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GaInAsP/InP Multiple-Layered Quantum-Wire Lasers Fabricated by CH_4/H_2-Reactive-Ion-Etching

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1. Introduction

Quantum-wire (Q-Wire) and quantum-box (Q-Box) lasers have been expected to have a lot of advantages, such as low threshold current, high differential quantum efficiency and narrow linewidth.[1,2] For realization of such high performance operation, it is important to fabricate highly uniform and high-density low-dimensional quantum structures.

From various fabrication methods reported to date, we chose etching and regrowth method.[3,4] Especially, dry etching is very attractive fabrication process for optical devices with required size of sub-μm range structures because of vertical etching and less side etching, however, it is known that larger damage induced by kinetic energy remains in the sample compared with wet etching. Recently, we realized fairly low threshold current operation of distributed feedback lasers with wire-like active regions formed by a reactive ion etching (RIE) using CH_4/H_2 mixture gas.[5]

In this paper, we would like to report a realization of multiple-layered Q-Wire lasers (width 21 nm) by using the same method mentioned above. Better lasing properties at room temperature than those fabricated by a wet-chemical etching were also obtained.[3]

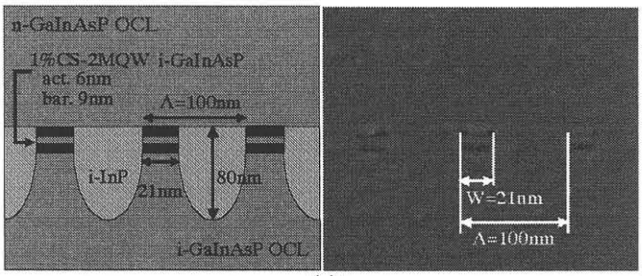
2. Fabrication of Q-Wire lasers

The initial wafer consists of 1% compressively-strained $Ga_{0.22}In_{0.78}As_{0.81}P_{0.19}$ (well layer: 6nm) /$Ga_{0.18}In_{0.82}As_{0.40}P_{0.60}$ (barrier layer: 9nm) five multiple-quantum-wells (1%-CS-5MQWs) and an optical confinement layer (OCL) whose composition was the same as that of barrier layers grown by an OMVPE on (100) InP substrate. After 20nm thick SiO_2 deposition wire patterns were described along the <011> direction by an electron beam (EB) lithography using ZEP520/C_{60} composite resist. Using SiO_2 as a mask, a CH_4/H_2 RIE was carried out with conditions were as follows; gas flow rates of 10/40 (CH_4/H_2) sccm, the pressure of 6.5 Pa and the RF power of 100W. In order to remove the polymer deposited during the etching, we carried out an O_2 ashing in the same chamber. Its conditions were 30 sccm, 10 Pa and 50W, respectively. For the etching of narrow grooves with good vertical shape, this sequence of etching/ashing was repeated four times.

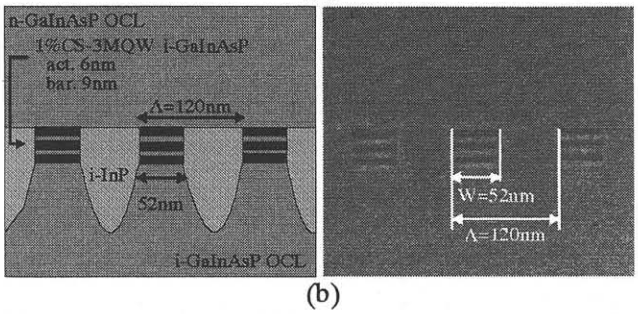
After a shallow wet etching as a cleaning process for etched surface, an embedding growth was done by the OMVPE. First, i-InP was grown at 600 °C with a slow growth rate of 0.25 μm/h that is 1/5 compared with our ordinary growth rate of 1.2 μm/h. Then n-GaInAsP OCL (170 nm thick), n-InP cladding layer and n^+-GaInAs contact layer (50 nm thick) were grown with the growth rate of 1.2 μm/h. Finally, 20μm wide mesa stripe laser structure was formed by photolithography and wet etching.

Figure 1 shows scanning-electron-microscope (SEM) views and their illustrations of wire structures with a period (Λ) of (a) 100 nm and (b) 120nm. As can be seen, uniform width of active layers was realized. However, the number of active layers of Q-wire lasers decreased to 2 (Λ=100nm) or 3 (Λ=120nm), probably due to an undercut etching during the wet cleaning process. This problem would be overcome by choosing an appropriate mask and conditions of the wet etching.

3. Lasing Properties



(a)



(b)

Figure 1 SEM views and illustrations of Q-Wire lasers
(a) period of 100 nm, wire width of 21 nm
(b) period of 120 nm, wirewidth of 52 nm

Figure 2 shows I-L characteristics of two different period Q-Wire lasers and quantum film (Q-Film) laser formed on the same wafer. And their characteristic properties are listed in Table I, *i.e.* cavity length L, threshold current I_{th}, threshold current density J_{th}, differential quantum efficiency η_d, number of quantum wells N_w, wire width W and optical

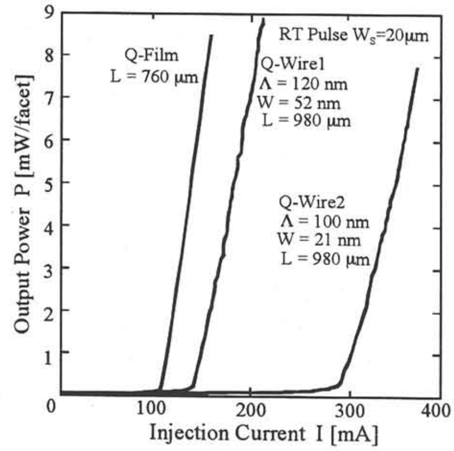


Figure 2 I-L characteristics of Q-Wire and Q-Film lasers

Table I Lasing properties of Q-wire and Q-Film lasers

	L [μm]	I_{th} [mA]	J_{th} [A/cm^2]	η_d [%]	N_W	W [nm]	ξ [%]
Q-Film	760	103	680	38	5		5.08
Q-Wire1 (dry) Λ=120nm	980	137	700	29	3	52	1.13
Q-Wire2 (dry) Λ=100nm	980	285	1450	20	2	21	0.32
Q-Wire (Wet) Λ=70nm [3]	1050	390	2400	15	1	25	0.46

confinement factor ξ. Characteristics of the Q-Wire laser fabricated by wet etching reported in the previous work [3] are also listed in Table I.

The J_{th} of 120nm period Q-wire laser was nearly the same as that of the Q-Film laser however wire width was too wide for quantum size effect.

In case of 100 nm period Q-Wire2 laser, its optical confinement factor became too low to obtain high performance operation because upper three active layers were etched away, this is the reason why the J_{th} became higher than that of other lasers. But the Q-Wire1 laser obtained this time exhibited better quality of the CH_4/H_2-RIE process, namely lower J_{th} and higher η_d than those of the Q-Wire laser fabricated by a wet-etching process.[3] Therefore our dry etching and OMVPE regrowth method can be considered to be low damage fabrication technique.

Figure 3 shows temperature dependences of (a) the threshold current density and (b) the lasing wavelength. At low temperature, the Q-Wire laser oscillated at lower J_{th} than the Q-Film laser, this may be attributed to a volume effect. As can be seen in Fig. 3(b), the energy shift of the Q-Wire1 (W = 52 nm) was estimated to be 28 meV. Since the quantum size effect for this size is supposed to be much smaller, this energy shift can be attributed to strain and composition change. Therefore, in energy shift of 47 meV at Q-Wire2 (W= 21 nm), more than 19 meV is considered to be due to the lateral quantum confinement effect.

4. Conclusion

We realized 1.5μm wavelength GaInAsP/InP double-layered quantum-wire lasers by CH_4/H_2-RIE process and OMVPE regrowth. To our knowledge J_{th}=1.45 kA/cm^2 is the lowest value among those of GaInAsP/InP quantum-wire lasers fabricated by etching/regrowth method.

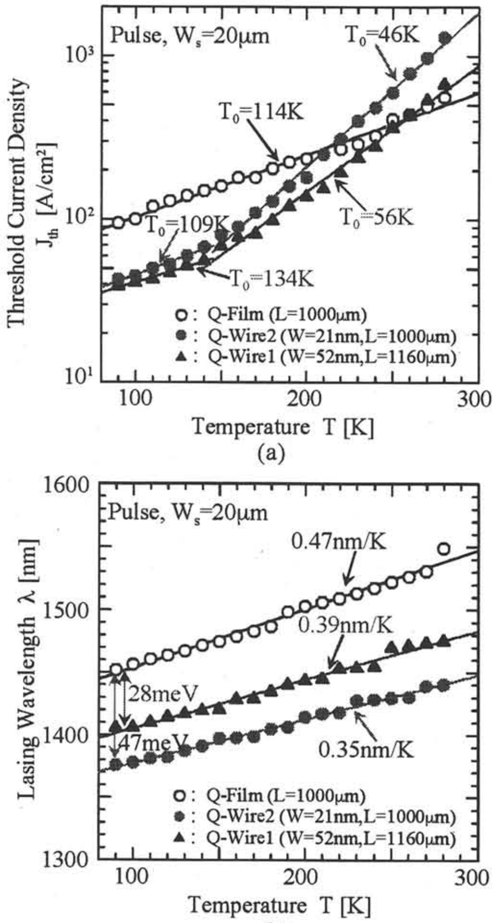


Figure 3 Temperature dependences of
(a) threshold current density
(b) lasing wavelength

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