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High-Power Operation of Index-Guided Visible GaAs/GaAlAs Multiquantum-Well Lasers

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Stable transverse mode operation has been realized for the first time in visible (780nm) multiquantum-well (MQW) lasers. Visible MQW lasers were realized with use of thin (3nm) GaAs wells. A self-aligned structure (SAS) with a built-in optical waveguide to stabilize the transverse mode was fabricated using a two-step epitaxial MOCVD technique. Low threshold current (35mA), high output power (up to 40mW) in the fundamental transverse mode and a very low degradation rate at 70 °C have been confirmed.

1. Introduction

Extensive work has recently reported on multiquantum-well (MQW) lasers. These lasers have a number of superior properties when compared with conventional DH structure lasers. Among them, lower threshold current density (J_{th})[1], better J_{th} temperature dependence[2] and shorter emission wavelength[3] have been reported for infrared and visible lasers. However, most MQW lasers so far have been gain-guided [4)5)], and an index guided MQW laser has only been reported in the infrared wavelength range.[6] In order to utilize visible MQW lasers for such practical applications as optical disc systems and laser beam printers, stable transverse mode must be realized using a built-in refractive index optical waveguide. Furthermore, lasers with high output power are needed for high speed operation in these application systems.

In this paper, we report on the first realization of high-power (40mW) stable transverse-mode oscillation in visible $GaAs/Ga_{0.8}Al_{0.2}As$ MQW lasers with a self-aligned-structure grown by MOCVD. These MQW lasers have a very low degradation rate at 70°C, with 20mW output power.

2. Device structure

Two approaches were considered in the attempt to achieve visible wavelength operation for GaAlAs MQW lasers. First, the energy gap of wells could be broadened by employing ternary alloy (GaAlAs) wells. Second, the quantum energy shift could be increased by applying thin GaAs wells (L_w< 5nm). Results regarding emission wavelengths (e-hh,n=1) in these cases

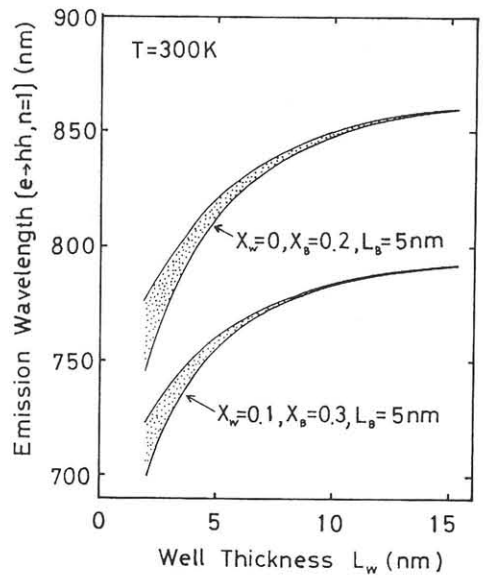

Fig. 1 Emission wavelength of the lowest (n=1) confined particles for electrons to heavy holes as a function of well thickness for GaAs and GaAlAs (x=0.1) wells.

calculated using a Kronig-Penney analysis are shown in Fig. 1. In the second case (GaAlAs wells) ,it is thought that the degree of two-dimensionality of the carrier decreases due to irregularities in the atomic arrangement. Therefore, in the present work GaAs wells with a thickness of 3nm were employed to obtain visible lasers (wavelength ~ 780nm). The quantum energy shift of the lowest (n=1) confined-particle was 118~150meV from the bottom of the GaAs conduction band for electrons, and 19~25meV from the top of the valence band for heavy holes.

In the case of visible lasers, barrier height and thickness should be designed to obtain a low threshold current. For this purpose, we fabricated and evaluated MQW lasers having various MQW structures. We found experimentally that the threshold current did not depend on barrier thickness (5~7nm), barrier height (Al mole fraction x=0.2 or 0.3) or well thickness (3~9nm), and ranged between 25~40mA in our MQW lasers. These results are inconsistent with those reported by Tsang[1], though the reason is not clear.

In this work, thickness and the Al mole fraction of the barrier were 5nm and 0.2, respectively. The number of wells was set at seven to obtain a practical confinement factor (>20%). Thus, the active region consisted of seven GaAs wells separated by six 5nm-thick $Ga_{0.8}Al_{0.2}As$ barriers.

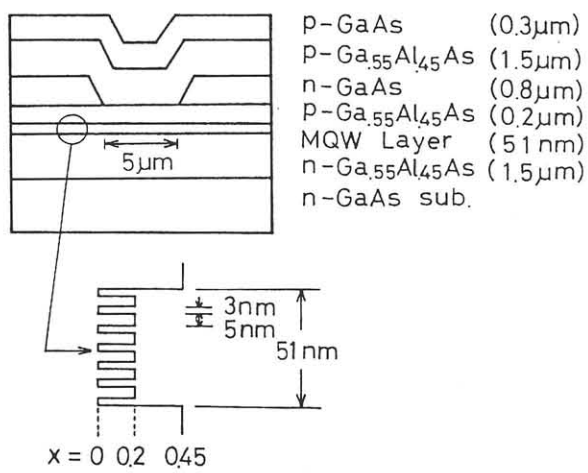

Fig. 2 Schematic of an MQW laser with a self-aligned structure (SAS).

A schematic drawing of the self-aligned-structure (SAS)[7] for this visible MQW laser is shown in Fig. 2. In this structure, the evanescent optical field penetrates into a highly absorbed n^+-GaAs epitaxial layer through a thin (~0.2μm) p-GaAlAs layer outside the stripe region. Therefore, the transverse mode is confined to the stripe region and is stabilized, as with CSP lasers.[8] The effective refractive index change (Δn) is about 1.0×10^{-2}, which is the value neccesary for fundamental transverse-mode operation. Furthermore, current injection is restricted within the stripe region by a current-blocking p-n junction reversely biased between the n^+-GaAs epitaxial layer and the lower p-GaAlAs layer. This device was fabricated using a two-step epitaxial technique for MOCVD. The cavity was 300μm long, and the laser was coated with an antireflective film at the front facet, and with reflective films at the rear facet.

3. Results and discussion

To confirm the quantum size effect,

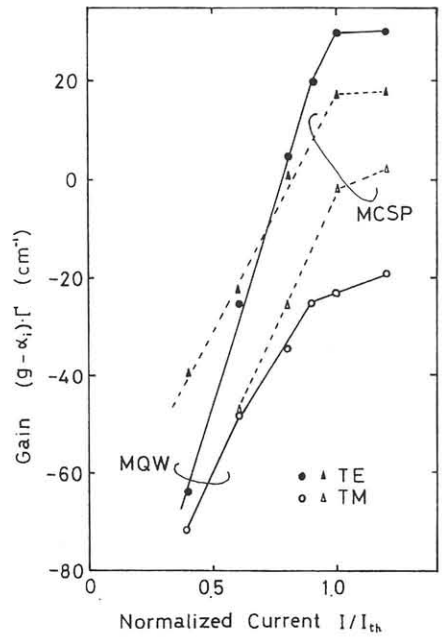

Fig. 3 Peak gain of TE and TM modes shown as function of current in MQW laser (solid line) and MCSP (DH) laser (dashed line) .

we measured the TE and TM polarization dependences of the gain coefficient , β ($\beta = \partial g/\partial I$, g:gain, I:current) , for visible MQW lasers (see Fig. 3) . A Glan-Thompson prism was used as the polarizer, and experimental measurement of the gain coefficient was undertaken using the method developed by Hakki and Paoli [9] , at room temperature. It was found that the gain coefficient for TE polarization was 1.4~1.7 times larger than that for TM polarization in MQW lasers, while visible DH (MCSP) laser have almost the same value. This result coincides with the result reported by Kobayashi et al.[10].

Figure 4 shows light-output power versus current (L-I) characteristics and far-field patterns for MQW-SAS lasers under CW operation at room temperature. The threshold current (I_{th}) was 37mA , which is as low as 60% of the I_{th} for DH lasers with the same SAS structure. The differential quantum efficiency was 40% from the front facet. Beam divergences (FWHP) perpendicular ($\theta_\perp$) and parallel ($\theta_{//}$) to the junction plane were 32° and 10°, respectively. The output versus current relationship was linear up to 40mW, and without kinks. Furthermore, the

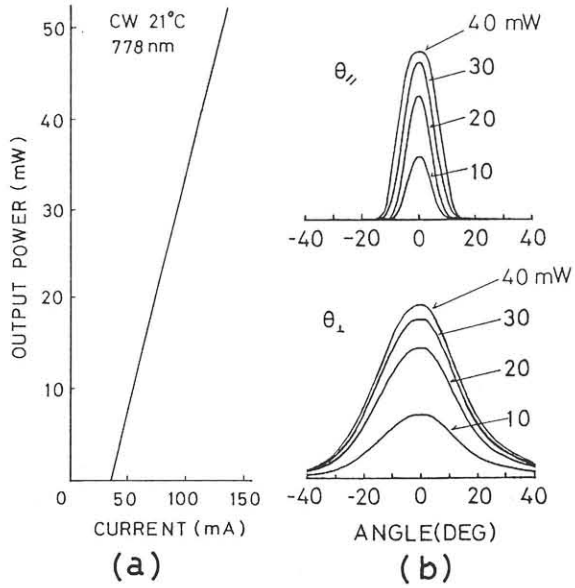

Fig. 4
(a) CW light-output power vs. current (L-I) characteristics for visible MQW laser at room temperature.
(b) Far-field patterns for same laser.

laser operated stably in the fundamental transverse mode, with a Gaussian-like profile. Laser beam astigmatism was also less than 6μm. These phenomena indicate that the transverse mode is stably controlled by the built-in refractive index waveguide.

CW emission spectra are shown in Fig. 5 for different light outputs. The lasers operated in a single longitudinal mode at a wavelength of 778nm. This value is in good agreement with theoretical calculations made using Kronig-Penney technique. Longitudinal mode hopping did not occur up to 24mW, and a large deal of

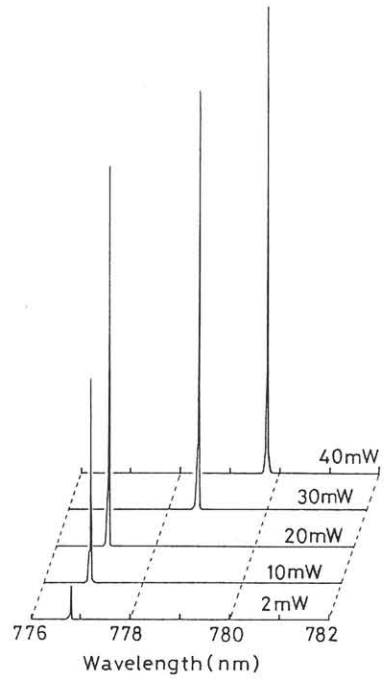

Fig. 5 CW emission spectra for visible MQW laser at different light outputs.

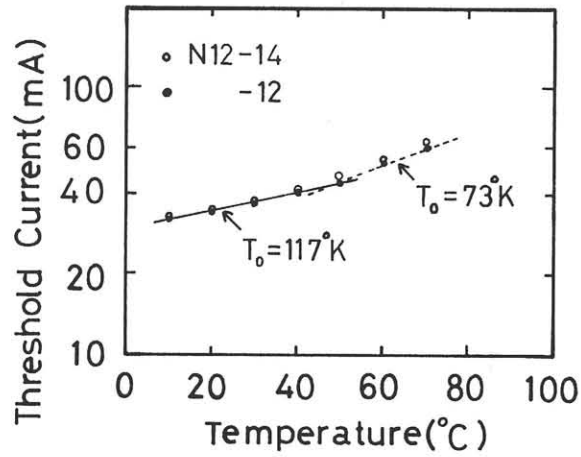

Fig. 6 Temperature dependence of pulsed threshold current in visible MQW lasers.

hysteresis phenomena were observed in the wavelength versus output-power relationship. This can be explained in terms of the step-like density of states in these MQW structures.

Figure 6 shows the dependence of temperature (T) on threshold current (I_{th}) under pulsed operation for these MQW lasers. This I_{th} versus T curve can be described by the relation $\exp(T/T_0)$, with T_0=117°K in the temperature range 10~50°C and T_0=73°K for 50~70°C. These T_0 values are lower in MQW lasers. The explanation for this is as follows. The quantum energy shift of electrons in an indirect valley (L) with large effective masses is less than that in a direct valley (Γ). The energy difference between Γ-electrons and L-electrons is small in the case of an MQW with thin quantum wells. In the present case, the energy difference is about 150meV, and therefore waste current increases with temperature due to electron overflow from Γ-valleys to L-valleys. For infrared MQW-SAS lasers with rather large quantum wells (~8nm), in which the overflow effect is small, we obtained T_0=225°K in the temperature range 10~110°C.

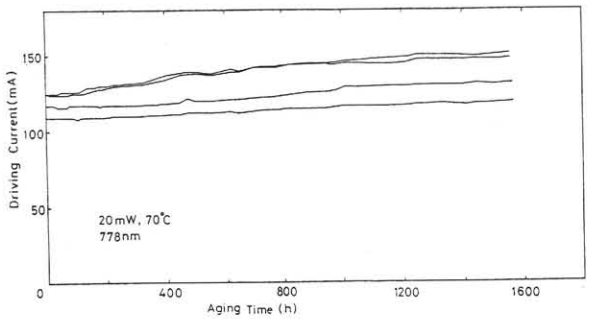

Fig. 7 Preliminary life-testing results for visible MQW lasers.

Figure 7 shows preliminary life-testing results for our MQW-SAS lasers at 70°C under a constant output of 20mW. As is shown, these lasers have operated for more than 1600 hours.

4. Summary

We have demonstrated, for the first time, stable transverse-mode operation in visible GaAs/GaAlAs MQW lasers. A highly stable transverse mode was obtained by applying an SAS structure, and laser oscillation in the visible region was realized by use of thin GaAs quantum wells. Low threshold current, high output power at up to 40mW, and a very low degradation rate at 70°C were confirmed.

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