can be selected by adjusting the thickness t. We chosed $t = 0.3\mu m$ as a minimum value which can be easily controlled by etching. This etching depth provides an index-guide structure and a low leakage current. By calculation, we estimated that the ridge stripe width $w = 5\mu m$ could be considered as an upper limite for single laterale mode laser operation in our ridge waveguide laser.

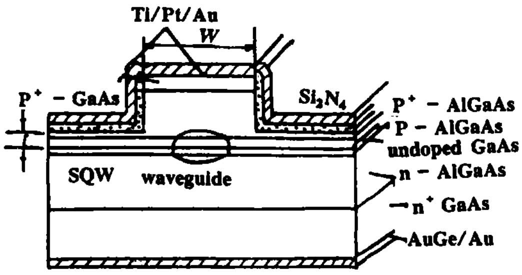

Fig. 2　Schematic AlGaAs/GaAs ridge-waveguide laser


Fig. 3　The SEM photograph of a cross section of a ridge waveguide processed by wet etching

Ridge waveguide lasers were fabricated with relative simple processing. Firstly, 5μm wide polymide stripes were placed on the top side of the wafer to define the ridges by standard photolithographic techniques. Secondly, the ridges were formed by wet chemical etching at room temperature (H_2SO_4 : H_2O_2 : H_2O = 1 : 8 : 100). Because precise etching depth is required to control the lateral laser mode, etching was stoped 0.3μm above the active layer. Fig. 3 shows a SEM photograph of a cross section of our ridge waveguide processed by wet etching. Then, a 1000Å Si_3N_4 layer was deposited by CVD and a contact window was opened on the top of each ridge. To obtain low resistance ohmic contact to the cap layer, shallow Zn diffusion was carried out. The Ti/Pt/Au (300Å / 1500Å / 1500Å) contact was then evaporated on the P − side by electron beam evaporation. The substrate was thinned to about 150μm, and a AuGe/Ni/Au (1500Å / 300Å / 1000Å) contact was evaporated. The contacts were alloyed at 420℃ for 1 mintue. Finally, the wafer was cleaved into bars of various cavity length ranging from 300μm to 1000μm. For simplicity, no facet coatings were employed.

4. Device characteristics

The current-voltage curves of the laser diodes showed a voltage drop at threshold of about 1.5V and a series resistance at 30mA of 3Ω for 5250μm^2 area. No current leakage was observed with reverse bias up to the breakdown votlage of 8V.

Laser performace paramefers were measured under CW condition. The devices were junction-side-up placed on a copper heat sink. The room temperature light output power-current characteristic of a 300μm-long laser with a 5μm wide ridge is shown in Fig. 4. The CW threshold current at room temperature was 23mA. The CW differential quantum efficiency was 48%, if the light from both laser facets was included. The laser with ridge width of 5μm emitted 15mW/facet CW power.

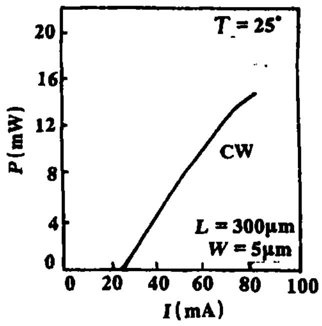

Fig. 4 Optical output from one facet versus injected current under CW operation of laser

The far-field intensity distribution was measured for CW lasers operated at current $2I_{th}$. Fig. 5 shows the measured far-field intensity distribution of laser with 5μm ridge width and 300μm cavity length. Near-Gaussian far-field patterns were observed. This confirms that the laser operated at single mode. From far-field pattern measurement, we know that the beam divergence is 40° in the direction perpendicular to the junction, and 18° in lateral direction. The transverse mode was confirmed to be stabilised in both directions over the whole range of the drive current. The wavelength of laser is near 850nm.

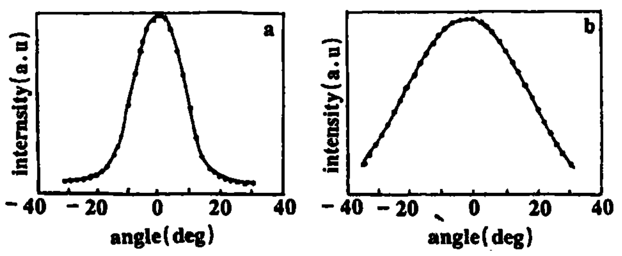

Fig. 5 Far-field pattern of a ridge waveguide laser with $w = 5\mu m$
a — Intensity distribution in direction parallel to the junction plane b — Intensity distribution in direction perpendicular to the junction plane

5. Conclusion

In conclusion, a ridge-waveguide GRIN-SCH SQW AlGaAs/GaAs laser was fabricated from a single growth step and one mask to make the ridges. The diode laser has shown a low threshold current and single mode properties. Further improvement to single-mode power capability of diode laser should be possible as further work is carried out to improve the heat sink of devices.

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高功率激光与材料相互作用机理研究进展

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摘要：本文综述了高功率激光和材料相互作用物理机理研究现状和存在问题，着重阐述了笔者在这方面已进行的理论和实验工作，并指出了本方向可继续进行的研究工作。
关键词：相互作用机理 高功率激光 材料

A research advance on the interaction mechanism of high－power laser and materials

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Abstract: The present situation and quastions in physical mechanism research of laser interaction to some materials are summarized in this paper. The theoretical and experimental works finished in our lab are emphasize. And the further research direction on this field is pointed out.
Key words: mechanism of interaction high－power laser materials

一、研 究 背 景

激光与材料相互作用机理研究是激光应用研究的重要课题之一。随着激光应用的日益发展，这一基础研究受到人们的重视[1~5]。

激光与材料相互作用的结果之一就是对材料产生的破坏。该相互作用过程既取决于激光光源因素，又与被作用材料及外部环境有关。激光光源的因素主要有波长、能量、功率、脉宽、脉冲结构、重复率以及作用次数等，其中的任一种因素都将对作用过程产生重要影响。而激光参数的多样化也给该研究增添了活力，这些研究为合理地使用激光器提供了理论基础和实验依据，从而进一步开拓了激光的应用范围。

当激光束尚未照射到靶材上时，激光和靶材是两个相对独立的部分。一旦激光照射到靶材表面，该表面就会吸收和反射激光，这种吸收和反射主要取决于靶表面的光学性质。靶表面吸收激光能量，使自身温度上升，从而能够改变靶材表面的结构和性能，甚至造成不可逆的破

Reference

1 Arakawa Y, Yariv A. IEEE J. Q E, 1985, QE-21:1666
2 Yariv A. Circuit and Devices, 1989, 5(6):25
3 Botez D, Channin D J, Ettenberg M. Opt Engng, 1982, 21(6):1066
4 Casey H. C, Panish M B. Heterostructure Semicomductor Lasers. New York: Academic Press, (1982)
5 Kaminow I P, Nahory, R E, Pollack M A *et al*. Electron Lett, 1979, 15:763

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