Scanning Probe Lithography on InAs Substrate

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ABSTRACT

In this study, we focus our interest on patterning a conventional electron beam resist by electron field emission exposure using Atomic Force Microscope (AFM). We have fabricated 50-140 nm deep structures in InAs with the resolution less than 100 nm through 20 nm thick PMMA resist that was exposed. According to our knowledge, electron field emission exposure of resist has already been performed on gold, silicon but never on InAs substrate.

Compared with other semiconductors, InAs has the Fermi level pinned in the conduction band leading to the superior electric property even for nanometer scale structures. Using electron field emission exposure technique, structures deeper than 100 nm can be performed that is enough to release suspended free structures after chemical etching, being ideal for nanowire and NanoElectroMechanical Systems (NEMS).

In the following, we will describe the experimental set-up and results of fabrication.

Keywords: nanolithography, atomic force microscope, scanning probe lithography, nanowire, InAs.

1 INTRODUCTION

AFM is nowadays a versatile tool for nanotechnology and has been used to perform many processes like nanomachining [1-2], electron field emission exposure [3], field evaporation [4], anodic oxidation [5], thermomechanical writing [6], polymer crazing [7] and electrostatic nanolithography [8].

In this study we focus our interest on the electron field emission exposure process also called Scanning Probe Lithography (SPL). SPL has many advantages for nanolithography with respect to the closest competitive technologies: Electron Beam Lithography and Scanning Tunneling Lithography that use an electron beam apparatus or a scanning tunneling microscope respectively. SPL can be performed in air and the feedback control of the gap between the tip and the exposed surface is decoupled from the exposure mechanism allowing exposure on insulating and conductive substrate. Compared with other semiconductor systems, InAs is an attractive material for nanotechnology, because the Fermi level is pinned in the conduction band leading to the superior electric property even for nanometer scale structures (about 15 nm [9]). That enables the fabrication of submicroscopic conductive structures with confined 2D electron gas in the near surface region [10-12].

2 EXPERIMENTAL SET-UP

Fig. 1 describes the set-up for our SPL experiment. The sample made of InAs substrate is coated by PMMA resist with a thickness of about 20 nm. Such thickness is obtained by dilution of PMMA in xylene that is a low vapor pressure solvent. During spin coating, such solvent has a slow evaporation rate resulting in very thin resist thickness [13].

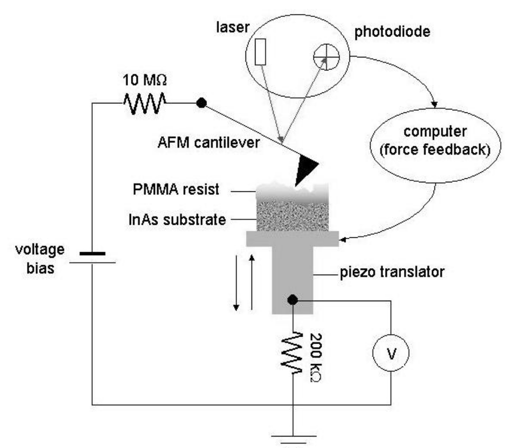

Figure 1: Schema of the scanning probe experiment.

A short length AFM cantilever, with a spring constant of about 40 N/m, was used in order to decrease the oscillations of the tip due to electrostatic forces between the resist and the cantilever. The tip of a radius of 20 nm was coated with a 30 nm titanium layer that has good mechanical and electrical properties. The tip is first approached to the surface of the resist. The force feedback of the AFM is set in order to maintain a repulsive contact force between the tip and the resist of about 1 nN. A DC voltage of about 20 Volts is then applied between the AFM tip and the backside of the substrate. High electrical resistance is added in the circuit in order to avoid electrical short cut if the tip falls inside a hole of the resist layer. The tip is negatively biased with respect to the substrate and a current of a few tenth of nano Ampere is measured. The metallic like behavior of InAs allows applying similar voltage as for gold surface [3].

For this voltage, PMMA resist behaves like a negative resist so that the exposed area corresponds to the final pattern after developing in acetone. The electrons are field emitted from the AFM tip and tunnel in air or a water meniscus before tunneling inside the resist. The energy from the electrons induces crosslinkings of the molecules in the exposed resist. After exposure, the patterns were transferred into the substrate by dry etching using a BCl_3 ECR-RIE system.

3 RESULTS OF FABRICATION

We have fabricated submicroscopic 50-140 nm deep structures in InAs through 20 nm thick PMMA resist using a commercial AFM. 3D structures like grating, square mound and wire were shaped (see Fig. 2 and 3).

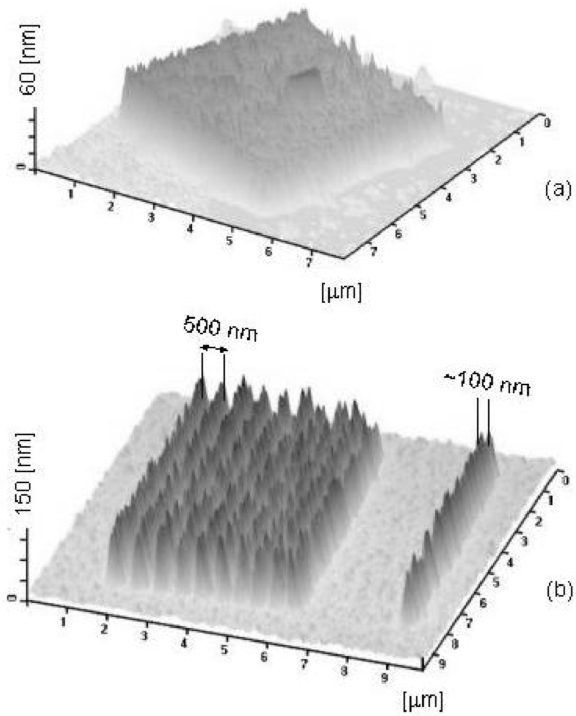

Figure 2: AFM topography of fabricated InAs structures: 5x5 μm^2 square mound (a) and 8 µm length grating (b).

The grating has a pitch of 500 nm and the width of the lines is about 100 nm that corresponds to the diameter of the AFM tip. The roughness observed on the structures in Fig. 2 may come from partial etching of the top of the structures where the very thin resist mask might have been completely etched away.

According to our knowledge, SPL has already been performed on gold [3], silicon [14] but never on InAs substrate. The conductive property of InAs provides a large advantage in future technological applications, especially for nanowires [15] and NEMS [10]. The advantage of SPL with respect to Electron Beam Lithography [11] is that patterning the wire can be done without alignment marks and precisely positioned with scanning prior to exposure.

Fig. 3 shows an AFM image of a fabricated wire between two Ti/Au pads and a close view taken by SEM of the center part of the wire.

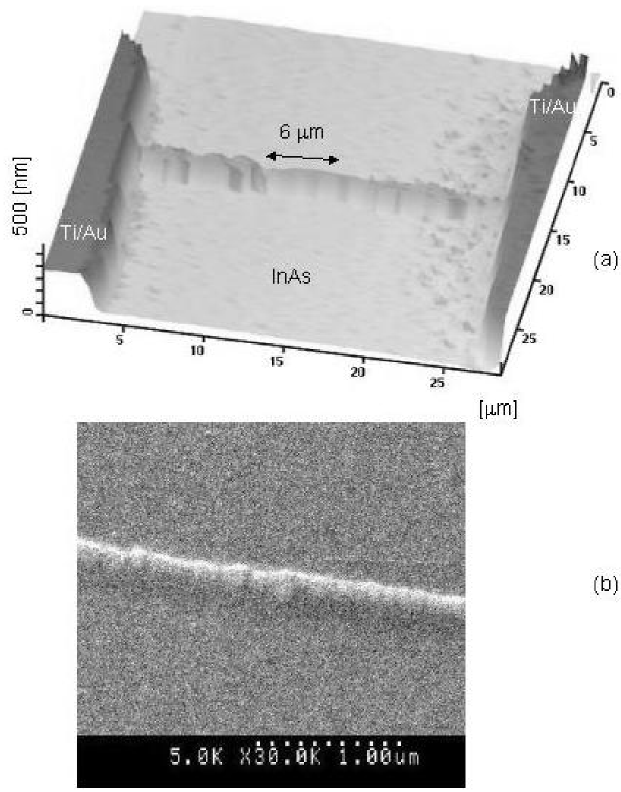

Figure 3: AFM topographic image of an InAs wire (a) and 40º tilted SEM view of the center part of the wire (b).

The Ti/Au pads were first fabricated and the resist mask was then prepared by SPL for patterning the wire. After developing in acetone, only the location of the wire is protected by the resist mask so that the pads and the unexposed area of InAs substrate are dry etched. We are currently working on obtaining good contact between the wire and the pads.

A cross section view of the center part of the wire shows that a minimum width of about 100 nm is obtained (Fig. 4). Due to the finite size of the tip, the foot of the wire seems to be larger than the actual size. Smaller width can be obtained if the applied voltage between the AFM tip and the substrate is decreased and a current feedback is used to control the variation of the field emission current with respect to the roughness of the exposed surface.

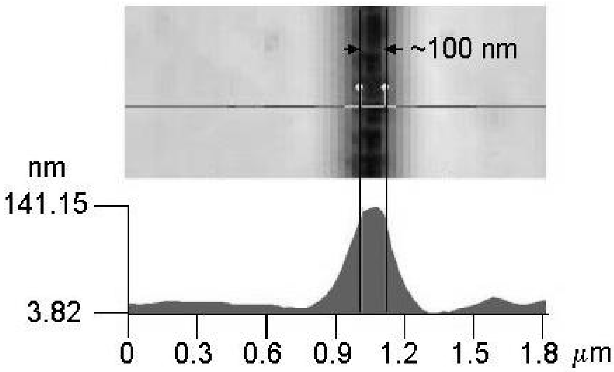

Figure 4: AFM Height profile of the center part of the wire.

AFM anodic oxidation was already performed to produce relatively shallow InAs-based structures [12]. 70 nm deep trenches in GaSb/InAs heterostructures were also obtained by mechanical cutting of 10 nm deep trenches with an AFM tip, followed by wet etching [2]. However, structures deeper than 100 nm can be performed using SPL that is enough to release suspended free structures after chemical etching, being ideal for nanowires and NEMS device fabrications.

4 CONCLUSIONS

In this study, the use of the Scanning Probe Lithography is reported on InAs substrate for the first time.

Submicroscopic 50-140 nm deep structures have been fabricated in InAs through 20 nm thick PMMA resist using a commercial AFM. 3D structures like grating, square mound and wire between Ti/Au pads were shaped. A wire width of less than 100 nm is achieved.

We are currently working on improving that structure to get a wire isolated from the substrate in order to study the electro-magnetic properties of InAs wires.

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