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VECTOR PROTON BEAM WRITING SYSTEM

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Vector method for scanning with focused beam of megaelectronvolt-energy in proton-beam writing is described. Vector proton-beam writing method was proven experimentally to have numerous advantages over raster method. Focused beam size and shape are measured by scanning standard copper mesh for e-beam microscopy. Prospectives of hardware and software upgrade are regarded. Vector proton-beam writing technology can be used in many applications, including X-ray optics, electronics prototyping, microrobotics, microfluidics, photonics and microstructure fabrication in new materials.

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INTRODUCTION

Nuclear scanning microprobe channel on the analytical acceleration complex based on the compact accelerator “Sokil” at the Institute of Applied Physics, National Academy of Sciences of Ukraine (Sumy, Ukraine) is described in [1, 2]. The channel’s creation and application are given in [3 - 5]. This computer-controlled channel allows fabrication of almost any arbitrary 3D small-sized structures according to programmatically-set pattern. In recent years, the channel was upgraded with new beam-scanning system based on NI 7852R module, described at [6]. This made the channel’s control program improvement much simpler.

Proton beam, used for lithography, may have mirco- or nanometer sizes. Beam form depends on rectangular window of collimators and on focusing lenses configuration [7]. The form may be round, elliptic or a thin line. The scanning system controls the beam’s deflection according to the programmatically-set pattern. Deflection is set for *X* and *Y* axis. After the needed deflection is set, the system waits according to the “dwell” delay needed for the pixel exposition (apx. 0.1 second). The scanning area size is apx. 2×2 mm, but too large (more than 500 um) deflection from the zero point leads to loss of focus.

During further work the beam-scanning system control program was improved. Among all the improvements, the possibility of vector lithography was added in addition to the raster method used earlier.

Vector image formats are scaled much better even in conventional computer graphics. Raster file (bmp) comprises of separate pixels that become visible when scaled closer. Instead, vector picture (svg and other vector formats) comprises not of pixels but of image proportion descriptions (lines, circles, curves). Vector image form will be clear in any scale.

Pattern for the proton-beam writing setup in first versions of the control software could be set only in raster bmp file. This lead to necessity of manual calculations for the resulting microstructures scaling and “pixel” artifacts in them. These problems, similar to vector and raster image formats differences in computer graphics, proved the necessity of serious software improvement and transition to much better vector method of proton-beam writing.

1. VECTOR LITOGRAPHY COMPARING WITH RASTER METHOD

After software improvement, a few experiments with microstructure fabrication were carried out. An old microstructure made with raster method is depicted on Fig. 1 to compare. Lithography in all cases is made in thin (<0.5 μm) films of PMMA made with spin-coating method on hard and smooth substrates.

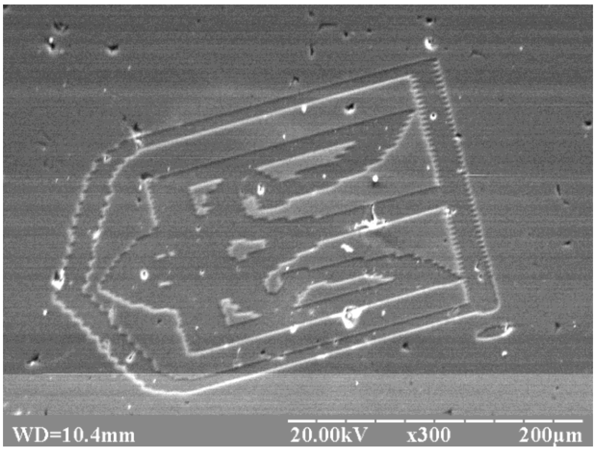

Fig. 1. E-beam microscopy of microstructure made with old raster method

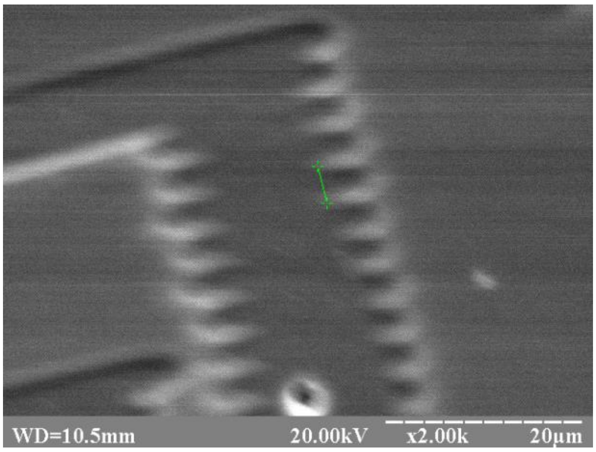

Fig. 2. Magnified image of part of the microstructure from Fig. 1. Green line on the picture is approximately 5 μm long

Obviously, the microstructure made with raster method has “pixel” artifacts resulting from the disadvantages of the raster method. They are seen even better when magnified (Fig. 2).

On Fig. 2 the defects of line edges are obvious. One can also notice that these defects are primarily related to the *X* axis. This happens because the proton beam has elliptic-like shape and is much thinner in *X* axis than on *Y* axis. It is hard to counter this effect when preparing raster image because proton beam size and shape may differ randomly in different experiments due to poor beam stability of the acceleration complex and other hardware-related factors. Only in-situ measurement during the experiment could make the shape and size of the beam clear.

Vector method does not have these disadvantages and allows to make images with smooth edges in all axes in any scales. Only image geometry and proportions matter. Parameters, needed for lithography, are set in "pbwvector" files. These files can be made and edited in a special image editor but import from other vector formats (such as dxf or svg) can be made possible in future if needed.

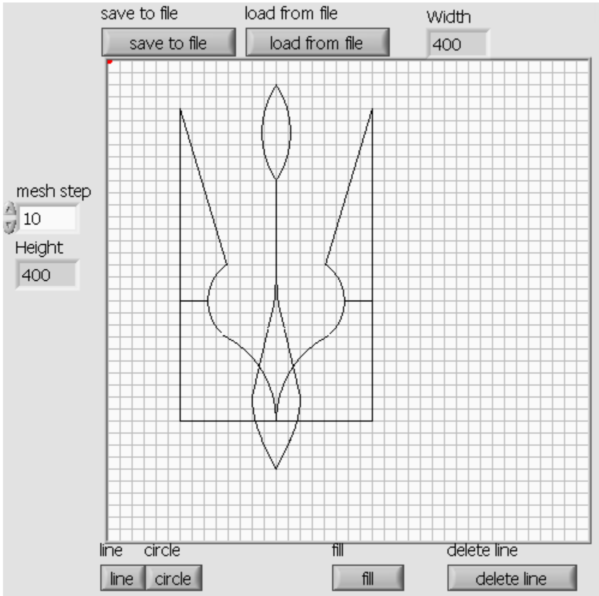

Fig. 3. Editor of "pbwvector" image format with vector image of the Coat of Arms of Ukraine

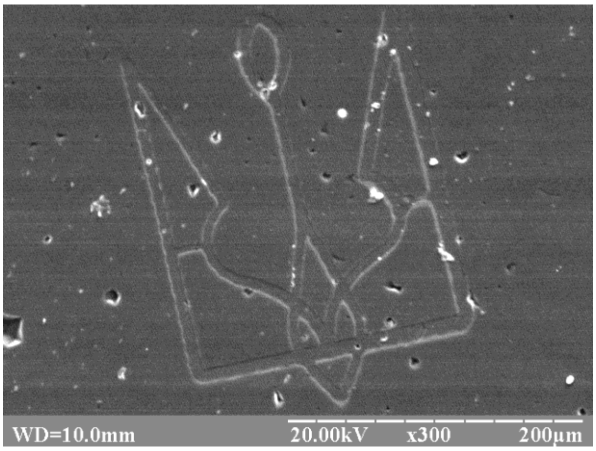

Fig. 4. E-beam microscopy of microstructure made from vector image on Fig. 3

On Fig. 4 one can see that a microstructure made from "pbwvector" file does not have obvious "pixel" artifacts seen in microstructures made with raster method. Both straight lines and curves are smooth. E-beam image scale is the same as in Fig. 1.

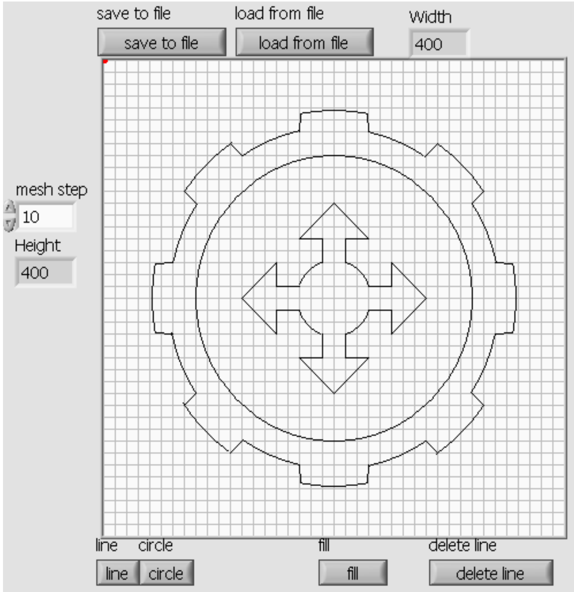

Fig. 5. Editor of "pbwvector" image format with a "technocracy" image

Along with fabrication of the microstructure with the Coat of Arms of Ukraine, two "technocracy" microstructures of complex shape were made. They have more curves and circles (Fig. 5).

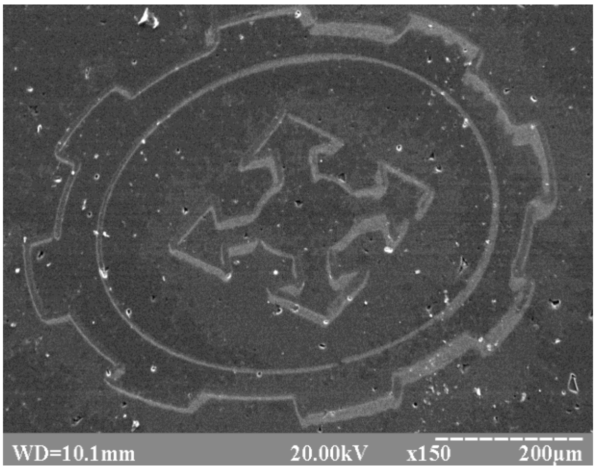

Fig. 6. E-beam microscopy of microstructure made from vector image on Fig. 5. Structure size is approximately 730 µm

These microstructures also do not have any sign of "pixel" artifacts (Fig. 6). Structure defects on the right half of the image is not related to the vector lithography method. They are likely connected with proton-beam instability and too large beam deflection from the zero point (more than 500 µm structure size) that led to loss of beam focus.

Second microstructure (Fig. 7) from the same vector image is twice lesser in scale but has the same proportions as in Fig. 6. Proton beam had the same parameters. The structure has similar but much lesser defects resulting from the beam's instability and deflection from zero point. At the same time one can see bigger structure defects of other kind because of lesser structure size. These defects appeared during vacuum metal deposition needed for e-beam microscopy.

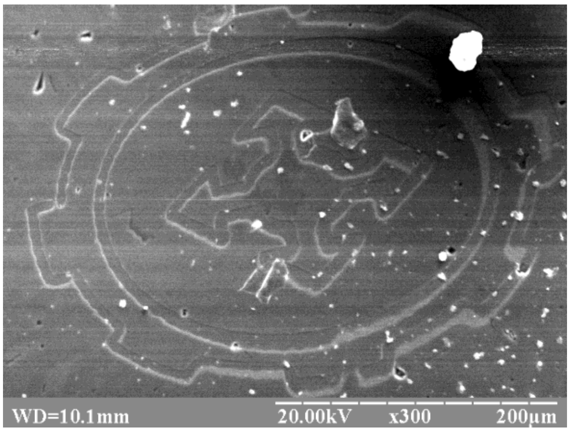

Fig. 7. E-beam microscopy of microstructure made from vector image on Fig. 5 (lesser scale). Structure size is approximately 370 μm

Proton-beam parameters evaluation is conducted via semi-automated analysis of the image of standard copper calibration mesh made for e-beam microscopy. The image is in relative intensities of secondary electrons that emerge during proton beam scanning.

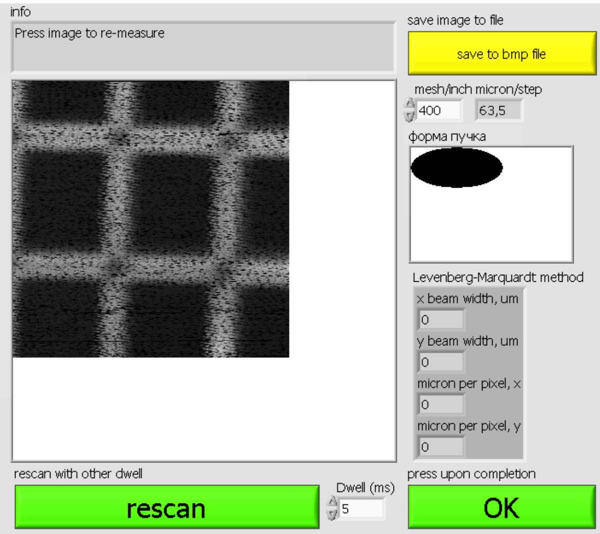

Fig. 8. Semi-automated evaluation of shape and sizes of proton beam

Beam shape and size evaluation is carried out in situ before the lithography. This data can be used to calculate the needed number of points for every line or curve. Contrary to raster method with strictly preset points, vector lithography software sets needed number of points according to the scale.

2. FURTHER EQUIPMENT UPGRADES AND TECHNOLOGY APPLICATION PROSPECTIVES

A number of upgrades for the lithography channel's equipment in the Institute of Applied Physics NAS Ukraine in Sumy is planned. It is planned to achieve large-size (up to 30×30 mm) microstructure fabrication. It can be done by dividing large vector pattern into subpatterns from 200 to 400 μm in size. This size is smaller than the electromagnetic scanning system can operate (up to 2×2 mm) but this way we can avoid loss of focus on the subpattern edges due to too large deflection from zero point. Every given subpattern lithography will be done by electromagnetic scanner. Transition between subpatterns will be done by means of mechanical *XY* stage movement. We have an *XY* stage now but its application for large-size structure lithography is practically impossible due to large and unpredictable mechanical backslashes that make accurate subpattern edges matching impossible. A new precision *XY* stage is being purchased. We also are working on "blanker"– device that quickly takes the proton beam off the stage. This is needed first of all for large-scale microstructure fabrication to take off the beam during mechanical transition between subpatterns. Along with hardware upgrades, the respective software upgrades will be needed.

Vector proton-beam writing, especially with large-scale microstructure fabrication, opens brand-new applications in many kinds of individual or small-series specialized microstructure fabrication, such as X-ray optics elements for phase-contrast tomography. Proton-beam writing makes lithography much easier for special integral circuits including silicon carbide circuits for special high-temperature and high-voltage applications: prototyping new generation of power electronics does not need very high resolution at the moment. Proton-beam writing allows fabrication of almost any arbitrary form of microstructures from programmatically set pattern. This can be used to fabricate individual and experimental structures with no need to fabricate pattern masks needed in EUV or X-ray lithography.

Another advantage of proton-beam writing is a possibility to work with new materials. We have already conducted a pilot experiment with proton-beam writing on chitosan [8] – an environment-friendly polymer that can be fabricated in mass by recycling chitin from seafood industry and developed in lithography just with pure water. We plan to experiment with other new materials for proton-beam writing. Among them are piezoelectric that can be user in microrobotics, microfluidics, microhydraulics, chemical microstructures, photonic integrated circuits. Our special attention concerns PVDF piezoelectric polymer and its mixtures with PMMA (classical lithography resist that should be easy to develop) that can be transparent (important for photonics). Proton beam writing may be used in many ways of micromachining new materials, mostly polymers.

CONCLUSIONS

Advantages of vector method for megaelectronvolt-energy proton-beam writing over raster method are proved experimentally. This allows fabrication of microstructures with smooth lines regardless of their curvature. Scaling setup before proton-beam writing is semi-automatic, based on focused beam size and shape measurement by means of scanning standard copper grid made for e-beam microscopy.

Our advances in proton-beam writing with hardware and software upgrades can give us possibility to use proton-beam writing to fabricate large-scale microstructures and many kinds of special and experimental microstructures of special purposes, including integral circuit prototyping. Proton-beam writing can be used with new materials further extending its application.

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СИСТЕМА ВЕКТОРНОЇ ПРОТОННОЇ ЛІТОГРАФІЇ

Г.Є. Положій, О.Г. Пономарьов, С.В. Колінько, В.А. Ребров

Дано опис векторного методу сканування сфокусованим пучком мегаелектронвольтних енергій в протонно-променевій літографії. Експериментально доведено, що векторний метод протонно-променевої літографії має ряд переваг перед растровим методом. Визначення форми та розмірів сфокусованого пучка здійснюється за рахунок сканування стандартної мідної сітки для електронної мікроскопії. Розглянуті подальші шляхи вдосконалення обладнання та програмного забезпечення. Технологія векторної протонної літографії може бути використана в багатьох застосуваннях, включно з рентгенівською оптикою, прототипуванням електроніки, мікроробототехнікою, рідинними мікроструктурами (мікрофлюїдика), фотонікою і створенням мікроструктур у нових матеріалах.