Deep fin-like AlGaAs nanostructure fabrications by CAIBE

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Abstract

We show that very narrow fin-like periodic nanostructure with 0.1μm width, 1μm depth, and a few microns length can be fabricated on AlGaAs using Chemically-Assited-Ion-Beam-Etching with oxidized AlGaAs as negative mask. This technique may have applications to nanoscale devices fabrication.

Keywords: Nanostructure, Fin-like,

With the advent of nanofabrication techniques[1], device structures with dimensions below 0.1μm are of interest[2,3]. Various methods have developed to reduce linewidths [1,4,5,6-10] , and to obtain high aspect ratios of the height to gap width [11]. It is in general difficult to fabricate nanostructures that are both thin and deep. During our attempt to fabricate AlGaAs gratings, we found a method to realize long period nanostructures on AlGaAs with a narrow width of 0.1μm and a depth exceeding 1μm. It turns out that in addition to have high resolution, the method we found allows us to form negative Aluminum oxide mask on AlGaAs. Negative mask is advantages in situation where if positive mask were to be used the pattern requires a large area of PMMA to be exposed by electron beam. In such situation, electron beam scattering can become a serious problems, which often destroy high resolution patterning written on PMMA. In that case, negative mask

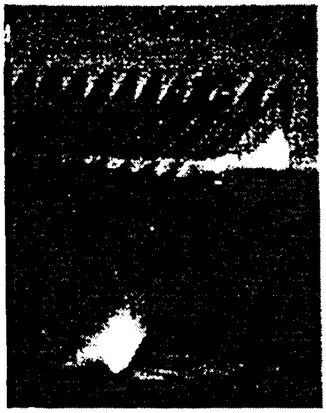

Fig. 1 Scanning electron microscope (SEM) image of the structure fabricated.

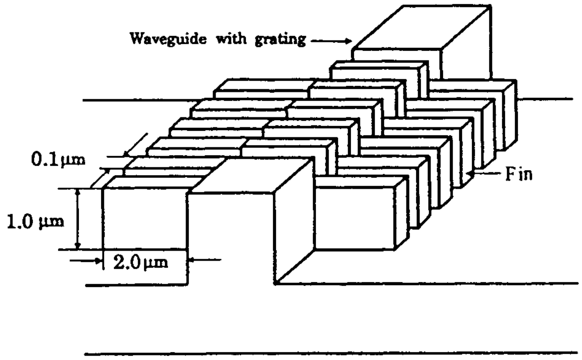

Fig. 2 The schematic of the structure.

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which have the complementary pattern, would only need a small area of PMMA to be exposed by electron beam and would help to remain the high-resolution features.

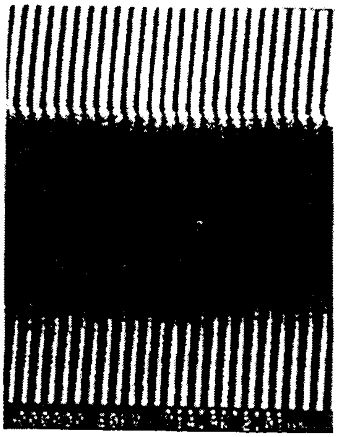


Fig. 3 Scanning electron microscope(SEM) image of the top view shown in Fig. 1.

The structure fabricated is shown by the scanning electron microscope photo in Fig.1, which corresponds to the schematic shown in Fig. 2. Fig.3 shows the top view of Fig.1. From the figures we see that a long and narrow fin-like structure has been fabricated on two side of a center ridge, which was intended to be an optical waveguide. The fabrication procedure is as follow. First a 3 μm thick $Al_{0.6}Ga_{0.4}As$ layer is grown on GaAs substrate. This layer will be referred to as the cladding layer. A 1.5μm thick $Al_{0.23}Ga_{0.67}$ As layer is then grown on top of the cladding layer and will be eferred as the waveguide layer. A 0.3 μm deep periodic grating structure having a period 250 nm is fist fabricated on the waveguide layer using electron-beam lithography and Chemically-Assisted-Ion-Beam-Etching. This is done via the following procedure. Fist, the AlGaAs wafer was coated with 1500 Å thick polymethacrylat (PMMA) photoresist and then baked for 1h. at 170 ℃. A 0.8 mm long grating pattern was then exposed using the JEOL JBX 5DIIU electron beam lithography system. The exposure condition were 300 Pico-Ampre current at 50-KeV accelerator potential, 80 × 80μm field, and 11mm working distance. The equivalent exposure dosage for the 250 nm grating was 3.3 nano-coulomb/cm. This expose condition was chosen to give the grating dusty cycle of approximately 125 nm line and 125 nm space. The PMMA was then developed in a 1:3 solution of methylisobutylketone and isopropyl alcohol for 40 seconds. The resist image was transferred to the AlGaAs wafer by CAIBE using chlorine gas in conjunction with a 500 V, $0.1 A/cm^2$ argon-ion beam resulting in the pattern shown in Fig.4a. The PMMA was then striped using a three step

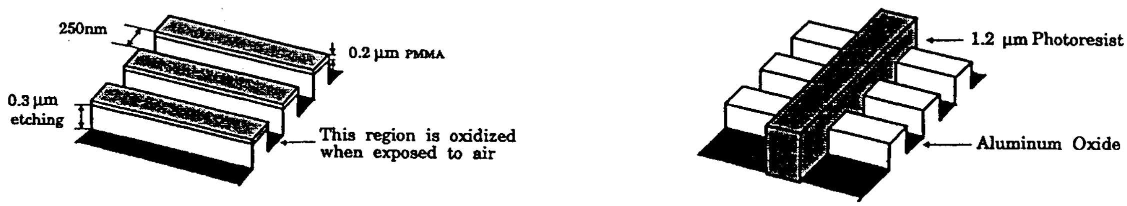
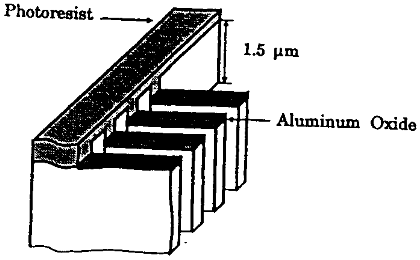


Fig. 4 (a) PMMA resist and CAIBE. (b) Long strip of waveguide pattern.



© After CAIBE showing the fin-like structure.

rinse of methylane chloride, acetone, and isopropyl alcohol, respectively. The grating depth was measured to be about 0.3 µm. After this 0.3 µm deep grating fabrication, the wafer is coated with 1.2 µm thick photoresist. Long waveguide resist pattern with widths(w) of 2,4,6, µm was then formed perpendicular to the grating as shown in Fig. 4b. The wafer is subsequently etch down further using CAIBE for a depth of 1.5 µm (see Fig.4c). The CAIBE was achieved with the same etching condition as before. After the etching, we found that a fin-like structure appeared on two sides of the waveguide pattern. The formation of this fin-like pattern was unexpected as the PMMA mask has been totally removed. We think that after the sample was taken out from the chamber of CAIBE machine, a thin layer of aluminum oxide was probably formed on the unmasked region of the wafer due to exposure to air while the sample was still warm(50-80 ℃). Thus, the fin-like structure appeared because the aluminum oxide layer formed acts as a hard mask for the CAIBE. Note that the aluminum oxide forms a grating-like mask pattern that is the " negative " of the original PMMA grating pattern. This is clearly shown in Fig.3, where the 0.3 µm deep grating pattern at the center waveguide region is inverse of the 1.5µm deep fin-like grating pattern formed along the two side of the waveguide.

To confirm that aluminum oxide is likely to be the material that formed the mask responsible for the formation of the deep fin-like structure, we repeated the experiment with an additional step to remove the presumed aluminum oxide layer. Specifically, the wafer was etched with a 10%HF for 1 minute before photoresist waveguide patterning. The wafer was then patterned with waveguide pattern using photoresist and subjected to CAIBE. The result for this case is shown in Fig,5, from which we can see that no fin-like structure was formed. This indicates that the hard material that formed the negative grating mask has been removed by the 10%HF and is likely to be aluminium oxide. This process can be useful for masking hard negative mask in electron beam lithography with a resolution of better than 0.1µm.

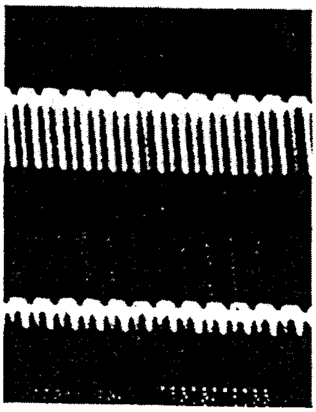


Fig.5 After CAIBE (10%HF was used to remove the aluminum oxide layer before photoresist waveguide patterning.) showning no fin-like structure formed.

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