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1989 Jpn. J. Appl. Phys. 28 740

(http://iopscience.iop.org/1347-4065/28/4R/740)

JAPANESE JOURNAL OF APPLIED PHYSICS
VOL. 28, NO. 4, APRIL, 1989, pp. 740–741

Short Note

Application of the Multiquantum Well (MQW) to a Surface Emitting Laser

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(Received November 10, 1988; accepted for publication February 25, 1989)

The threshold current density of a surface emitting laser using the multiquantum well (MQW) is theoretically estimated to be about 60% that of a surface emitting laser with a bulk active layer. MQW structures with 10 ~ 100 wells were grown by MOCVD and characterized by forming stripe lasers. A GaAlAs/GaAs MQW surface emitting laser was fabricated and the first lasing operation by current injection at 77 K under pulsed condition was obtained.

KEYWORDS: multiquantum well, surface emitting laser, first lasing operation, 77 K, current injection

In order to maintain high reliability in surface emitting lasers, the reduction of threshold current density is required. Improvement of mirror reflectivity is primarily effective for reducing the cavity loss, and dielectric multilayer reflectors have been employed[1] for this purpose. Another way is to increase the optical gain in the active region using quantum wells. The quantum well laser exhibits superior characteristics such as low threshold current,[2,3], high relaxation oscillation frequency,[4] better temperature immunity,[5] etc. Thus a surface emitting laser with a quantum well active region is expected to provide not only a higher gain but also better performance. The applicability of multiquantum wells (MQW) to surface emitting lasers was theoretically investigated and some preliminary results have been reported*. Yamada *et al.* also proposed modulation doped quantum wells for surface emitting lasers.[6] The lasing characteristics of a GaAlAs/GaAs multilayer with distributed feedback cavity structure for a surface emitting laser was reported previously,[7] but the results were obtained by optical pumping. In this study, the possibility of a GaAlAs/GaAs MQW surface emitting laser operated by current injection is experimentally investigated.

The schematic model of the MQW surface emitting laser to be realized is illustrated in Fig. 1. First of all, it is important to know the optimum number of wells needed to minimize the threshold current density. The threshold current density has been calculated for the GaAlAs/GaAs system using the density-matrix theory with relaxation broadening[8,9] to determine how many quantum wells are needed. It is assumed that electrons and holes are injected vertically into MQW layers, and that carrier concentrations are the same in each well. The dependence of the resultant threshold current density on the number of wells is shown in Fig. 2. In calculation we have used the following parameters: cavity length $L = 7\ \mu$m, well width $L_w = 100$ Å, intraband relaxation time $\tau_{in} = 1 \times 10^{-13}$ sec and temperature $T = 300$ K. In comparison, the threshold current density of the MQW structure is found to be about 60% that of a bulk active layer. This is due to the increase of the optical gain by quantum size effect. There exists an optimum number of wells against mirror reflectivity or loss caused by the gain flattening effect.[10-12] Note that about 100 wells are needed to obtain the minimum threshold current density even when the reflectivity is 97%. This is because the cavity length of a surface emitting laser is much shorter than that of an edge emitting laser.

Next, GaAlAs/GaAs MQW wafers for surface emitting lasers were grown by an atmospheric metalorganic chemical vapor deposition (MOCVD) system. The substrate temperature was 780°C. The MQW active region consisted of multiple pairs of GaAs and $Ga_{0.8}Al_{0.2}As$ with nominal thicknesses of 100 Å and 100 Å (or 60 Å), respectively. The number of wells was varied from 10 to 100. Zn was doped both in wells and barriers. These MQW wafers were characterized by measuring the threshold current densities of stripe lasers, and the distribution of pumping was examined. The stripe width was 16 μm and the cavity length 300 ~ 500 μm. The near-field patterns of these lasers split into two parts vertical

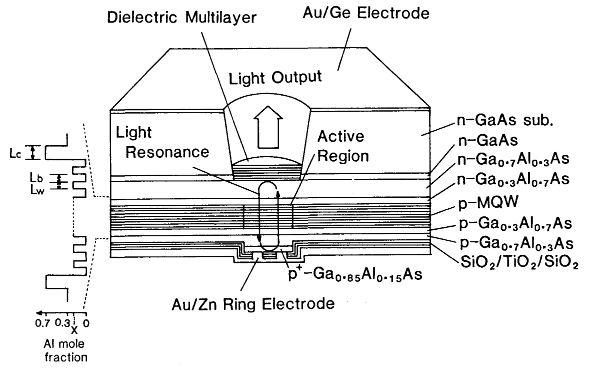

Fig. 1. Schematic structure of MQW surface emitting laser.

*H. Uenohara, F. Koyama, T. Sakaguchi and K. Iga: National Convention Record of IEICE of Japan, No. 279, November 1987.

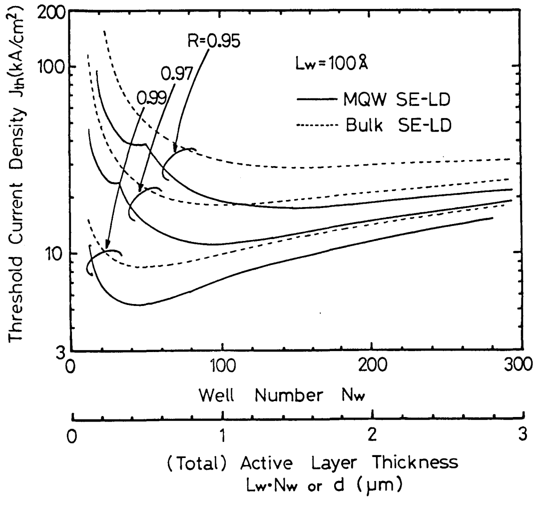

Fig. 2. The calculated dependence of the threshold current density of MQW surface emitting laser on number of wells.

to the epitaxial layers, even below the threshold current. This is considered to be due to the nonuniform injection of carriers into 100 quantum wells. The dependence of threshold current density on the number of wells is shown in Fig. 3. The parameter k represents the ratio of effectively injected carriers to total injected carriers, and we can estimate the difference between experimental results and theoretical ones. The experimental results were $2\sim3$ times higher than the theoretical ones for $k=1$, i.e., under the condition of no nonradiative recombination current. This is probably caused by the carrier overflow from quantum wells or inhomogeneous injection of carriers into quantum wells.

Although the obtained gain of MQW active layers was not satisfactory, it is important to try to fabricate and demonstrate a surface emitting laser. Thus we fabricated an MQW surface emitting laser with a round low mesa structure (Fig. 1). In this particular device, one hundred wells were used. The photoluminescence wavelength of a wafer was 8440 Å at room temperature, which corresponds to a well width of 85 Å. The period of MQW was also estimated to be 190 Å from a satellite peak of X-ray diffraction, that is consistent with the nominal period of 200 Å (100 Å + 100 Å). The fabrication process of surface emitting lasers is similar to that described in ref. 13. A p-side and an n-side mirror consisted of $SiO_2/TiO_2/SiO_2$ and 15 TiO_2/SiO_2 pairs, respectively. A p-side electrode with inner and outer diameters of 10 μm and 26 μm, respectively, was formed on a 30 μm-diameter mesa. A light output/current characteristic at 77 K under pulsed condition is shown in Fig. 4. The threshold current was 140 mA. The output light of this device showed the linear polarization above the threshold and no preference in polarization below the threshold.

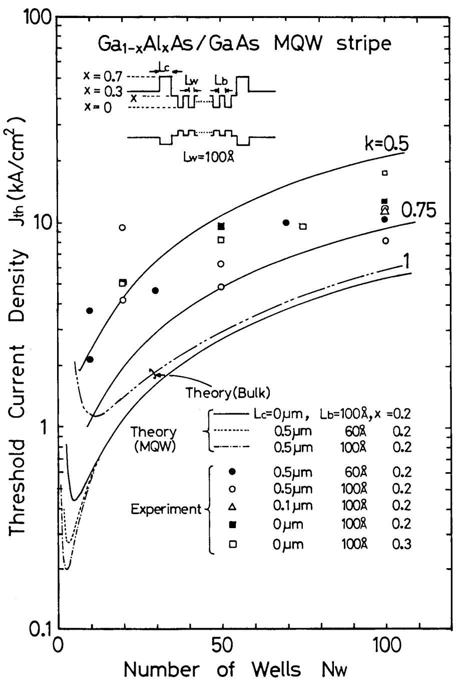

Fig. 3. The experimental results of the threshold current density of MQW stripe lasers vs. the number of wells. L_b and L_c represent the thickness of barrier layers and $Ga_{0.3}Al_{0.7}As$ layers, respectively.

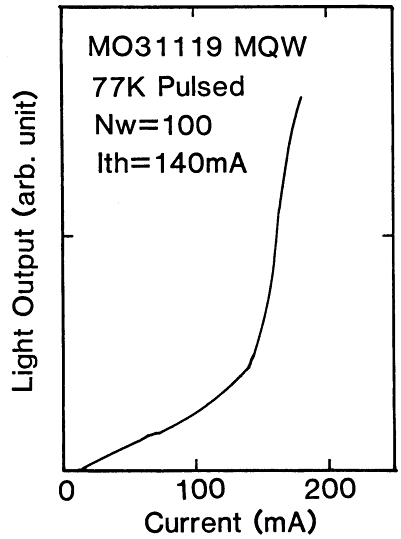

Fig. 4. Light output/current characteristics at 77 K under pulsed condition.

We believe that this is the first lasing operation of the MQW surface emitting laser by current injection. The threshold current obtained was not as low as expected due to the following: 1) inhomogeneous current injection which increases the threshold current density of the MQW wafer; 2) reflectivity of the mirror was insufficient for laser operation. Quality improvement of MQW structure and efficient current injection are open for future study. Light output/current characteristics of other devices showed kinks with a minimum of 520 mA at room temperature, implying laser oscillation. Further investigation is in progress.

The authors wish to thank Prof. Y. Suematsu of Tokyo Institute of Technology for encouragement and discussion. This work was supported by a Scientific Research Grant in Aid (#61065002) from the Ministry of Education, Science and Culture.

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