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Invited

Epitaxy and Pattern Formation of III- V Semiconductors as a Through UHV Processing towards 2- and 3-Dimensional Nanostructures

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Selective-area epitaxy and pattern etching of GaAs using a thin oxidized layer as a mask are performed in an ultra-high vacuum (UHV) multichamber system. These processes are based on the *in situ* electron-beam (EB) induced Cl_2 etching of the photo-oxidized GaAs layer and will provide a new approach to 2- and 3-dimensional semiconductor nanostructures.

1. INTRODUCTION

There has been a growing interest in 2- and/or 3-dimensional semiconductor heterostructures in the nanometer scale for future electronic and optoelectronic devices.[1] To fabricate such nano-structures, a through ultra-high vacuum (UHV) processing of III-V semiconductors where the epitaxy and the pattern etching are performed successively without unintentional surface contamination caused by air exposure is regarded as a most probable candidate.[2,3] In this context, research concerning *in situ* patterning using focused-ion beam (FIB) has been carried out.[4-6] However, in the processing using ion beam, it turned out that inherent drawback such as the ion-induced damage which extends deeply into the sample remains.[7,8]

We have recently reported a lithography process named *in situ* electron-beam (EB) lithography which is compatible with a through UHV processing of GaAs/AlGaAs system.[9-11] In *in situ* EB lithography, an ultrathin oxide of GaAs is used as both the resist film and the etching mask, which can be patterned by EB-induced Cl_2 etching, and can be removed by heating. In addition to *in situ* EB lithography, we have also demonstrated a selective area growth of GaAs using a GaAs oxide layer as a mask.[12]

In this paper, EB-induced Cl_2 etching and selective area growth of GaAs using GaAs oxide film both as a resist film and as a mask film are described.

2. *In situ* EB LITHOGRAPHY

The UHV multichamber system used for EB lithography is shown in Fig.1. The basic process of *in situ* EB lithography is the local removal of the surface oxide layer of GaAs by a simultaneous irradiation of electron beam and Cl_2 gas.

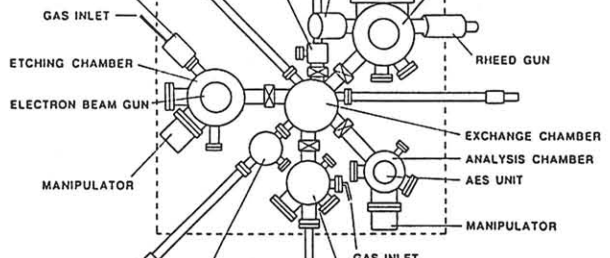

Fig.1. Schematic structure of the UHV multichamber system used for *in situ* EB lithography.

The procedure of *in situ* EB lithography comprises the following five steps; 1) preparation of a clean GaAs surface by MBE, 2) formation of the thin surface oxide layer as a resist-film by photo-oxidation in a pure oxygen, 3) patterning of the oxide layer by EB-induced Cl_2 etching, 4) Cl_2 etching of GaAs as a pattern transfer, and 5) removal of the surface layer by heat-treatment under arsenic flux in the MBE chamber. In Fig.2, the etched depth in the step 3) & 4) is plotted against the total electron dose. A steep rise of etching depth is seen at around the electron dose of 10^{17} cm^{-2}, under which etching does not proceed effectively. In other words, this dosage is minium EB-dose to remove the oxide layer completely. This nonlinear etching characteristics are quite favorable for lithography. Furthermore, it has turned

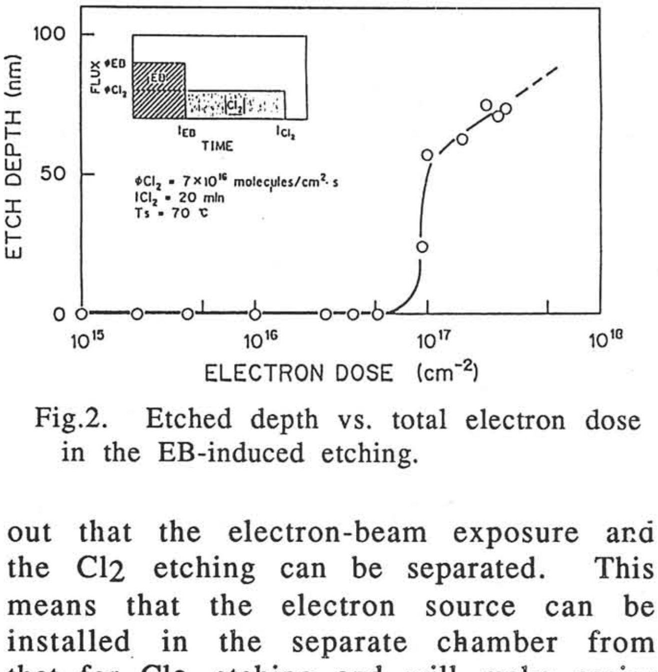

Fig.2. Etched depth vs. total electron dose in the EB-induced etching.

out that the electron-beam exposure and the Cl_2 etching can be separated. This means that the electron source can be installed in the separate chamber from that for Cl_2 etching and will make easier the design of a UHV system for *in situ* EB lithography. The details of the five steps and their modifications are reported elsewhere.[9-11,13]

An example of the fine patterns of GaAs produced by *in situ* EB lithography is shown in Fig.3. The resolution of patterns is about 0.1 μm, which is determined by the radius of the EB, and needs a future improvement. Further, photoluminescence (PL) measurements were made to evaluate the damage generated by the EB-induced etching. The PL spectra taken for etched and unetched areas had much the same at the peak wavelength, the full-width at the half-maximum and the total intensity. This indicates that EB-induced Cl_2 etching produces little damage to the specimen.[10,11]

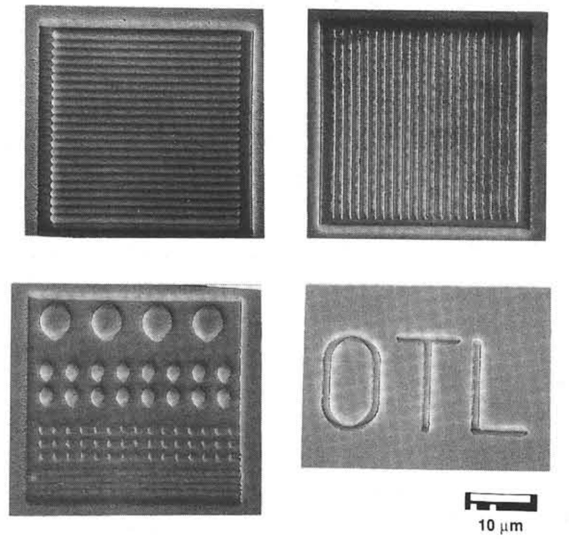

Fig.3. Fine pattern of GaAs formed by *in situ* EB lithography.

3. SELECTIVE AREA GROWTH

A selectrive-area growth of GaAs by MOMBE using a SiO_2 film as a mask has been known.[14] If the selective growth is achieved by using a GaAs oxide as a mask, this also will be included as an additive basic process in *in situ* EB lithography. A mass-spectrometric analysis of thermal decomposition of trimethiygallium (TMG) using a cryoshrouded quadruple mass spectrometer (QMS)[15] revealed that TMG does not decompose the GaAs oxide on the condition that TMG decomposes on the bare GaAs surfaces.[12] Then, the selective-area growth of GaAs was made by an alternate supply of TMG and As_4 on a GaAs(100) surface patterned by *in situ* EB lithography. An example of the microphotograph of the wafer thus processed is shown in Fig.4. The rectangular area corresponds to the window of the GaAs oxide layer for selective area growth.

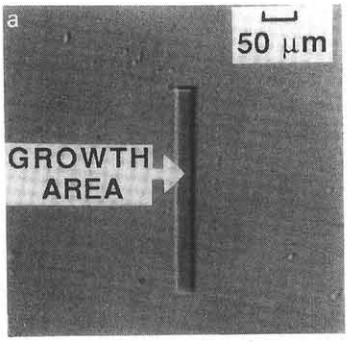

Fig.4. Microphotograph of selective-area grown GaAs.

4. THROUGH UHV PROCESSING

Integrating the *in situ* EB lithography and the selective-are growth, a totally UHV-processing of III-V semiconductors as illustrated in Fig.5 is being developed. As the key issue in this processing is the EB-induced local removal of the GaAs oxide layer with the thickness of several monolayers (~ 1 nm), this method will be a potential candidate to fabricate hetero-structures in the nanometer scale.

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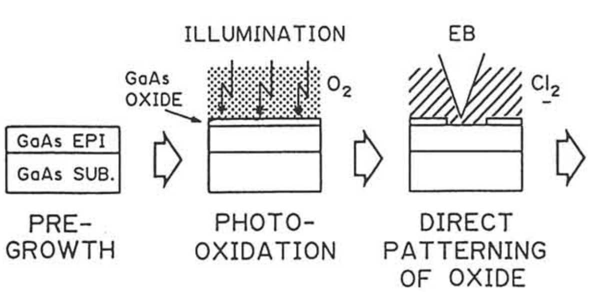

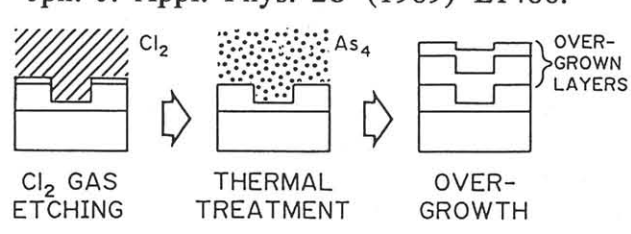

Fig.5. Schematic illustration of *in situ* EB lithography and selective-area growth of GaAs.

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