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Short Note

GaInAsP Microcylinder (Microdisk) Injection Laser with AlInAs(O_x) Claddings

Masayuki FUJITA, Reona USHIGOME, Toshihiko BABA, Akihiro MATSUTANI[1], Fumio KOYAMA[1] and Kenichi IGA[1]

Faculty of Electrical and Computer Engineering, Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan
[1]*Precision and Intelligence Laboratory, Microsystem Research Center, Tokyo Institute of Technology, 4259 Nagatsuta, Midori-ku, Yokohama 226-8503, Japan*

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We propose and demonstrate a 1.5-μm-GaInAsP/AlInAs microcylinder laser which improves the fragility of the microdisk laser. The threshold current density was comparable to that reported for the 0.98-μm-GaInAs microcylinder laser. The selective oxidation of the AlInAs claddings will further reduce the threshold by strong optical confinement in the disk like structure and will simplify the large-scale integration of this type of device.

KEYWORDS: AlInAs, GaInAsP, microcavity, microcylinder, microdisk, selective oxidation semiconductor laser

Microcavity semiconductor lasers are suitable for large-scale integration due to their ultrasmall volume and ultralow threshold. In particular, microdisk lasers[1–5] have simple geometry and can easily realize a high Q whispering galley (WG) mode. This is because of the strong optical confinement in both vertical and lateral directions by the total internal reflection at semiconductor and air boundaries. In the GaInAsP/InP system, we have demonstrated room-temperature continuous-wave operation with a threshold current of 40 μA[4] and the smallest injection device with a disk diameter of 2 μm.[5] However, the structure of injection devices is fragile, since the disk active layer is exposed to the air and supported by posts of submicron width. As an alternative, a microcylinder laser having a simple circular mesa cavity has been investigated.[6] However, the optical confinement is lower and therefore, the threshold is higher than those in microdisk lasers. In this study, we propose a GaInAsP/AlInAs microcylinder laser to solve these problems. An $Al_{0.48}In_{0.52}As$ layer lattice-matched to an InP substrate has a refractive index of 3.16 at a wavelength λ of 1.55 μm, which is slightly lower than that of InP. The use of this layer as cladding is expected to improves the optical confinement factor into quantum wells (QWs) by 10%, compared with that for InP claddings. In addition to this, it is expected to achieve a much higher optical confinement, as in microdisk lasers, by selective oxidation. In this paper, we first describe the fabrication and evaluation of the microcylinder laser. Then, we discuss the possibility of the oxide cladding structure.

In the experiment, we prepared an epitaxial wafer by low-pressure metal-organic vapor-phase-epitaxy. It had a GaInAsP (Q) active layer composed of six 1% compressively strained (CS) QWs each of 4 nm thickness, 1.2-μm-Q barrier layers each of 10 nm thickness, and 1.2-μm-Q and 1.1-μm-Q cover layers of 50 nm and 30 nm thickness, respectively. The spontaneous emission peak wavelength was $\lambda = 1.525\,\mu$m. The thickness of the upper p-type and lower n-type $Al_{0.48}In_{0.52}As$ claddings was 1.5 μm, and the highly p-doped GaInAs top contact layer was 0.3 μm. For this wafer, circular mesas of 12 μm in diameter and 4.8 μm in depth were formed by electron-beam (EB) lithography and Cl_2 inductively coupled plasma (ICP) etching using SAMCO International Inc. RIE-101ip.[7] For GaInAsP/InP, we sometimes use CH_4-based plasma etching, since it achieves a smooth etching profile.[1] However, the etch rate of this plasma against AlInAs is too low to form fine mesas using an EB resist mask. Cl_2 ICP etching successfully solves this problem. We employed a gas pressure of 0.5 Pa and a Cl_2 flow rate of 10 sccm. This flow rate is higher than 3 sccm, the optimum value for InP. It is effective for increasing the etch rate of AlInAs, which is nearly 60% of that for InP, and the etching selectivity of AlInAs against the EB resist. Figure 1 shows the scanning electron micrograph (SEM) of the fabricated microcylinder laser. The side-wall angle of formed mesas was 87° against the substrate plane, and the side-wall roughness was less than 10 nm. As the injection device, it has an AuZn electrode for the top p-side and a AuGe one for the n-side.

Figure 2 shows lasing characteristics at room temperature under the pulsed condition. The lasing is observed at $\lambda = 1507$ nm and 1520 nm. The mode space of 13 nm is narrower than 19 nm, which was calculated for two differ-

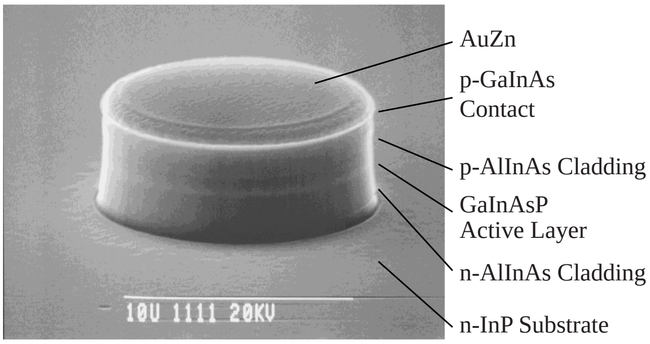

Fig. 1. SEM of fabricated 12-μm-diameter GaInAsP/AlInAs microcylinder laser.

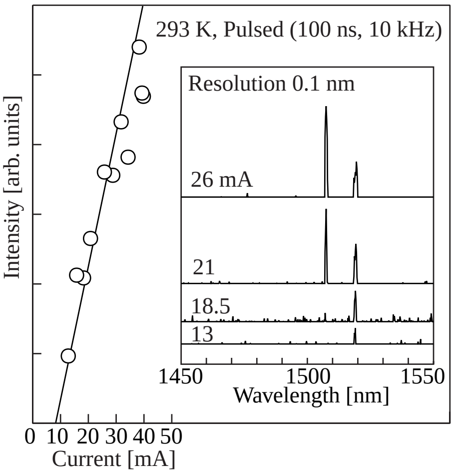

Fig. 2. Lasing characteristics of 12-μm-diameter GaInAsP/AlInAs microcylinder laser.

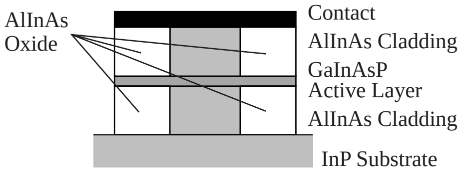

Fig. 3. Schematic of GaInAsP microdisk laser with selectively oxidized AlInAs claddings.

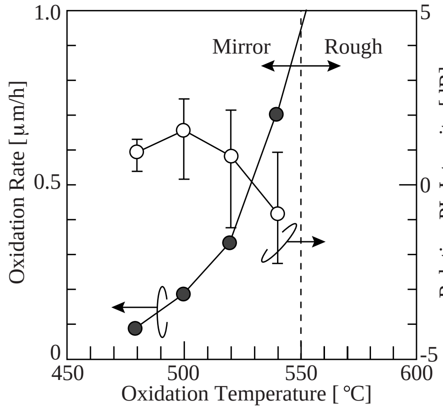

Fig. 4. Temperature dependence of AlInAs oxidation. Open and closed circles denote oxidation rate and relative PL intensity, respectively.

ent azimuthal modes by the formula $\lambda^2/(2\pi a n_\mathrm{m})$ with the disk radius a and the modal index n_m. The lasing modes are considered to be different radial modes. The threshold current is 9 mA. The threshold current density J_th, which is obtained as the threshold current divided by the mesa area, is 8.0 kA/cm^2. This value is comparable to that reported for a microcylinder laser with a 0.98-μm-Ga$_{0.8}$In$_{0.2}$As CS-QWs active layer, which is expected to have a higher gain than that of GaInAsP.[6] A reasonable explanation is the low surface recombination of GaInAsP and the smooth side-walls formed by the ICP etching. However, compared with the threshold of microdisk lasers, these values are too large, even considering the large leakage current ($\sim$70% of the total current) passing through the center region. Clearly, this is caused by the low optical confinement of the GaInAsP/AlInAs or GaInAs/GaInP structure.

For the threshold reduction, we next discuss the possibility of the oxide cladding device. A schematic of the target structure is shown in Fig. 3. It has the appearance of a microdisk laser buried by the oxide. It has been reported that the index of AlInAs is decreased to 2.4 by the oxidation.[8] The estimated optical confinement factor in one QW will be enhanced to 2.3 times that by InP claddings and 0.8 times that by air claddings. Thus, this structure achieves both the mechanical stability and the strong optical confinement simultaneously. The optimum oxidation depth for low light scattering loss of the lasing mode and efficient current injection through unoxidized claddings is nearly 0.7 μm.[3] As a similar structure, a GaAs/GaInAs QW active layer with oxidized AlGaAs cladding has been reported.[9] A GaInAsP active layer bonded on a GaAs/AlAs substrate has been investigated as another candidate.[10] However, GaInAsP/AlInAsO$_x$ is more advantageous for the reduction in device size and threshold due to the lower surface recombination and/or the simple process that does not involve bonding.

As a preliminary experiment for the oxidation of AlInAs, we prepared a wafer without the top contact layer. The oxidation was carried out by using water vapor with N$_2$ gas. Figure 4 shows the temperature dependence of the oxidation rate and the relative photoluminescence (PL) intensity normalized by that before the oxidation. The oxidation rate simply increases as the temperature increases. However, the surface after oxidation was very rough due to the evaporation of As at a temperature over 550°C. The oxidation rate was much slower than those reported for thin films of less than 0.1 μm thickness.[11–13] The PL was not degraded or was improved at a temperature less than 520°C due to an annealing effect. One problem with the oxidation which we noted is the nonuniformity of the oxidation depth. This will be improved by controlling the vapor flow in the furnace, as has been done for oxide confinement vertical-cavity surface-emitting lasers.

In conclusion, we proposed novel schemes for the microdisk-like laser, i.e., the GaInAsP/AlInAs microcylinder laser and its oxidized device. We achieved lasing operation of the former device, and performed the preliminary experiment for the latter device. The strong optical confinement and the mechanical stability expected for the oxidized device will help the planarization of the device substrate by a polymer and the formation of metal pads. Thus, this device will be effective for the large-scale integration of this type of device.

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