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# Selective Growth by Electron Beam Induced MOCVD for Quantum Microstructures

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We have demonstrated the selective growth and ungrowth of semiconductor crystal using electron beam induced MOCVD method. As a result, a wire structure whose dimension is about 1000Å is successfully formed in the selective growth method. On the other hand, using the selective ungrowth technique the GaAs wire structure which is narrower than 1μm is also formed. These techniques can be applied to the fabrication technology of quantum microstructures.

## 1. Introduction

Use of quantum microstructures such as quantum well wire and quantum well box structures leads to improvements of various properties of semiconductor devices. For this purpose, fabrication technologies such as the fractional layer superlattice growth[1)], the laser assisted atomic layer epitaxy[2)], the facet wire growth[3)] have been actively studied. In this paper, we propose a novel selective growth named electron beam induced MOCVD (EBI-MOCVD), in which

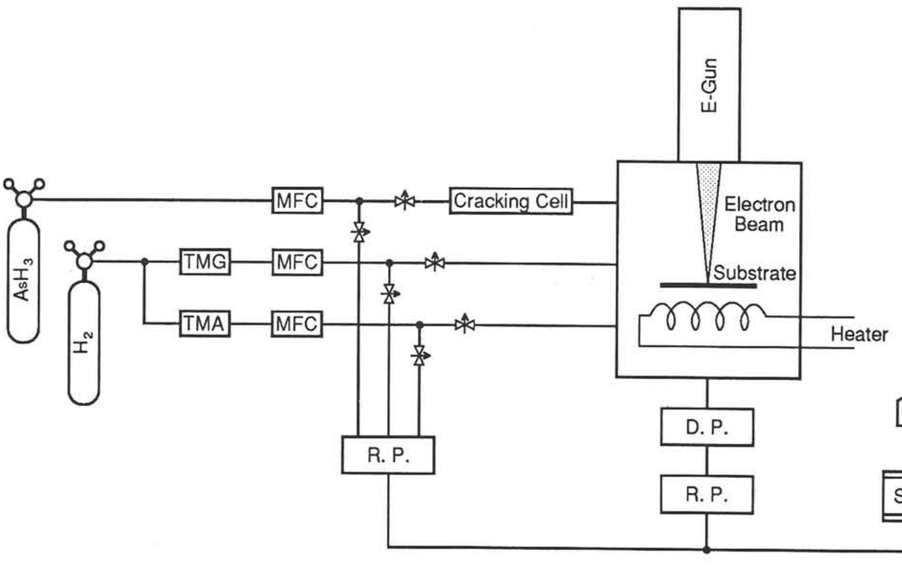


Fig.1 Electron beam induced MOCVD (EBI-MOCVD) system. In this system, source materials are tri-methyl-gallium (TMG) and tri-methyl-aluminium (TMA) carried by $H_2$ gas flow and $AsH_3$, and substrates can be heated up to 700°C. The back-ground pressure is about $10^{-7}$torr and the pressure during the growth is about $10^{-4}$torr.

irradiation of electron beam enhances or suppresses adsorption and/or decomposition of source materials on the substrate surface, resulting in formation of sub-nanometer-scale structures. We will report the selective growth condition, the source material dependence and the substrate temperature dependence of the deposition on GaAs substrates. In addition, the possibility of a *selective ungrowth* is also discussed.

## 2. Electron Beam Induced (EBI) MOCVD System

Our EBI-MOCVD system is shown in Fig.1. In this system, source materials are the same as the conventional MOCVD system; These are $AsH_3$, tri-methyl-gallium (TMG) and tri-methyl-aluminium (TMA) carried by $H_2$ gas flow. The gas flows are controlled by the mass flow controllers. We can crack $AsH_3$ by the cracking cell up to 1200°C. The growth chamber and the electron beam gun are evacuated separately by the differential exhaust systems which consist of diffusion pumps and rotary pumps. The back-ground pressure in the chamber is about $10^{-7}$torr and the pressure during the growth is about $10^{-4}$torr. We can irradiate the electron beam onto the substrate surface during the growth. Substrates can be heated up to 700°C by the radiation heater.

## 3. Selective Growth

We investigated the source material dependence and the temperature dependence of the selective growth on GaAs substrates. Fig.2 shows a SEM photograph of the selective growth area by the electron beam irradiation, when only TMA is supplied into the chamber at 400°C substrate temperature. The electron beam irradiation time is 1 hour. As shown in this figure, a wire structure is successfully formed by this method. The dimension of the wire is about 1000Å, which is not determined by the diameter of the electron beam but by some vibration problems in the system. Similar formation of the wire can be achieved at the temperature range between room temperature and 700°C. On the other hand, when only TMG is supplied, the selective growth is realized below 400°C. Thus, there exists difference in the temperature dependence between TMA and TMG.

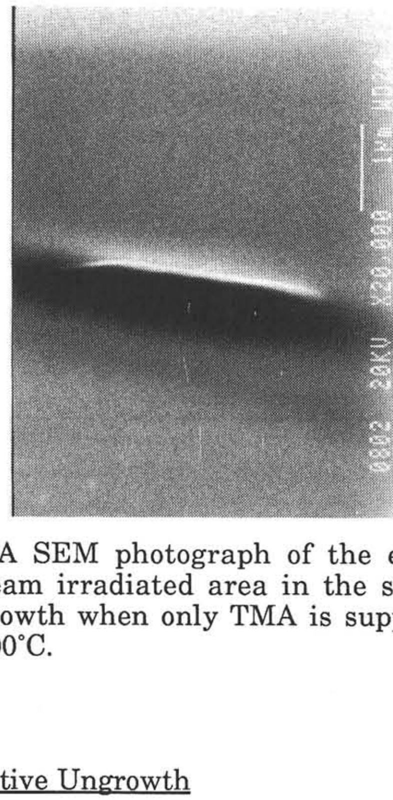

Fig.2 A SEM photograph of the electron beam irradiated area in the selective growth when only TMA is supplied at 400°C.

## 4. Selective Ungrowth

We have also achieved a *selective ungrowth*. Fig.3 shows this selective ungrowth with $AsH_3$ cracked at 1000°C and TMG. Substrate temperature is 500°C and growth time is 1 hour. As shown in this photograph, GaAs crystal is grown outside of the electron beam irradiated area. In this case, the electron beam is irradiated before the crystal growth and the selective ungrowth area is about 20μm×20μm. A possible mechanism for this phenomenon is that the ungrowth area is coated by carbon or something else by the electron beam irradiation. When the electron beam is scanned by the line scanning mode, the ungrowth area width is wider than the spot size of the electron beam. Fig.4 shows the ungrowth area width as a function of the acceleration voltage. As shown in this figure, the ungrowth area width becomes narrower with the decrease of the acceleration voltage. On the other hand, the spot size of the electron beam is smaller than 1000Å and the spot size becomes smaller with the increase of the acceleration voltage. Therefore, our result suggests that not the electrons which are directly irradiated onto the substrate surface but the electrons and/or holes generated after scattering of electron beam inside the substrate contribute to the observed ungrowth. This selective ungrowth technique can be applied for a fabrication technology of the semiconductor microstructures like the quantum well wire and the quantum well box as shown in Fig.5. Fig.6 shows a successfully fabricated GaAs wire structure using this technique. The GaAs wire width is narrower than 1μm.

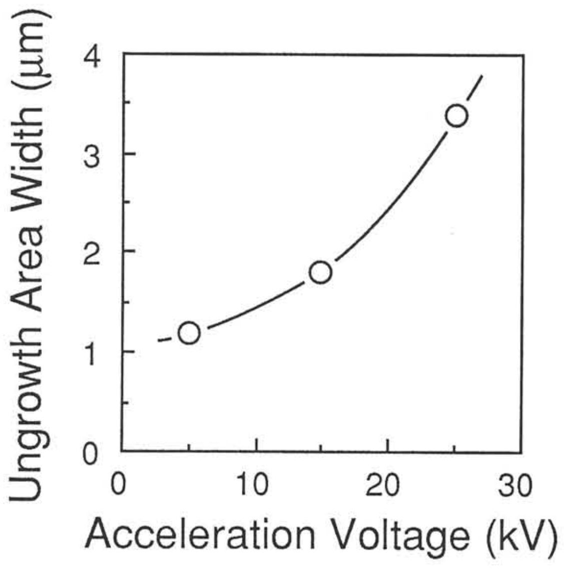


Fig.4 Selective ungrowth area width as a function of the acceleration voltage of the electron beam.

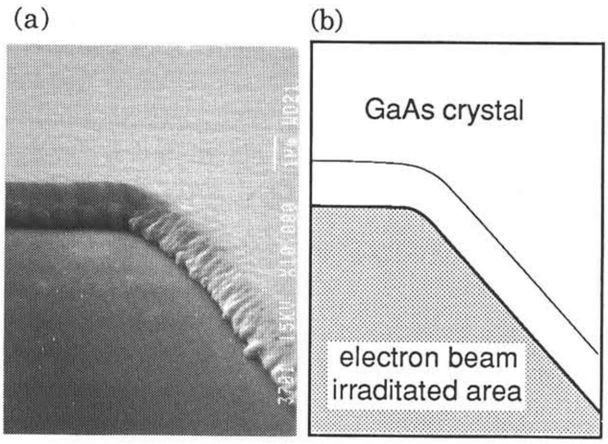


Fig.3 (a) A SEM photograph and (b) an illustration of the electron irradiated area in the selective ungrowth when $AsH_3$ cracked at 1000°C and TMG are supplied. Substrate temperature is 500°C and growth time is 1 hour.

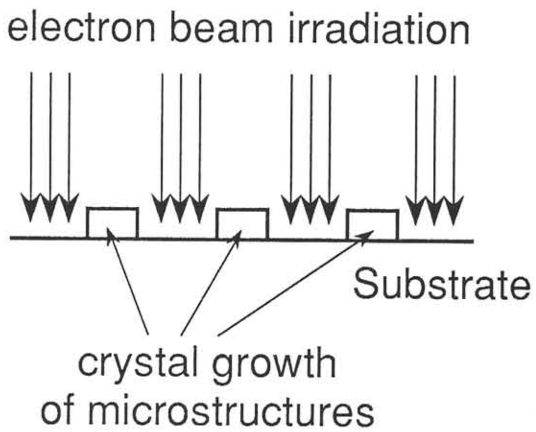


Fig.5 Proposal of fabrication technology using selective ungrowth method for semiconductor microstructure like quantum well wire or quantum well box.

## 5. Conclusion

We have demonstrated the selective growth and ungrowth of semiconductor crystal using EBI-MOCVD method. As a result, a wire structure whose dimension is about 1000Å is successfully formed in the selective growth method. On the other hand, using the selective ungrowth technique the GaAs wire structure which is narrower than 1μm is also formed. These techniques can be applied to the fabrication technology of quantum microstructures.

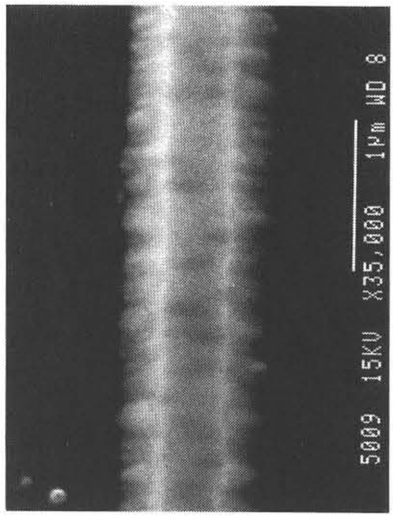


Fig.6 A SEM photograph of the GaAs wire fabricated by the selective ungrowth technique.

## References


1) P. M. Petroff, A. C. Gossard and W. Wiegmann; Appl. Phys. Lett. 45 (1984) 620.

2) Y. Aoyagi, S. Masuda, S. Namba and A. Doi; Appl. Phys. Lett. 47 (1985) 95.

3) H. Asai, S. Yamada and T. Fukui; Appl. Phys. Lett. 51 (1987) 1518.