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Formation of elements of integrated acousto-optic cell based on LiNbO₃ films by methods of nanotechnology

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Abstract. In the experiments we defined modes, and developed the technology of formation of elements of input-output laser emission and microlens of integrated acousto-optic cell by Pulsed Laser Deposition and Focused Ion Beams by using nanotechnology cluster complex, allowing controlled creation of elements in a single process cycle.

1. Introduction

Acousto-optical devices are widely used in all kinds of radio-astronomy observatories, including terrestrial, airborne and space-based ones, as well as in atmospheric monitoring systems in many countries. Acousto-optic modulators and deflectors are used to control the amplitude, frequency, phase, polarization, direction of propagation of light beams. One of the budding directions is the development and study of the technology of the formation of elements of integrated acousto-optic cells, which allows reducing the size of devices, power consumption, and increasing sensitivity to vibrations, reproducibility of the parameters and provides for cost-effective mass production [1]. One of the budding materials for the production of acousto-optic cells is LiNbO₃ [2, 3].

At present time, one of the most promising approaches to the production of micro-, nano-, opto- and acousto-electronic devices are those, which combine capabilities of analytical and technological methods in a single manufacturing process and controlled environment without venting. It excludes negative influence of the environment at all stages of production and research.



Besides, an important and urgent issue in the technology of manufacturing of structures for integral acousto-optics is the method of sublimated profiling of substrate surface. Traditional methods of the microelectronic technology, based on processes of optical lithography and liquid and plasma etching, have a number of basic limitations linked to complexity of achieving nanometer space resolution, the necessity of using photoresists, development of specialized masks and templates, and impossibility of forming complex profile structures in a single process cycle.

One of the promising methods to overcome the limitations of traditional production methods is the method of Focused Ion Beams (FIB). The method is based on the interaction of a beam of accelerated gallium ions, focused to ~ 10 nm in diameter, with a solid surface which results in local physical sputtering of the substrate with a resolution collated with the diameter of the beam. The possibility of controlling FIB parameters within a wide range, and using a 16 bit digital image generator allows forming micro- and nanoscale structures with high accuracy and resolution.

Cluster nanotechnological complex NANOFAB NFS-9 (NT-MDT, Russia) is one of the most budding systems as it combines several methods, including pulsed laser deposition (PLD), local nanoscale profiling by focused ion beam FIP, scanning probe microscopy (SPM), scanning electron and ion microscopy (SEM), diffraction of fast reflected electrons, and creates new opportunities for research, development of manufacturing technology, and the production of advanced micro- and nanoelectronics devices [4-7].

2. Formation of elements of integrated acousto-optic cell

During experimental part of the work, we carried research of rate of etching LiNbO_3 and Al_2O_3 by FIB. Also, during the experimental research on a substrate by ion-beam etching, we formed a rectangular shape array of recess with the size of each element of $2 \times 2 \mu\text{m}$ at a constant time of etching of 30 sec, the accelerating voltage of 30 keV, and values of FIB current in the range from 1 pA to 1 nA (Figure 1). The research of topology of the formed structures were carried out by methods of SEM and AFM.

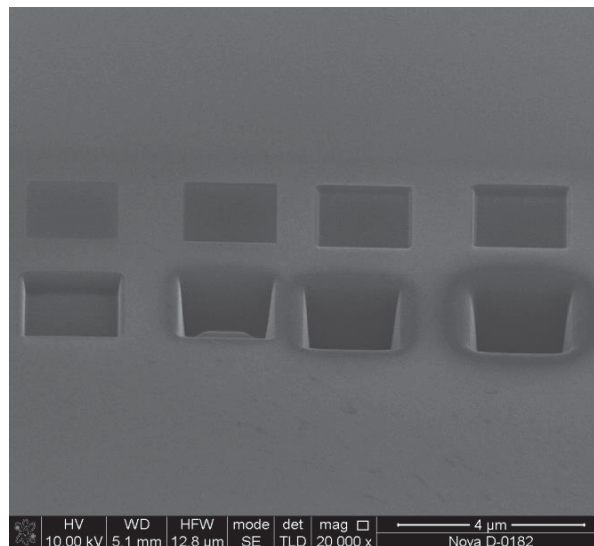


Figure 1. SEM image of an array of test structures on sapphire substrates for the investigation of the etching rate of materials by FIB

The speed of ion beam etching was calculated as the ratio of the volume of material removed per unit to etching time. During experiments it was found that in the range of FIB currents from 1 pA to 1 nA, the

speed of ion-beam etching was as follows: from 0.20 to up to 322 nm³/sec for Al₂O₃, and from 0.33 to 395 nm³/sec for LiNbO₃. Dependence of the speed of etching on the ion beam current are shown in Figure 2.

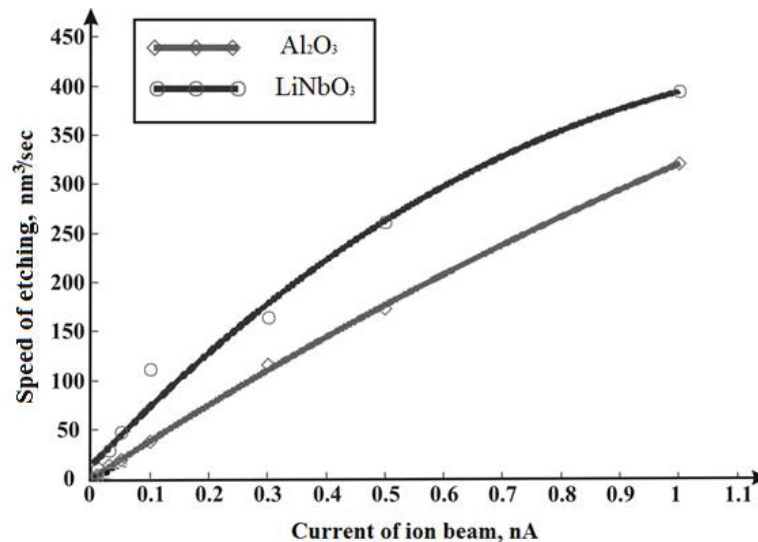


Figure 2. Relationship between the speed of the etching of Al₂O₃ и LiNbO₃ and the ion beam current

Analysis of the experimental curves shows that the speed of ion-beam etching increases linearly with the increase in ion beam current. It's due to the fact that with the increase in current, diameter of FIB increases due to the increase the number of ions, pulled out of the source per unit of time. With increase in diameter of FIB, the effective area of the ion beam interaction with the surface increases, hence the intensity of the substrate material spraying increases.

For forming LiNbO₃ films we used a Pulsed Laser Deposition module (Neocera Inc., USA) of complex NANOFAB, which provides for controlled deposition of films consisting of multicomponent oxides. The films were deposited on sapphire at the energy density of the laser emission of 2.5 J/cm², the laser wavelength of 248 nm (KrF), and substrate temperature of 600°C. In order to control the in-situ width and the structure of LiNbO₃ under formation, RHEED system kSA 400 (STAIB Instruments, Germany), as part of PLD, was used. Film thickness - 400 nm.

After the formation of LiNbO₃ films, the samples were passed through a vacuum transportation system to the modules of complex NANOFAB with Focused Ion Beams (Orsay Physics, France), which are used for local nanoscale operations, including local spraying, cutting, ion implantation, and local growth. Resolution of nano-profiling operations by means of ion beam is 10 nm. Etching was performed for each element at an accelerating voltage of 30 keV ion beam, the ion beam exposure time at each point of the pattern is 10 μsec. Control of geometrical parameters generated structures was performed by SEM with built-in image processing software, as well as by semicontact AFM module SPM.

Figure 3 shows the SEM images of obtained elements of input-output laser emission and microlens in integrated version formed on LiNbO₃ film.

To sum up, as a result of experimental studies we identified modes and developed the technology of formation of elements of acousto-optic cell using nanotechnology cluster complex, allowing controlled creation of elements in a single process cycle.

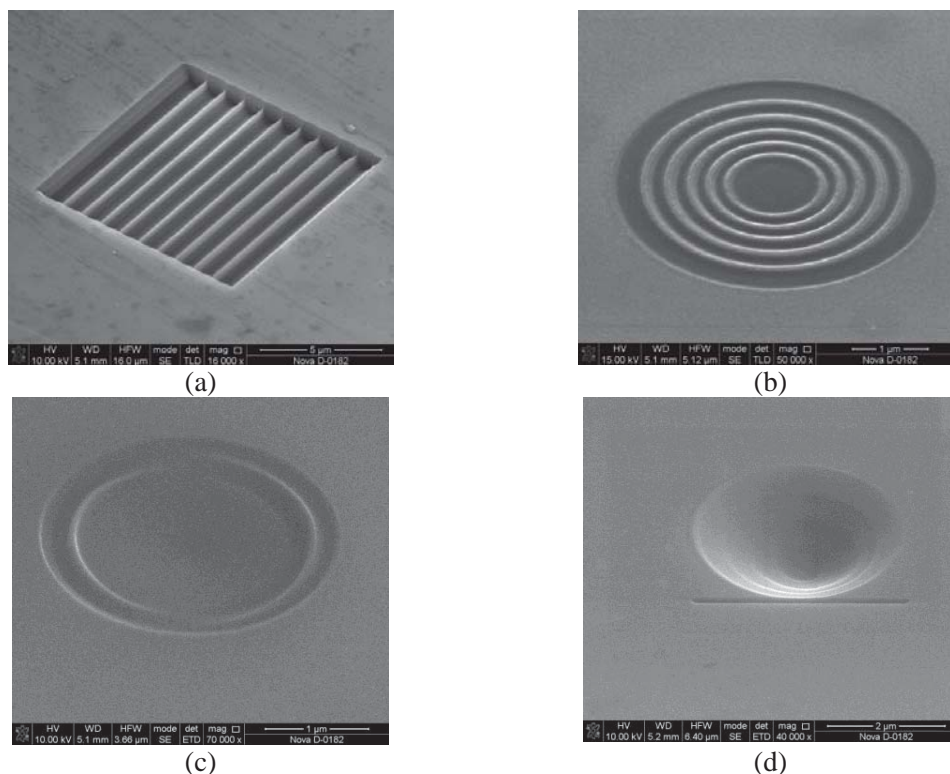


Figure 3. Element of input-output laser emission (a) and microlens (b)-(d) in integrated version.

3. Conclusion

The results were obtained by using the equipment of the Center for Collective Use "Nanotechnology" and the Research and Education Center, "Nanotechnologies" Southern Federal University.

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