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Fabrication of GaAs Microstructures on CaF_2 by Selective Growth Method Using a Focused Electron Beam

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One of methods to fabricate quantum structures, a selective growth method on the insulator using a focused electron beam is considered. In order to fabricate GaAs microstructures by this method, the key factor to get narrower structure was investigated by Monte Carlo simulation of injected electron scattering traces. By considering the results of the simulation, GaAs wires whose widths were less than 700 nm were obtained by using an electron beam with the energy of 40 keV and the dose of 1 μ C/cm.

1. Introduction

We reported the feasibility of a novel selective growth method of GaAs on a CaF_2 film by surface modification effect using electron beam exposure [1]. This method has been investigated as a candidate of the microfabrication method [2], because additional patterns such as SiO_2 mask formations are not necessary and the arbitrary patterning by the direct writing of a focused electron beam is possible. However, there was a problem of broadening of the growth patterns much larger than the electron beam size.

In this paper, experimental results of submicron GaAs wires made by this new method will be demonstrated and a method to reduce the structure size will be discussed using Monte Carlo simulation.

2. Selective Growth Method Using a Focused Electron Beam

A process of selective growth of GaAs on a CaF_2/Si(111) substrate, which is an application of EBE-Epitaxy [3], is shown in Fig. 1. An As/CaF_2/Si substrate is exposed by a focused electron beam by a SEM apparatus, where the As film covering the CaF_2/Si structure is supposed to protect the surface of the epitaxial CaF_2 film from the contaminants of O_2 or C and to work by itself as a replacing material on the surface modification. After thermal annihilation of the surplus As in a GaAs MBE chamber, the selective growth of GaAs on the electron beam exposed region is performed.

3. Experimental

A CaF_2 film with the type-A epitaxial relation was grown on a Si(111) substrate by a two-step growth method [4] using the MBE method, because the type-A CaF_2 has better surface morphology than that of type-B and it can be expected to obtain good selectivity of GaAs growth. The 10 nm thick initial layer was grown at around 200 °C. Then, succeeding layer of 170 nm thick CaF_2 was grown at 780 °C. After that, a 700 nm thick As layer was deposited on the CaF_2 / Si substrate after cooling the substrate bellow room temperature in a MBE chamber.

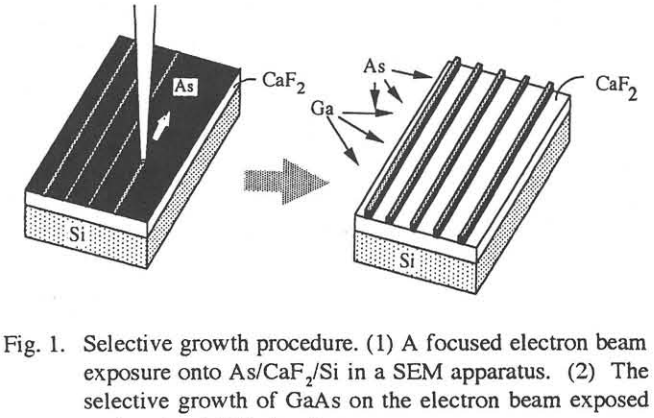

Fig. 1. Selective growth procedure. (1) A focused electron beam exposure onto As/CaF_2/Si in a SEM apparatus. (2) The selective growth of GaAs on the electron beam exposed regions in a MBE chamber.

This substrate was carried to a SEM apparatus through an air environment and was set there. The surface of the CaF_2 was exposed linearly by the scanning electron beam through the As layer with various energies and electron doses. The beam size can be estimated as not more than 100 nm from the resolution of SEM images. After that the sample was set into the MBE chamber again, 50 nm thick GaAs selective growth on the CaF_2 surface was carried out after thermal annihilation of surplus As from the surface of the sample. The growth temperature and the growth rate of GaAs were chosen as 630 ℃ and 50 nm/ hour, respectively.

4. Results

A result of the selective growth of GaAs wires on the CaF_2/Si(111) is shown in Fig. 2. It is found that line widths depend on the electron dose and that rather sharp structures and good selectivity of GaAs can be obtained.

Figure 3 shows experimental results of relations between the line width and the electron dose for electron energies of 10 keV and 40 keV. In the high dose case (more than 10 μ C/cm), it seems that the line width is independent of the electron dose. However, in the low dose case, the electron dose dependence on the line width is observed for both electron energies, moreover the change of the line width in the case of 40 keV is much larger than that in the case of 10 keV. An origin of these phenomena will be discussed by using Monte Carlo simulation.

Fig. 2. Nomarski optical micrograph of traces of GaAs wires fabricated on CaF_2/Si(111). Accelerated energy of electrons was 40 keV. Doses of each lines were 100, 50, 25, 15, 10, 7.5 and 6 μ C/cm, from left to right respectively.

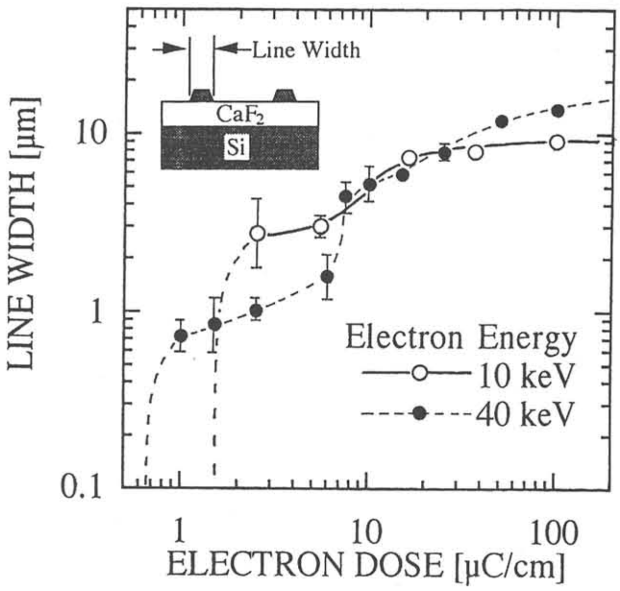

Fig. 3. Experimental results of relations between the line width and the electron dose as a parameter of accelerated energies. The thickness of As film was about 700 nm.

5. Theoretical Estimations of Line Width

We could obtain the sharp line whose width was as narrow as about 700 nm, when an electron dose was 1 μC/cm. However, taking into account the electron beam size, this line width is still larger than the beam size. It is considered that the surface modified region on which a GaAs line structure would be formed is extended more than the beam size. In order to examine the region where the surface of CaF_2 is modified by an electron beam, Monte Carlo simulation about traces of scattered electrons was performed in the As/ CaF_2/Si system using a single scattering model [5].

Figure 4 shows a profile of distribution of electrons which have passed through an interface between As and CaF_2. The number of injected electrons is 2000 in this calculation. In order to define the line width, we assume that there is a *threshold* number of electrons to modify the surface of CaF_2. The line width is defined as the width of region where the number of electrons is not less than the threshold as shown in the figure. If twice electrons are injected, the profile will be twice higher so that the line width defined by the threshold will become wider. In order to examine the dose dependence of the line width, the line width was calculated by varying the threshold level for the profile at fixed number of injected electrons, instead of varying the number of injected electrons.

Figure 5 shows calculated relations between the line width and the electron dose as a parameter of the electron energy and As film thickness. In the high dose case (more than 10), the line widths are almost constant with its electron energy. However, in the low dose case (less than 10), the line widths are much reduced. In the case that the electron energy is 20 keV and the thickness of As is 0.7 μm, as the electron dose reduces, the line width becomes rapidly narrower. However, it seems difficult to control the line width by the electron dose in the low dose condition. On the contrary, in the case of 40 keV energy, it seems easy to control the line width because there is a gentle gradient region in the low dose condition. But if the thickness of the As film increases, the gradient becomes steep. These results agree with the experimental results. So, it can be considered that using higher energy and thinner As film, which would make forward scattering in As films smaller, is expected to be better to make narrower structures.

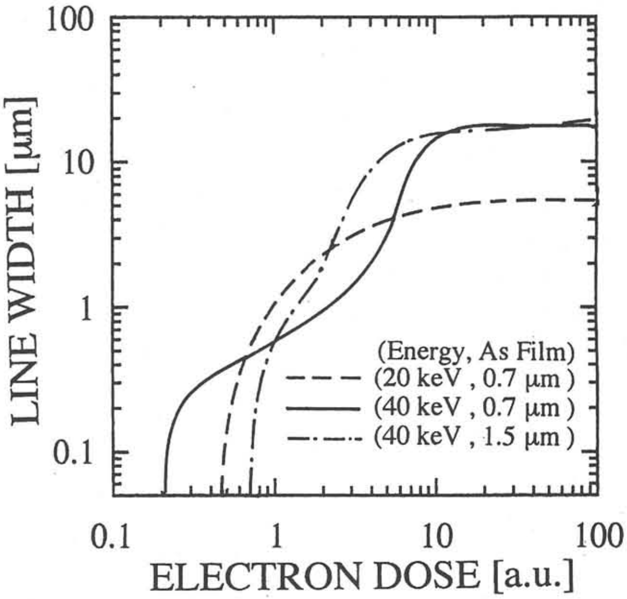

Fig. 5. Simulated results of relations between the line width and the electron dose as a parameter of film thickness of As and electron energies.

6. Conclusion

Wire structures of GaAs whose widths as narrow as 700 nm were fabricated on the CaF_2 / Si(111) by the selective growth method using a focused electron beam. The line width fabricated was strongly dependent on the dose of an electron beam when the electron energy was rather high, which agreed with the result from Monte Carlo simulation. It can be said that further thinnings of the As film and uses of higher energy electrons would make the structure size smaller.

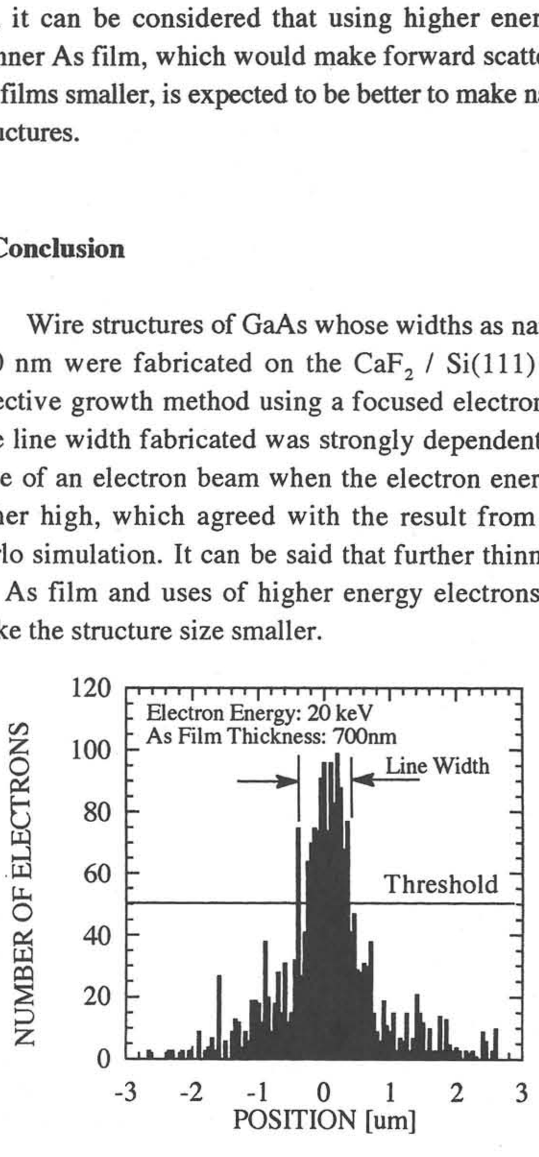

Fig. 4. A calculated profile about number of electrons which passed through an interface between As and CaF_2 by Monte Carlo method. It was assumed that 2000 electrons whose energy is 20 keV were injected. The film thickness of As and CaF_2 are 700 and 200 nm, respectively.

References

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