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Investigation of Surface Damage in GaInAs/GaInAsP/InP Wire Structures by Low-Energy-Reactive-Ion Assisted Radical Etching

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A vertical 20nm line pattern with 70nm period GaInAs/GaInAsP/InP multi-quantum-wire (MQW) was successfully obtained by electron cyclotron resonance (ECR) dry etching with negative acceleration bias condition of -50V. The photoluminescence (PL) intensity at 77K of the MQW buried in GaInAsP by OMVPE, which is normalized by the space filling factor of the active region, is 66% of the as-grown multi-quantum-film (MQF) wafer. The sidewall recombination velocity S of 2.5×10^3cm/s was obtained under low excitation level of Ar^+-ion laser ($\sim$1W/cm^2) at 77K.

1. Introduction

Recently, a large number of studies have been made on quantum-wire and quantum-box semiconductor structures because of their possibility to high performance photonic and optoelectronic devices.

An electron cyclotron resonance reactive ion beam etching (ECR-RIBE) is one of the most effective method to fabricate high density and uniform quantum-wire (QW) and quantum-box (QB) structures. Until now, much works have been done to fabricate such lower dimensional quantum well structures by using dry etching[1-7].

In our previous study, low-damage and vertical etching was achieved with low ion extraction voltage and low pressure[8].

In this work, we calculated the sidewall recombination velocity of GaInAs/GaInAsP/InP quasi-wire structures fabricated by ECR dry etching. The sidewall recombination velocity S of 2.5×10^3cm/s was obtained under extremely low excitation level of an Ar^+-ion laser ($\sim$1W/cm^2) at 77K.

Moreover, we demonstrate fabrication of high density and uniform GaInAs/GaInAsP/InP multi-quantum-wires by using modified low pressure ECR-RIBE. A 20nm line pattern with 70 nm period multi-quantum-wire structure was achieved.

The relative PL intensity of the MQW embedded in GaInAsP was 66% of the as-grown multi-quantum-film wafer.

2. Etching condition

A schematic diagram of the ultra-high vacuum ECR dry etching system used in this report is shown in Fig.1. This system consists of three parts; an ECR plasma section, an etching section, and a load lock section. The ion extraction voltage V_{ex}, the substrate voltage V_s, and substrate temperature T_s can be controlled up to 1000V, 400V, and 1000℃, respectively. We used Cl_2 as an etching gas.

Dry etching conditions are listed in Table I. Especially, it is necessary to decrease the ion extraction voltage as well as substrate voltage to achieve low-damage etching on surface because surface damage by dry etching is proportional to ion's velocity of the etching gas. We obtained good results from V_{ex} = 0V and V_s = 0 $\sim$ -50V. In addition, the background pressure in the chamber was reduced to 5×10^{-6} Torr in order to increase the mean-free path of Cl^+ ions and Cl^* radicals.

3. Fabrication

The n-InP buffer layer (3μm thick), i-GaInAsP step OCL (200nm thick, λ_g=1.15μm), and lattice matched i-$Ga_{0.47}In_{0.53}As$/GaInAsP quantum-film (QF) layers (5nm) were successively grown on n-InP

substrate by OMVPE.

Then a 30nm thick SiO2 stripe mask with various periods of pattern were formed along the <01$\bar{1}$> direction by electron beam lithography and CF4 reactive ion etching (RIE). Finally, the ECR dry etching was done. Conditions of the RIE etching were listed in Table II . The PL measurement were made after ECR dry etching with cleaning process of extremely slow rate wet chemical etchant H_2SO_4: H_2O_2:H_2O = 1:1:40 at 0°C for 20secs.

Figure 2 shows PL intensity of the wires normalized by that of the quantum film and the space filling factor, which is the volume ratio of the active region of the MQW to that of the MQF, cut out from same wafer. As can be seen, normalized PL intensity of the wires fabricated by ECR dry etching is almost same to wires fabricated by wet chemical etching.

We used eq. (1) to calculate sidewall recombination velocity S of the wire structure.

$$\frac{I_{wire}}{I_{film}} = \frac{\frac{1}{2}W - W_d}{S \cdot \tau + \frac{1}{2}W - W_d} \qquad (1)$$

where W, W_d, τ are the geometrical wire width, the width of so-called "dead layer" and the bulk carrier lifetime[6]. We obtained S of 2.5×10^3cm/s at 77K from eq. (1) and from fig.2 under extremely low excitation level of a Ar^+-ion laser ($\sim$1W/cm^2). As can be seen, the sidewall recombination velocity of the wires fabricated by ECR dry etching are almost same to that of wire fabricated by wet chemical etching.

We also fabricated 20nm line patterned GaInAs/GaInAsP/InP MQW structure with 70nm period by ECR dry etching. Figure 3 shows a cross-sectional SEM photograph of the three pairs of lattice matched MQW structure which is buried in GaInAsP. As can be seen, the wire width is approximately 20nm with the period of 70nm. Figure 4 shows the PL spectrum of the MQW buried in GaInAsP. The absolute PL intensity of this MQW sample buried in GaInAsP was 19% of that of MQF sample cut out from the same wafer and the PL intensity of the MQW, which is normalized by the space filling factor 29%, was 66% of that of the MQF structure.

4. Conclusion

Low-damage dry etching was achieved with negative acceleration bias condition of -50V.The sidewall recombination velocity S of 2.5×10^3 cm/s was obtained at 77K under extremely low excitation power ($\sim$1W/cm^2).

And also, the fabrication of 20nm line pattern with period of 70nm GaInAs/GaInAsP/InP multi-quantum-wire structure was demonstrated by combining electron beam lithography and ECR dry etching. The normalized PL intensity of the MQW buried in GaInAsP was 66% of that of the as-grown multi-quantum-film.

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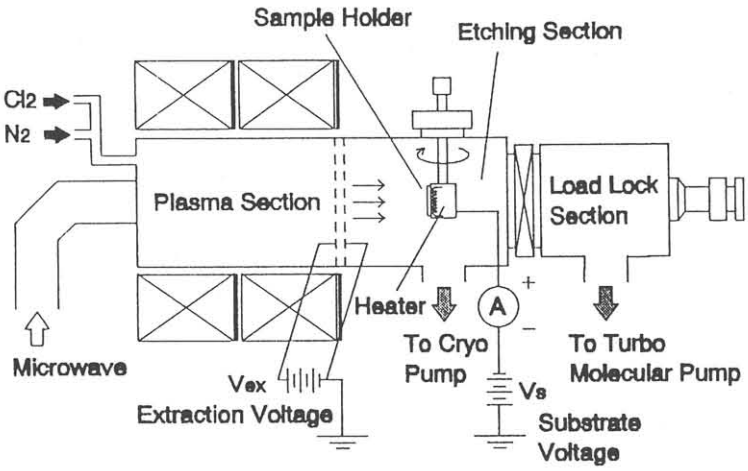

Fig.1 ECR Dry Etching System.

Table I. ECR Dry Etching Conditions.

Etching Gas	Cl_2
Micro Wave Power	300W
Gas Flow Rate	1sccm
Pressure	5×10^{-6} Torr
Ion Extraction Voltage Vex	0V
Substrate Voltage Vs	-50V
Sample Temperature Ts	300℃

Table II. RIE Etching Conditions.

Etching Gas	CF_4
RF Power	17W
Gas Flow Rate	5sccm
Pressure	1.3×10^{-1} Torr

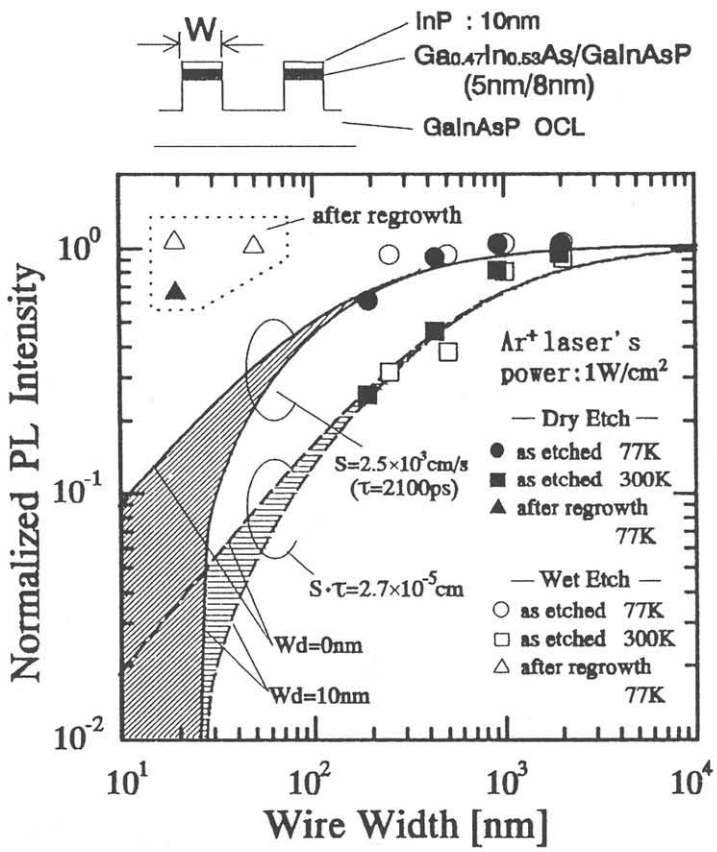

Fig.2 Normalized PL intensity as a function of wire width.

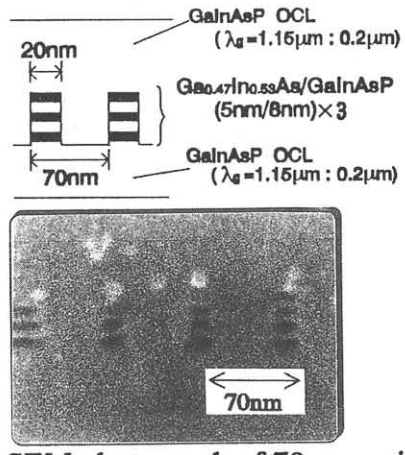

Fig.3 SEM photograph of 70nm period 3 layered Multi-Quantum-Wires buried in GaInAsP.

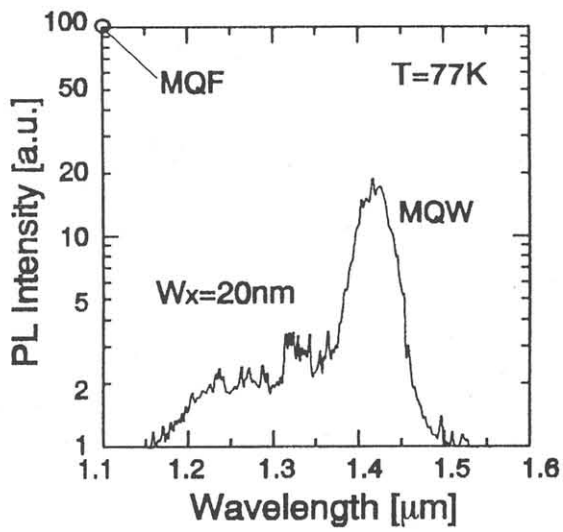

Fig.4 PL Intensity of 70nm period 3 layered Multi-Quantum-Wires buried in GaInAsP.