ION BEAM SYSTEM FOR NANOTRIMMING OF FUNCTIONAL MICROELECTRONICS LAYERS

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This paper concerns with investigation of the trimming process which uses ion beam etching for high-precision adjustment of the thickness of functional microelectronics layers. The layer deposited on the substrate is etched by scanning focused ion beam; its position and power is regulated according to the topography of layer non-uniformity. The trimming allows to create pre-defined topography of the non-uniformity with accuracy down to 4 Å and decrease the roughness of the surface.

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1. INTRODUCTION

Ion beams are widely used in both fundamental scientific studies and in various technological applications including fusion, high-energy particle accelerators, ion propulsions, ion-beam microprobes, ion-beam lithography, implantation, etching, surface polishing, thin film deposition [1,2], vacuum welding, etc.

This work describes the trimming process based on ion beam etching for adjustment of the thickness of microelectronics and optics functional layers with high precision on the large diameter wafers. This system may find a variety of its applications, where the initially non-uniform layer requires the correction of the thickness: gradient layers, polishing of the surface and coatings on high-grade optics, memory microelectronic devices, the adjustment of the electrical resistivity of resistive and infrared layers.

Particular focus of interest for the trimming is the manufacturing of the thin film bulk acoustic resonators (FBAR). The layer thickness of FBAR defines the bandwidth, which is required to be as narrow as possible. This can be obtained in high volume production only if very uniform layer is available; however, this is not possible to obtain with the help of a conventional deposition process.

2. EXPERIMENTAL TECHNIQUES AND RESULTS

The experiments were performed using the ion beam trimming installation for high-precision adjustment of the thickness of functional microelectronics layers which utilizes the wafers with a diameter of 100…200 mm (Fig. 1). The system is mounted inside the vacuum camera (1), which provides the residual pressure of 10^{-7} Torr (working pressure is 10^{-5} Torr) with the use of turbomolecular pump. The ion-beam system consists of ion source generating the ion beams of the keV range (2), coordinate system for the positioning and scanning (3, 4). The coordinate system is controlled through the specialized software and allows precise local etching of the material.

Fig. 1 shows the scheme of the trimming device, where the positioning is implemented using 2-D polar coordinates. The implementation of the positioning system using Cartesian coordinate system is also possible.

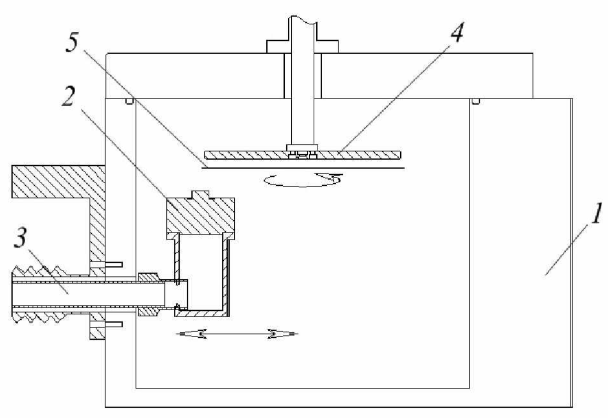

Fig. 1. The scheme of the ion-beam trimming system:
1 – vacuum chamber, 2 – ion beam source,
3 – coordinating system using polar coordinates,
4 – spinning wafer holder, 5 – processing wafer

The surface is treated with small-sized hall-type ion beam source (Fig. 2), which designed to provide the ballistic and magnetic focusing of the ion beam [3].

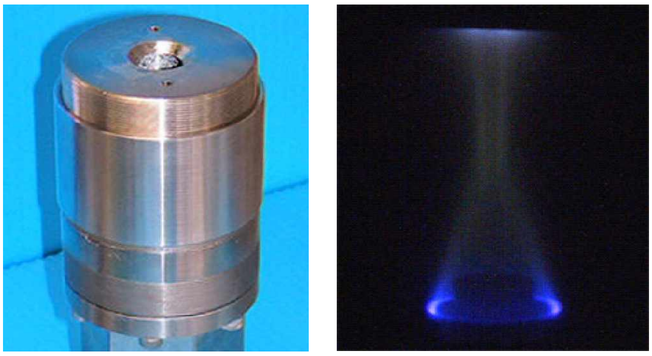

Fig. 2. The ion source used for trimming and the focused ion beam

It generates conical beam of Ar ions with energy of 300…1500 eV and current of 1…50 mA. The increase of the ion beam current density in comparison to cylindrical one is described by coefficient of the beam compression. For the ion source used for the trimming the compression coefficient is about 200.

The local etching rate of the functional layers is regulated by varying the power of the beam. The gas discharge power in hall-type ion source with anode layer can be easily regulated by varying the voltage applied to the anode. Therefore, the software controls the positioning mechanism and the voltage of the discharge.

The profile of the ion beam intensity was measured by etching the SiO layers. These layers are of different colors for different layer thicknesses. Fig. 3 shows typical color pattern of SiO layer after etching by the focused ion beam. One can see that the beam intensity is well concentrated within the diameter of 5 mm.

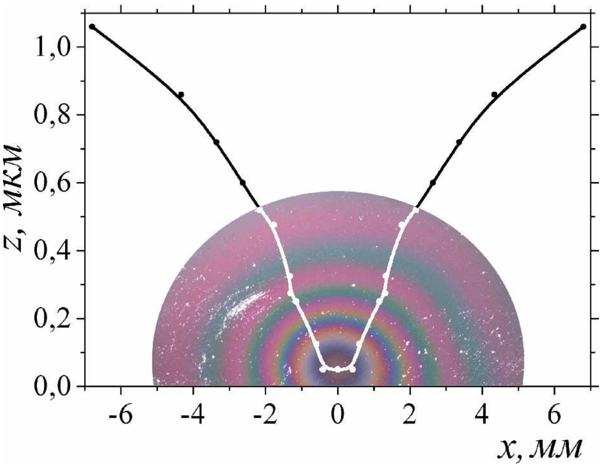

Fig. 3. The surface etching profile obtained by sputtering of the SiO layer with Ar ion beam (beam current is of 40 mA and average ion energy is 1000 eV)

The etching rates for the most used materials are shown in the table (the etching Ar beam with ion current of 40 mA and average ion energy of 1000 eV):

Material	Rate (Å/min)
Al	6125
AlN	1995
SiO2	4400…5200
Al2O3	1365…3000
Si	3500
Si3N4	3000

This ion source also equipped with charge neutralizer, which utilizes the discharge instead of hot filament. The discharge is non-self-sustained one and it is magnetron type using hollow-cathode effect. Its application allows effective charge neutralization of the ion beam, which extends the application of the device to processing of the dielectric materials.

The investigation of surface polishing by trimming has been performed using the Si wafers with a diameter of 150 mm with aluminum nitride layer. The layer thickness was 1…1.5 micrometers and it has been deposited by magnetron physical sputtering.

The process of the ion beam polishing consists of two stages. At first, the triradial interferometer measures the thickness of the layer at a number of points. The number of measurement points can be varied up to 1000, however, typical number of the points corresponds to number of chips manufactured on the wafer. The topography of the functional microelectronics layer is created by the software basing on the results of measurements. The topography map is used then to calculate the parameters of the topography correction: the position of the ion source and its discharge power. For example, Fig. 4 shows typical topography of the aluminum nitride layer deposited by magnetron sputtering. The parameters of the topography are: average layer thickness is 8265.4 Å; maximum thickness is 8341.7 Å; minimum thickness 8179.8 Å; the scattering of the layer thickness due to non-uniformity is 161.8 Å.

The topography of the layer would differ only slightly if the batch of Si wafers with aluminum nitride deposition have been produced in the same manufacturing process. Therefore, one can use average parameters of the topography for the trimming of the whole batch of the samples.

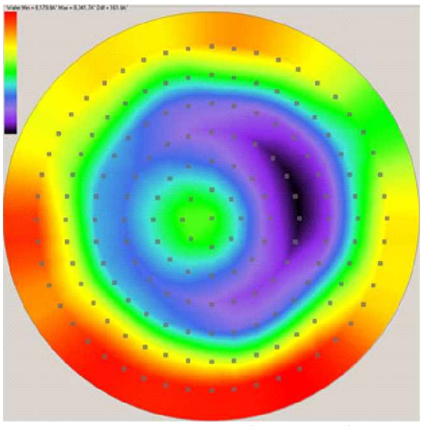

Fig. 4. Typical topography of non-uniformity of the aluminum nitride layer obtained by magnetron deposition. The gray dots show the points, where the layer thickness has been measured

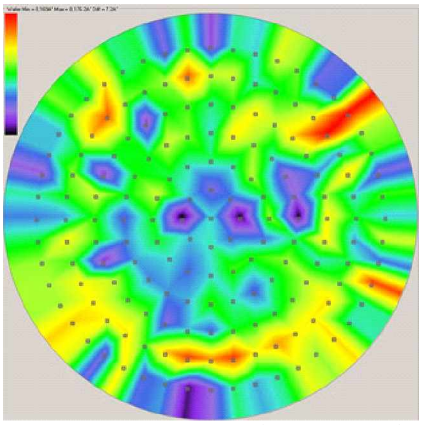

Fig.5. Typical topography of the non-uniformity measured for the layer of aluminum nitride after the single pass trimming with Ar ion beam

After measurement of the topography, the functional layer is etched by the trimming, i.e. it is exposed to the scanning ion beam. The position and the power of the ion beam is controlled by the software, which set the trimming parameters according to measured map of the layer topography. Following the trimming process, the topography of the layer is measured again in the same way. Fig. 5 shows typical topography of the layer non-uniformity, obtained after the single pass trimming process.

The parameters of the topography, obtained in this particular case, are: average layer thickness is 8172.3 Å; maximum thickness is 8176.2 Å; minimum thickness 8169.0 Å; the scattering of the layer thickness due to non-uniformity is 7.2 Å.

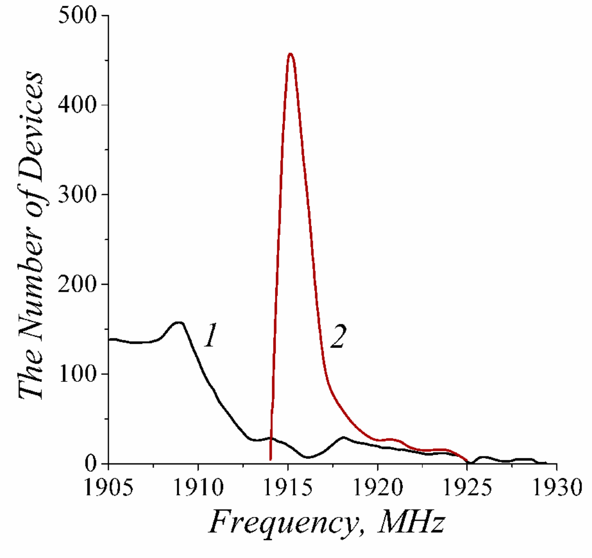

Fig. 6. Distribution of number of the FBAR chips obtained from the same wafer as a function of their working frequency: 1 – initial; 2 – after single trimming

Therefore, the non-uniformity of the aluminum-nitride layer has been strongly decreased down to sub-nanometer scale over the diameter of 150 mm.

The obtained layer can be used as FBAR, and the thickness value defines the acoustic frequency, generated by FBAR. Fig. 6 shows the distribution of the number of FBAR chips, obtained from the same wafer, as a function of their working frequency. One can see that chips obtained from the wafer, which has not been processed with the trimming, have wider spread of the working frequencies ranging from 1905 to 1930 MHz. In contrast, the working frequency of the chips obtained from the trimmed wafer is located mainly around the value of 1916 MHz.

Narrower distribution of the chip frequencies increases the chip yield per wafer, decreasing their prime cost and increasing, therefore, the overall economical efficiency of the chip manufacturing.

3. CONCLUSIONS

The trimming process which uses ion beam etching for high-precision adjustment of the thickness of functional microelectronics layers has been investigated. The layer deposited on the substrate has been processed by scanning focused ion beam; its position and power is regulated through the software correspondingly to the topography of layer non-uniformity. The trimming has allowed creation of pre-defined topography of the non-uniformity with accuracy down to 4 Å and decrease the roughness of the surface. It has been shown that the surface roughness can be decreased down to sub-nanometer scale.

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ИОННО-ЛУЧЕВАЯ СИСТЕМА НАНОРАЗМЕРНОЙ ПОЛИРОВКИ ФУНКЦИОНАЛЬНЫХ СЛОЕВ МИКРОЭЛЕКТРОНИКИ

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Исследован процесс корректирующего ионно-лучевого травления для регулировки с высокой точностью толщины функциональных слоев микроэлектроники. Функциональный слой на подложке травится сканирующим сфокусированным ионным пучком, локализация и мощность которого соответствуют топографии неоднородности толщины функционального слоя. Показана возможность регулировки распределения толщины пленок по поверхности подложек до +/-4 Å и уменьшения шероховатости поверхности.

ІОННО-ПРОМЕНЕВА СИСТЕМА НАНОРОЗМІРНОГО ПОЛІРУВАННЯ ФУНКЦІОНАЛЬНИХ ШАРІВ МІКРОЕЛЕКТРОНІКИ

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Досліджено процес коригувального іонно-променевого травлення для регулювання з високою точністю товщини функціональних шарів мікроелектроніки. Функціональний шар на підкладці витравлюється скануючим сфокусованим іонним пучком, локалізація та потужність якого відповідають топографії неоднорідності товщини функціонального шару. Показано можливість регулювання розподілу товщини плівок по поверхні підкладок до +/-4 Å та зменшення шорсткості поверхні.