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The Formation of a Height-Modulated Dielectric Film

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Abstract. The local anodic oxidation process allows creating a constantly-heighted local dielectric mask. In the course of mask formation the scanning probe moves over a particular surface area applying simultaneous constant bias voltage in each scanning point (these bias voltage impulses have the same value and duration). It is obvious that if we need to create a dielectric mask with a different oxide thickness or a height-modulated film, it is necessary to vary the impulse duration or its value at different scanning field areas. This investigation illustrates the possibility of creating a height-modulated oxide by applying the method of local anodic oxidation based on any greyscale modulated mask when the impulse duration and its magnitude is varied proportionally to the gray scale intensity.

1. Introduction

The investigation of local probe oxidation process of solid bulk materials and thin conducting films started a long time ago [1]. In contrast to the present-day projection-type photolithography where extreme ultraviolet is currently used for structure formation, the probe nanolithography based on local anodic oxidation is much more cost-effective and available for research laboratories. This method can be efficiently used both for local modification of different hard materials' properties and for the study of various active and passive components in nanoelectronics. The theoretical underpinnings of the procedure are being constantly advanced [2].

Earlier, there were theoretical attempts to make the process of height modulated oxide film formation multifunctional [3].

In the present work it is shown the peculiarities of height modulated dielectric mask formation over solid state surfaces including wafers and thin metallic films with respect to present fabrication process limitations and intrinsic natural limitations of the oxidation in the tip to surface the chemistry.

2. Selection of optimal pressing force of the conductive cantilever to the surface

A lot of semiconducting materials and metal films consist of natural oxide with adsorption surface water [4]. Consequently, successful performance of electrical measurements requires determination of the minimal pressing force on the conductive cantilever to the researched surface, which provides a close contact with the sample [5]. Therewith, using conductive cantilever of good quality is also very important in nanolithography method. Investigating outline of a volt-ampere characteristic can clarify both the minimal pressing force on the conductive cantilever to the surface and reliability conductive coating of cantilever.

The pressing force of different conductive coatings of the cantilever to the surface was investigated on the high-alloy silicon wafer. Conductive coating thicknesses of the cantilever were: W_2C and TiO_{2-x} 5nm, Pt and Au-15nm. It should be noted that the hardness of selected materials decreases array: W_2C,

TiO$_{2-x}$, Pt, Au. Afterwards, tip of the cantilever landed to the surface and the pressing force was determined by the force- height spectroscopy in atomic force microscopy. Simultaneously with the detection the force- height spectroscopy the volt-ampere characteristics of the system "conductive coating of a cantilever to conductive sample" were measured for different the pressing force. The pressing force was calculated according to hardness of the lever that was given by the fabricator.

Figure 1 demonstrates volt-ampere characteristics using W$_2$C conductive coating cantilever with various pressing force to the high-alloy silicon surface.

For little pressing forces of a tip there are non linear volt-ampere characteristics (Figure 1, *a-c*) of the system "conductive coating of a cantilever - dielectric layer- high-alloy conductive silicon sample".
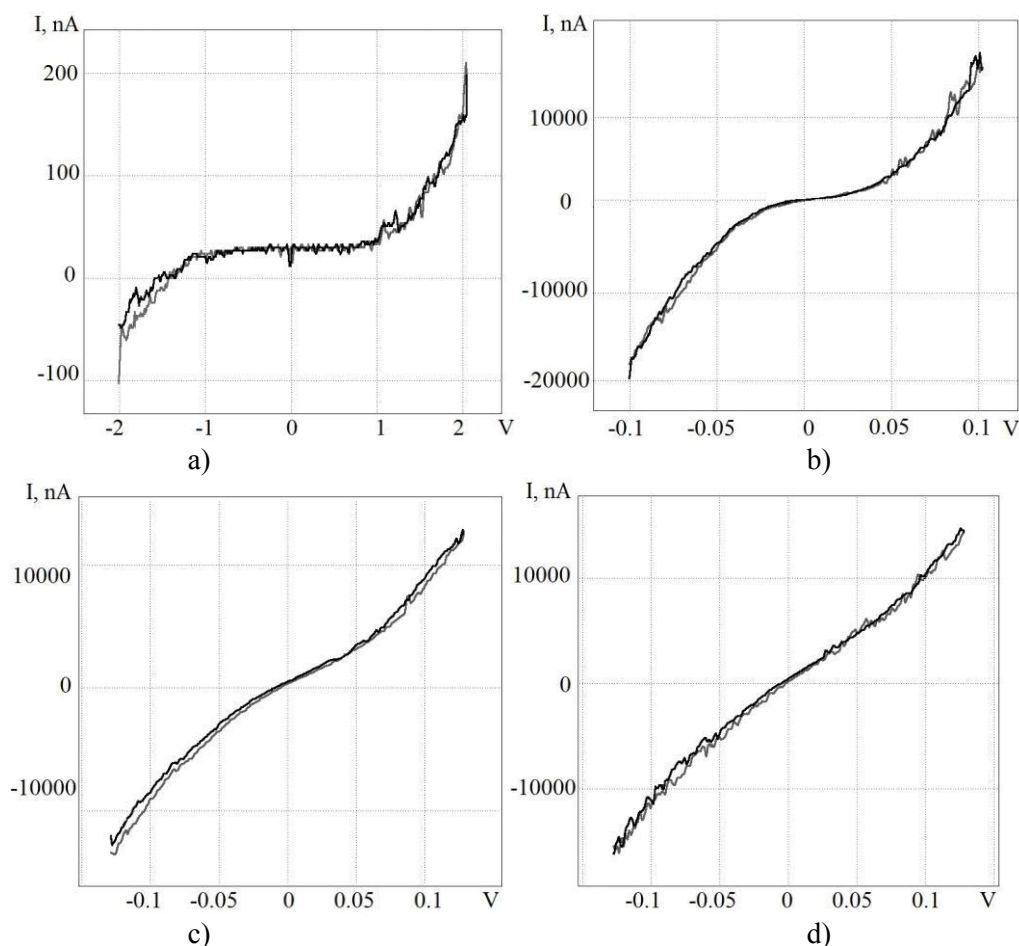
Figure 1. Volt-ampere characteristics of W$_2$C cantilever with various pressing force to the surface: a)- 80nN, b)-150 nN, c)- 200 nN, d)- 250nN.

In beforementiones case (a) the dielectric layer is a double-layer structure: the adsorbed layer of water –natural oxide of silicon, and electrical breakdown has begun under 1V. The strong ohmic contact is achieved under 250nN pressing force and more, when we see linear outline of a volt-ampere characteristic (Figure 1, d).

We were revealed that cantilever with TiO$_{2-x}$ coating has close ohmic contact under 280nN pressing force, with Pt coating − 350nN, with Au − 390nN. Minimum required pressing force depends on thickness of conductive coating (distinction in value of radius conductive tips) and hardness of material coating. Using sharp tips in strong ohmic contact the pressing force should be less.

Hence, for effective research the optimal pressing force of the conductive cantilever to the investigation surface should be found for specific cases depending on the material being used and conductive cantilever.

3. The process of height modulated oxide film

Formerly, there were attempts to create the constantly-heighted local dielectric mask with a different oxide thickness [6]. For instance, a mask of this sort could be used while developing highly-alloyed areas with complex doping profiles in semiconductor technology by the ion-implantation method as well as in nanoelectronic devices production, etc.

This nanolithography method is based on the following assumptions.

The local anodic oxidation process allows creating a constantly-heighted local dielectric mask. In the course of mask formation the scanning probe moves over a particular surface area applying simultaneous constant bias voltage in each scanning point (these bias voltage impulses have the same value and duration). Thus, it is obvious that if we need to create a dielectric mask with a different oxide thickness or a height-modulated film, it is necessary to vary the impulse duration or its value at different scanning field areas. It should be noted that this approach enables us to attain either step variations of the oxide height or a continuously changing oxide height. Essentially, the height modulation of the mask is determined by the function of impulse parameters in different scan areas. Nonetheless, such an easy approach is extremely effective in reproducible dielectric mask formation in accordance with the required modulation.

Specifically, the process of local dielectric height-modulated mask formation can be demonstrated experimentally by creating a nanometer size structure copy using a grey scale modulated mask of a digital photography.

a)   b)
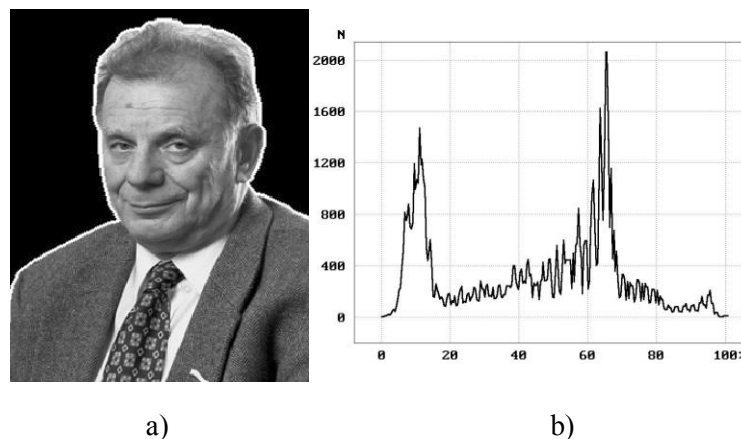
Figure 2. The digital photography of Alferov J I a) and the gray scale gradation in percentage values b).

The process consists of the following steps. Initially, the scan pattern of the mask is uploaded into the scanning probe microscope software and projected over a particular surface area. By a scan pattern we mean a three-dimensional array of pixels each characterized by two coordinates and the grey scale intensity values expressed as percentage. Further, the titanium film deposited over a silicon wafer is scanned at amplitude modulation mode in order to get a clean area of the thin film with no defects or dust. Then, via the use of a statistical analysis, the gray scale mask is converted to percentage values in the range of 0 – 100%.

As the mask we have chosen the digital photography of Nobel prize winner in physics professor Alferov J I as the idea based on which we were creating nanometer scale patterns on thin titanium film of 20nm thickness. Figure 2 demonstrates a digital photography of Alferov (a) and gray scale gradation in percentage values according to photo (b).

For height modulated oxide mask formation we used impulses of 1 millisecond with voltages between 6 to 10V according to the intensity of grey scale mask. There were used conductive cantilevers with W_2C coating [7].

a)   b)
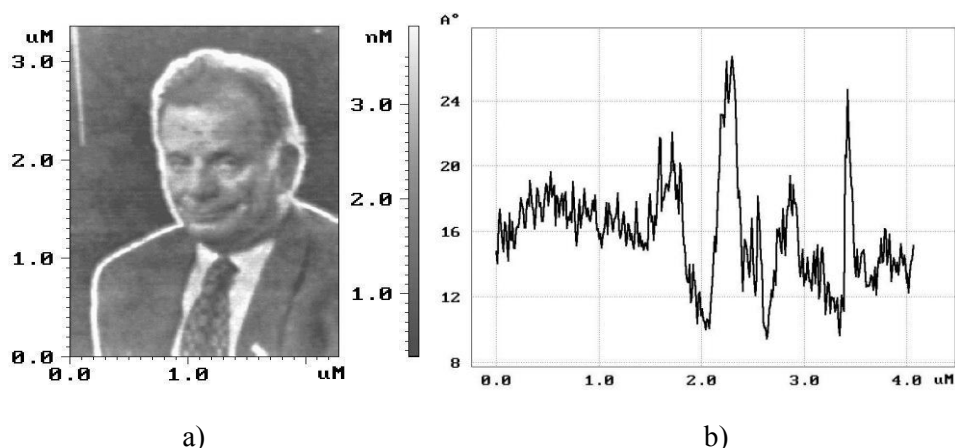
Figure 3. AFM image of the titanium film surface after local anodic oxidation process a), and cross – section profile over the image b).

After scanning second time over same area which were treated by local anodic oxidation method the we observed nanometer scale oxide thickness formed on the titanium film according to loaded mask (see Figure 3 a). Oxide thickness variations are 0-3nm (see Figure 3 b).

Thus such example demonstrating the ability of whatever height modulated oxide creation by local anodic oxidation process based on any grey scale modulated mask and variation of the impulse duration or its value proportionally to gray scale intensity.

4. Conclusion

In paper the formation of a height-modulated dielectric film is proposed. It is obvious that if we need to create a dielectric mask with a different oxide thickness or a height-modulated film, it is necessary to vary the impulse duration or its value at different scanning field areas.

The correlation of the required pressing force on the conductive cantilever to the surface, which provides a close contact with the test sample, with material hardness and the thickness of the cantilever conductive coating, has been revealed.

The statements regarding height modulated dielectric mask formation on the solid state surfaces demonstrate the wide ability of local anodic oxidation by atomic force microscope for creation of different nanolelectronic devices.

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