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NANOSTRUCTURAL FORMATION OF SELF-ASSEMBLED MONOLAYER FILMS ON CLEAVED AlGaAs/GaAs HETEROJUCTIONS

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Abstract We have demonstrated that nanostructures of self-assembled monolayer (NSAM) films of alkanethiols can be formed on the GaAs surface of a AlGaAs/GaAsheterojunctions by cleaving the substrates in an octadecylthiol solution diluted with ethanol. NSAMs with line width as narrow as 5 nm were observed by phase imaging using tapping mode cross-sectional atomic force microscopy (TMXAFM). Time dependent observation of the surface in air revealed that the nanostructual formation occurred as a results of both selective chemisorption of alkanethiol on GaAs surfaces and the oxidation of AlGaAs surface.

INTRODUCTION

The formation of the nanostructures with complex molecular architectures and interconnections is of great interest for molecular device applications. Molecular self-assembly is one strategy for generating stable structures on the nanometer scale.[1-5] It is also important to control the lateral size of the self-assembled monolayer (SAM) film with a sub nm scale precision from the view point of evaluating reduced dimensional or isolated molecular properties. One way to satisfy above requirement is to utilize molecular selective chemisorption on precise prepatterned substrates. Previously, we have demonstrated nanostructures of self-assembled monolayer (NSAM) films of octadecylthiol as narrow as 10 nm on a cleaved $Al_{0.3}Ga_{0.7}As$/GaAs heterostructure surface using selective chemisorption of thiol groups onto the GaAs, in which AlGaAs/GaAs layered structure plays a role as a template.[6] In this paper, we investigate the limit of NSAM on the AlGaAs/GaAs heterostructure which extends to sub 10 nm scale patterning. Since the dimensions are approaching the possible material limits, difference on surface chemical properties with phase imaging[7] as well as its topographic imaging were also imaged with tapping mode

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cross-sectional atomic force microscopy (TMXAFM).

EXPERIMENTAL

The epitaxial structure $Al_{0.35}Ga_{0.65}As$/GaAs with layer thickness ranging from 5 to 500 nm were grown by molecular beam epitaxy (MBE) on a 3-in. diameter semi-insulating GaAs substrate followed by a 500 nm-thick GaAs buffer layer, as shown in Fig. 1. The aluminum mole fraction and the growth rate of each layer were determined by performing X-ray diffraction (XRD) analysis on both GaAs and AlGaAs single layers prior to the heterostructure growth. NSAM was formed by cleaving the sample in an ethanol solution of 1.1 mM octadecylthiol [ODT, $CH_3(CH_2)_{17}SH$] and preserving this condition in a nitrogen purged flask for 17 h. The solution was initially deaerated by bubbling with dry nitrogen for 1 h. After taking out the sample from the solution, the sample was rinsed with pure ethanol, and then dried under a stream of nitrogen. XAFM was performed with a silicon cantilever tip in tapping mode. The phase lag of the cantilever was also imaged during scanning to detect variations in surface chemical properties.

RESULTS AND DISCUSSION

Figure 2(a) shows topographic and phase images taken simultaneously near GaAs buffer layer. Two regions of different height can be observed on the topographic image. Lines widths larger than 10 nm can be clearly resolved, while lines of 5 nm width cannot be resolved. The height difference between bright and dark region is about 0.5 nm; however, a height difference of 0.75 nm is observed in the buffer layered GaAs substrate layer. In the phase image, however, seven GaAs layers of 5 nm width on the right side of the buffer layer can be identified as shown in the magnified image of Fig. 2(b) and its cross sectional linecut. When this sample is exposed to air for about 10 h, the surface drastically changed

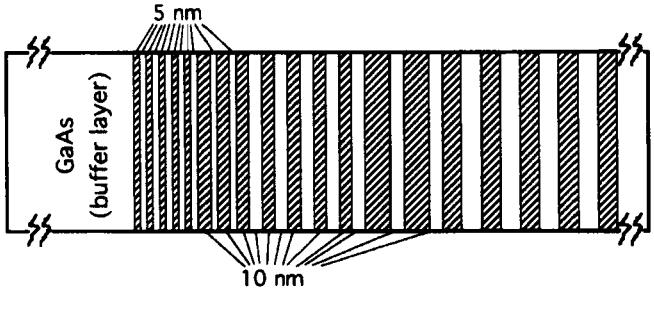

FIGURE 1 Schematic structure of $Al_{0.35}Ga_{0.65}As$/GaAs epitaxial layers near GaAs buffer layer. Regions with dashed lines denote $Al_{0.35}Ga_{0.65}As$ layers.

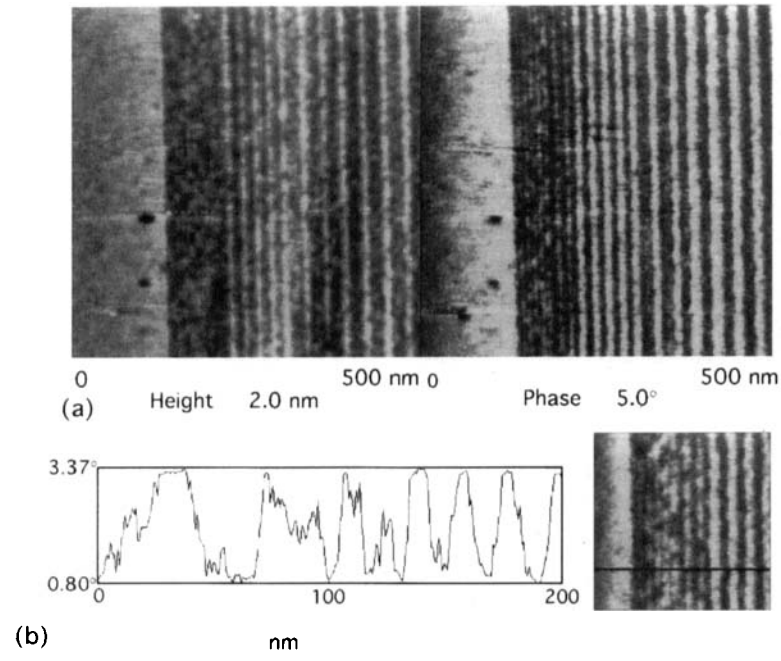

FIGURE 2 (a) XAFM and phase image of $Al_{0.35}Ga_{0.65}As$/GaAs heterostructure just after 17 h immersion in the ODT solution. (b) Phase image near GaAs buffer layer along with cross-sectional profile showing that line width of 5 nm can be resolved.

as shown in Fig. 3. In the topographic image, the AlGaAs/GaAs growth pattern can become clearly resolved and AlGaAs regions are approximately 0.5 nm higher than those of GaAs , while in the phase image AlGaAs and GaAs regions exhibit smaller difference in phase response. From above results, ODT molecules selectively chemisorbed on the GaAs regions and NSAM formed. After the sample was exposed to air for about 10 h, the ODT molecules desorbed from the GaAs surface due to surface oxidation. The height difference in Fig. 3 may derive from degree of surface oxidation between them.[8] There are some possible reasons for difficulty in detection of NSAM with 5 nm width in topographic image of Fig. 2. As the line widths become smaller, the ODT monolayer height becomes shorter, because the band edge effect of the NSAM cannot be neglected at this scale. Altenatively, partial oxidation on the GaAs regions also may disturb the imaging. This oxidation may decrease the monolayer height, and is most likely due to small amounts of impurities in the solution during the sample immersion. However, both precise control of sample preparation (*i.e.*, solvent, concentration of the solution, immersion time) and fabrication of finer heterostructure may improve this limitation, since materials limit of AlGaAs/GaAs heterostructure is a lattice spacing of ~0.6 nm on (110) surface orientation and in principle such NSAM formation is based on chemical reaction of thiol groups with GaAs atoms.

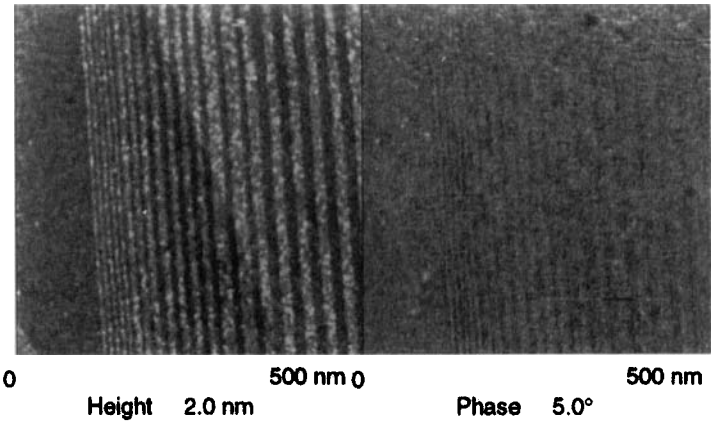

FIGURE 3 XAFM and phase response image of $Al_{0.35}Ga_{0.65}As$/GaAs heterostructure exposed in air for 10 h after taken out from the ODT solution.

CONCLUSIONS

The limit of NSAM formation of ODT on the cleaved $Al_{0.35}Ga_{0.65}As$/GaAs heterostructure has been investigated by using TMXAFM. Bands of SAM as narrow as 5 nm could be observed with phase mode imaging, while the same regions could not be resolved by topographic mode imaging. This result indicates that the observation limit of NSAM with AFM is around 5 nm to 10 nm, and that the combination of alkanethiol SAM on cleaved GaAs with use of AlGaAs/GaAs heterostructure is useful for forming NSAM.

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