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Application of nanoscratching in electronic devices

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The lithography is a basic operation in the fabrication process of semiconductor devices. The scaling ability is the reason why the atomic force microscopy (AFM) nanolithograpy is currently studied in many laboratories. In the paper, the results of the mechanical AFM lithography, named nanoscribing or nanoscratching, are presented. In this method, the pattern is created by mechanical interaction between the AFM tip and a sample. This interaction requires the application of large forces in micronewtons scale.

Keywords: nanolithography, nanoscratching, AFM lithography.

1. Introduction

Atomic force microscopy (AFM) has been recently used in nanolitography. The resolution of this technique depends on the tip geometry and is much higher than in optical lithography. AFM lithography is based on the interaction between a sample and the tip. There are three methods making use of this technique. The first one is the local oxidation of the surface of silicon or metal [1]. In this approach, a bias voltage is applied to the tip. The second one is a dip-pen method in which the tip is used as a nanoscale pencil that deposits material on the sample surface [1]. These two methods use a chemical mechanism to create the pattern. The last one is nanoscribing where the pattern is formed due to the mechanical interaction between the tip and a sample [2]. This interaction is a result of a large force applied to the tip. This force is larger than the force used for the imaging of the surface topography, and its value depends on the type of the surface. This method allows to create the pattern in the resist, metal and semiconductor surface [3–6].

Progress in electronics determines the scaling process of devices. In that purpose, the AFM lithography is used to obtain properly small patterns. Standard lithography requires the application of two layers of resists and a mask with a pattern. In the experiment, the possibility of applying the AFM lithography to create a pattern in both resists, a metal layer and multilayer was investigated. The multilayered testing sample consisted of two layers of resists and a thin gold layer in which the pattern was scratched. Through windows opened in the gold layer, the resist could be irradiated in standard photolithography and removed in proper chemical treatment. After that step, the deposition of metallization and further removal of remained resists with Au layer lead to the achievement of metal stripes of reduced sizes, demanded in designing state-of-the-art devices.

2. Experiment

The AFM system used in the experiment was Veeco Multimode V. The scratching was made on the area of 5×5 μm^2 in the contact mode. The topographic imaging has been performed in the tapping mode, using the same tip. For nanoscratching, a standard silicon tip normally used in the tapping mode was applied. The nominal force constant of the cantilever was 40 N/m and tip radius was 10 nm [7]. In order to evaluate optimal parameters of the nanoscratching process, a series of four different substrates were used. This optimization included two parameters, force applied to the tip and scratching speed. Additionally, the effect of multiple scratching of one line was examined.

The force applied to the tip was calculated from the following equation:

$$F = -kz$$

where: k is the force constant and z is the tip velocity.

Because in the proposed method the nanoscratching process has to be used in combination with the optical lithography, resist coated samples were applied. During the experiments, two types of Shipley company resists were examined: LOL 2000 and SPR 700-1.2. Coating with the resist was made by a spin-on method. Suitable thickness of the resist was assured by applying proper speed of spining. In our case, the layers thicknesses were 250 nm for LOL 2000 and 1.2 μm for SPR 700-1.2.

3. Results

A preliminary investigation showed that scratching speed does not affect the pattern, thus the value of 5 μm/s was used in further examinations.

Firstly, samples covered by LOL 2000 and SPR 700-1.2 were examined. The values of force applied to the tip were 2, 4, 6 and 8 μN. Figures 1 and 2 present topographies and height profiles for investigated samples.

Optimization of the nanoscratching process for these two samples showed that SPR 700-1.2 resist is more resistant to the interaction with the tip. For the same force applied to the tip, the pattern formed in LOL 2000 is almost twice deeper than that in SPR resist. It means that the SPR resist is more mechanically resistant than the LOL resist.

The third substrate was coated with a gold layer to use it as a mask for optical lithography. This part of the experiment was prepared to determine the possibility of scratching the metallization. The major problem which appeared in this case was

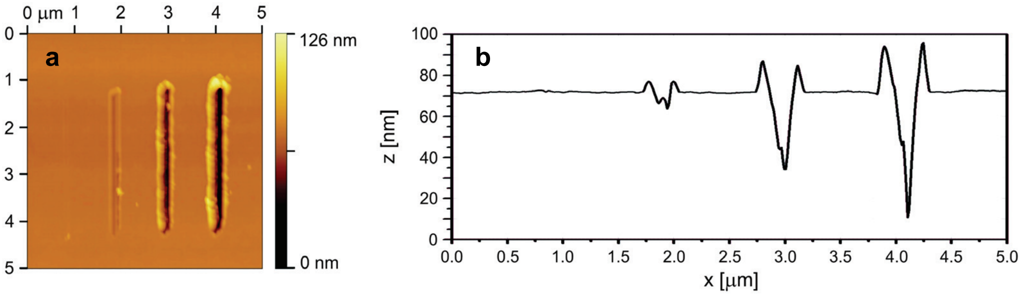

Fig. 1. Results of the nanoscratching process of LOL 2000 resist with the force applied to the tip: 2, 4, 6, 8 µN and scratching speed 5 µm/s: AFM topography of the sample (**a**), height profile (**b**).

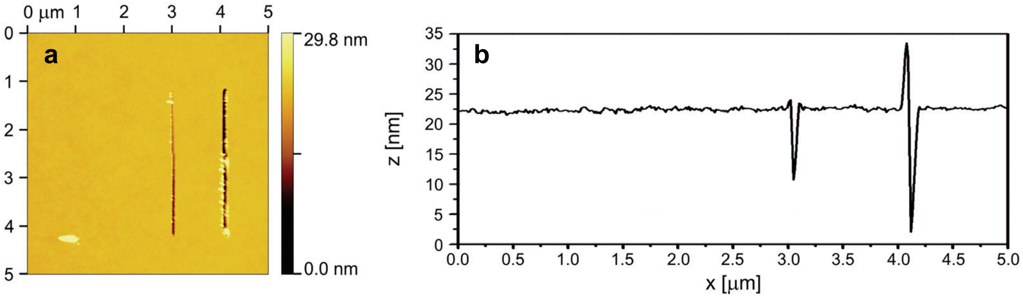

Fig. 2. Results of the nanoscratching process of SPR 700-1.2 resist with the force applied to the tip: 2, 4, 6, 8 µN and scratching speed 5 µm/s: AFM topography of the sample (**a**), height profile (**b**).

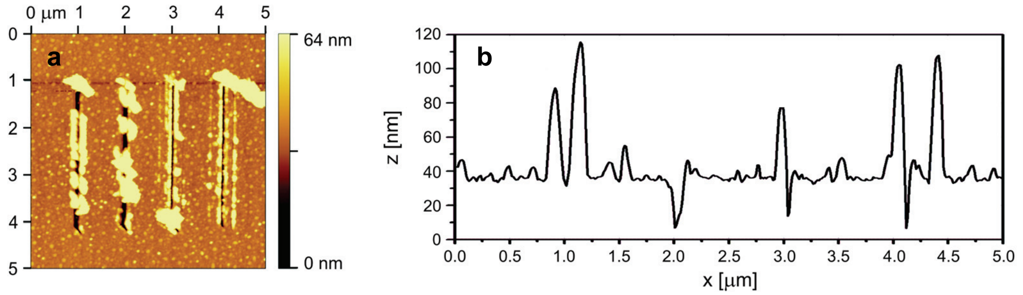

Fig. 3. Results of the nanoscratching process of the gold layer with the force applied to the tip: 8, 10, 12, 14 µN and scratching speed 5 µm/s: AFM topography of the sample (**a**), height profile (**b**).

the congregation of removed material close to the pattern which unabled to draw conclusions about the results (Fig. 3).

The other samples were prepared based on the observation of the process of gold scratching and resist scratching. The sample was coated with both kinds of resists and a thin gold film. The configuration of the layers was as follows: sapphire/GaN/LOL/SPR/gold.

For the multilayer samples, one of the crucial points in the investigation is to define the scratching speed. It was observed that in this case the scratching speed influenced the shape of the pattern. In performed experiment, this parameter has been altered within the range from 5 to 20 μm/s. Obtained results are presented in Figs. 4–6. It could be concluded that higher scratching speed is more appropriate for this application

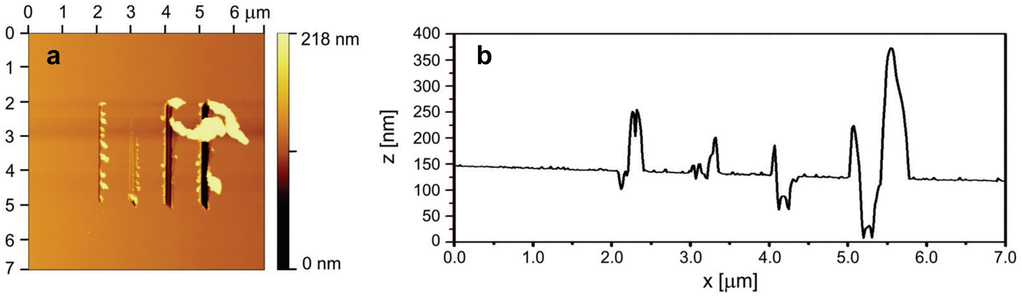

Fig. 4. Results of the nanoscratching process of the multilayer sample with the force applied to the tip: 4, 8, 12, 16 μN and scratching speed 5 μm/s: AFM topography of the sample (**a**), height profile (**b**).

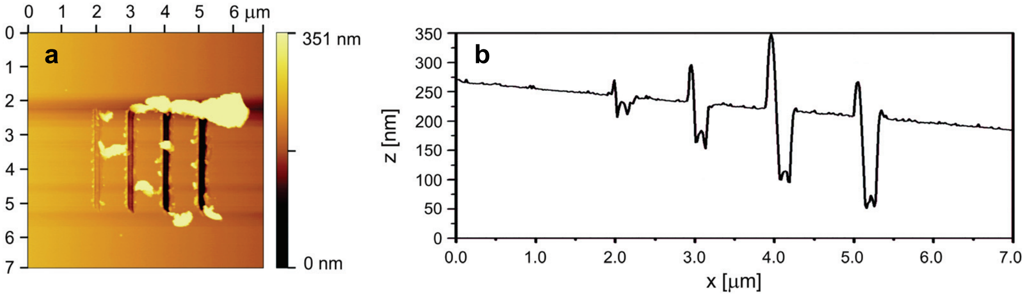

Fig. 5. Results of the nanoscratching process of the multilayer sample with the force applied to the tip: 4, 8, 12, 16 μN and scratching speed 10 μm/s: AFM topography of the sample (**a**), height profile (**b**).

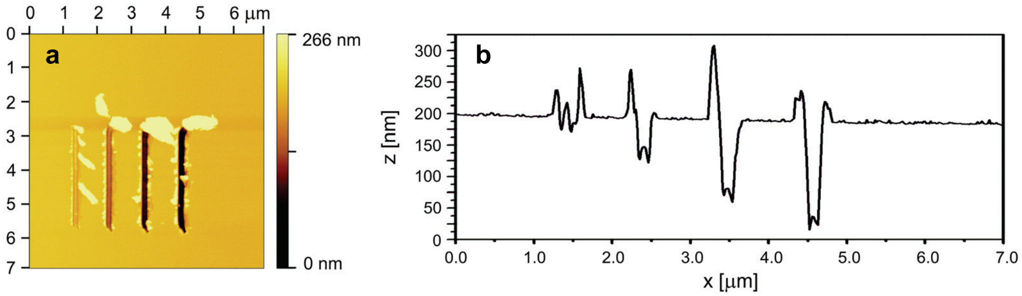

Fig. 6. Results of the nanoscratching process of the multilayer sample with the force applied to the tip: 4, 8, 12, 16 μN and scratching speed 20 μm/s: AFM topography of the sample (**a**), height profile (**b**).

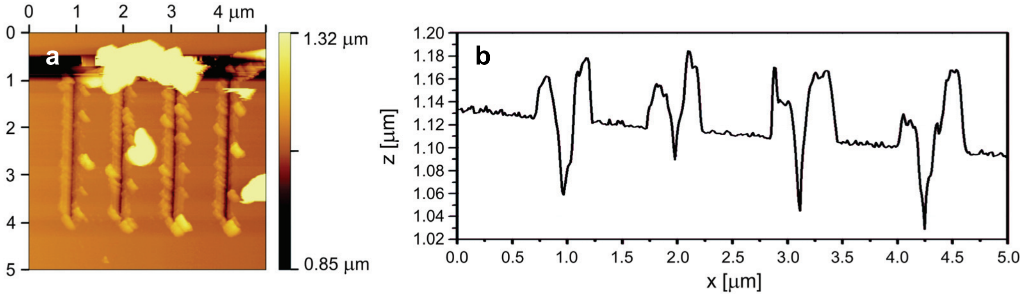

Fig. 7. Results of the nanoscratching process of the multilayer sample with the force applied to the tip: 8, 7.6, 7.2, 6.8 µN and scratching speed 2.5, 5, 10, 20 µm/s and three times scratching one line: AFM topography of the sample (**a**), height profile (**b**).

because material removed from the area of the pattern was congregated at the end of the scratching line. This effect is more remarkable in Fig. 7 which presents the AFM image of lines scratched three times with the same force applied to the tip.

For these samples, the most important was the application of high scratching speed and the force value as high as the force used for scratching of the gold layer. Optimal parameters for the multilayer system probably depend on hardness, thickness and sequence of layers. These parameters should be defined separately for each process.

4. Conclusions

The nanoscratching lithography is an attractive method which could be applied to modify the surface of different materials. It enables creation of the pattern on the semiconductor substrates coated with the resist or metal. It is critical to define proper process parameters for each material. Presented results have only a demonstrative character. The main goal of the experiments was to check the possibility of application the AFM tip to further reduction in the dimensions of the device.

Forces used during the modification of the surface of the sample showed divergences in the hardness of materials. Experimental results indicated that the LOL resist had lover hardness than the SPR resist. The hardness of a gold layer deposited directly on a substrate, compared to the gold layer deposited on the resist, had different values. Scratching speed for gold and the resist is not an important parameter. For the resist coated with a gold layer, the scratching speed should be high enough, as that used in the experiment.

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