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A LabVIEW™-based scanning and control system for proton beam micromachining

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Abstract

LabVIEW™ is steadily gaining in popularity as the programming language of choice for scientific data acquisition and control. This is due to the vast array of measurement instruments and data acquisition cards supported by the LabVIEW™ environment, and the relative ease with which advanced software can be programmed. Furthermore, virtual instruments that are designed for a given system can be easily ported to other LabVIEW™ platforms and hardware. This paper describes the new LabVIEW™ based scanning and control system developed specifically for proton beam micromachining (PBM) applications. The new system is capable of scanning figures at 16-bit resolution with improved sub-microsecond scan rates. Support for electrostatic beam blanking and external dose normalization using a TTL signal have been implemented. The new software incorporates a semi-automated dose calibration system, and a number of novel dose normalization methods. Limitations of the current beam scanning hardware are discussed in light of new results obtained from micromachining experiments performed in SU-8 photoresist. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

Proton beam micromachining (PBM) is a direct write lithographic process which can be used to manufacture microcomponents such as microstamps and micromoulds [1]. The technique utilizes a focused ion beam to irradiate a predetermined pattern on a photoresist material.

The energy required to appropriately modify the photoresist is delivered by a fine probe of energetic (MeV) protons produced by an electrostatic accelerator.

The system requirements of PBM are more stringent than those of traditional ion beam analytical techniques. Beam stability, precise scanning and resolution are of utmost importance in ensuring the quality of micromachined structures. At the Research Centre for Nuclear Microscopy (RCNM), much improved beam stability has been achieved with the acquisition of a new High

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Voltage Engineering Europa 3.5 MV Singletron™ accelerator. This new accelerator coupled with the already proven 100 nm performance of the RCNM nuclear microscope makes the new facility ideal for PBM [2].

As part of the ongoing efforts to improve the quality of the PBM structures produced at the RCNM, and to automate many of the tasks involved in producing these structures, a new scanning system has been developed. The new system uses a National Instruments™ PCI-6111 multifunction I/O card controlled by the National Instruments™ LabVIEW™ programming environment. The system boasts a number of improvements over the previous scanning system used for PBM [3]. The most significant improvements are in the scan resolution and the scan update time. The new system is capable of scanning a structure in 16-bit resolution (65536×65536 pixels), instead of the 12-bit resolution (4096×4096 pixels) of the old system, at an update time of $0.4 \mu\text{s}$. The time taken to expose a resist only depends on the area being exposed and not the resolution with which the scan is performed. The increased resolution will therefore allow finer detail in the scans without affecting the exposure time. For example, an area of $400 \times 400 \mu\text{m}^2$ of SU-8 is exposed in 8 min with a beam current of 10 pA regardless of the scan resolution. The new system also incorporates beam blanking and the ability to normalize beam dose with an external signal.

2. Software description

LabVIEW™ is the programming environment chosen for the new micromachining scanning system developed at the RCNM.¹ Using LabVIEW™, advanced control applications can be programmed with a minimum of development time. A vast array of bench top scientific instruments and computer based hardware produced by National Instruments and other

suppliers is already supported by the LabVIEW™ environment. Such support is an important consideration when developing a flexible data acquisition or control application which can be easily expanded in the future as the needs of the application grow.

The new software developed for PBM, which is named *ionscan* is designed to be user friendly, automating many of the tasks which are performed during a PBM experiment. The program is divided into multiple virtual instruments (*vi*'s), each designed to perform a specific task. The individual *vi*'s can be accessed directly from a button on the parent *vi*. The modular structure of the software makes it easy to add functionality in the future as new tasks are needed. The current version of *ionscan* supports seven tasks. These are scan file loading, scan file viewing, scan file simulation, resist calibration, setting run parameters, data log viewing and beam scanning.

Currently there are two image file formats used for defining scan patterns for PBM. The first is windows metafile (WMF) which is a vector file format, and the second is bitmap (BMP) which is a pixel file format. Both image file formats must be first converted using software into a scan pattern file format (SPL file extension), which can then be loaded with *ionscan*. The scan pattern file is comprised of a binary ordered list of *x-y* co-ordinates which trace out the path of the beam on the sample. The *ionscan* software reads the ordered list and uses a parameter known as the *minimum shape distance* to group the ordered co-ordinate into shapes.

Three dose normalization methods have been devised to cater for different exposure requirements. The normalization methods are known as *pixel*, *shape* and *figure*. For applications where the normalization signal count rate is high, pixel normalization can be used. Under this scheme, the beam dwells on each co-ordinate until the desired exposure dose is delivered before advancing to the next pixel. If shape normalization is used, the software will repeatedly scan over a shape for the required dose before deflecting the beam and advancing to the next shape. Pixel and shape normalization methods will only blank the beam once between each shape thus minimizing the effect of

¹ LabVIEW™ is a programming language developed by National Instruments Corporation, Austin, TX, USA.

stray dose. The final method of normalizing the dose is known as figure normalization. This scheme will repeatedly scan the whole pattern until the desired dose is obtained. Figure normalization is useful for scans where the number of normalization counts for each shape is low (e.g., when a highly sensitive resist like SU-8 is used). If a shape only requires a small number of normalization counts, uneven exposure or an overdose can result unless the figure is repeatedly scanned several times. A disadvantage of this normalization method is that scanning the whole figure several times results in multiple beam blanks between each shape.

Ionscan includes two file previewing functions which allow the user to observe the scan file before exposing the resist. The *view scan file* button can be used to show an x - y plot of the points which will be exposed in the run. In built LabVIEW™ zoom and plotting buttons can be used to check individual points. The points are by default connected by a line which traces out the scan path. The *simulate scan* button can be used to observe an animation of the scan pattern. This function is useful for determining the order of the scan and to check if the shapes in the scan figure have been correctly identified by the file loading procedure.

The *run parameters* button enables the user to enter key experimental parameters such as resist type, beam energy and species and various file paths and names which help define the experimental setup. These parameters are saved in a datalog which is generated automatically by the software. The *view datalog* button can be used to view the progress of the datalog at any time during the experiment.

The most important task which needs to be performed at the beginning of every PBM experiment is calibration of dose normalization for the resist being exposed. *Ionscan* uses an external TTL pulse signal to normalize the dose for each exposure. The normalization pulses used with the current system come from a surface barrier detector measuring RBS. In principal the TTL pulses can come from any detector measuring a signal which is related to the dose (for example, electron and photon detectors). The *calibrate resist* button displays the calibration *vi*. This *vi* allows the user to enter a number of calibration parameters which are used by *ionscan* to calculate a *normalization number* for each pixel, shape or figure in the scan pattern. The *normalization number* is essentially the number of normalization pulses required to correctly expose the resist. Using RBS normalization, a *normalization number* can be calculated if

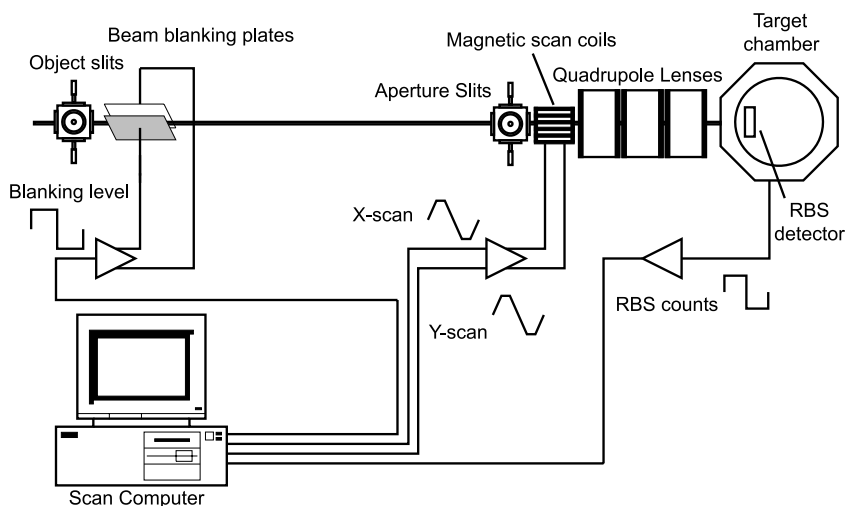


Fig. 1. Schematic diagram of the RCNM PBM hardware setup.

the detector solid angle, the scan area, the number of incident ions and the number of detected ions is known. The solid angle is known for a given experimental geometry and detector. The number of backscattered particles is measured and the number of incident particles is determined from a fit to the RBS spectrum acquired during the calibration exposure.

Once the resist is calibrated, an exposure can be performed by using the scan *vi* which is accessed through the *start scan* button. The scan *vi* allows the user to choose the normalization method, the scan update time and the figure scan size.

3. Hardware description

Fig. 1 shows a schematic diagram of the hardware used for PBM at the RCNM. Currently PBM is performed with the RCNM nuclear microscope which is based on the Oxford microbeams endstage, however in the future, a dedicated beamline will be built. The beam is scanned magnetically using a set of ferrite cored scan coils, and an OM40e dual scan amplifier. The scan amplifier is driven by two 16-bit digital to analog converters (DAC) on a National Instruments™ PCI-6111E multifunction I/O card. The beam is deflected in between shapes by a high voltage amplifier connected to a set of parallel copper plates which are positioned just after the object slits. The high voltage amplifier is controlled by a digital I/O line which supplies a 5 V level which is amplified to ± 100 V on the blanking plates. The rise time of the blanking signal is better than $1 \mu\text{s}$. The RBS counts which are used for dose normalization are monitored by one of the 20 MHz counter-timers on the PCI-6111 card. A timing SCA is currently being used to provide the TTL pulses to the scanning system from the surface barrier detector.

4. Discussion

Any new control or data acquisition system must be fully characterized and tested before it can

be used reliably. Several test exposures were performed to determine the practical limitations of the new scanning system. An array of $20 \mu\text{m}$ squares was exposed in a scan area of $400 \mu\text{m}$ on a sample of $30 \mu\text{m}$ SU-8 photoresist spin coated on a silicon substrate. The squares were all exposed to a dose equivalent to $30 \text{ nC}/\text{mm}^2$ using *shape normalization*. Exposures were repeated at scan update rates ranging from 1 up to $100 \mu\text{s}$. Since the square arrays were defined in a scan resolution of 512×512 pixels, the speed of the scan for these update times is between 0.0078 and $0.78 \mu\text{m}/\mu\text{s}$. The square arrays were scanned both in the raster mode and in a spiral mode in order to compare effects due to scan direction.

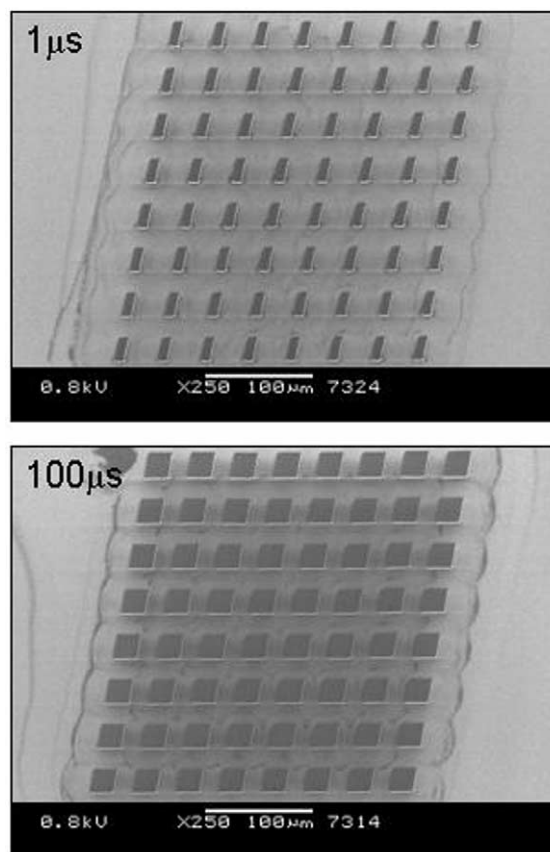


Fig. 2. SEM images of an array of squares raster scanned at two different DAC update times. The distortion in the scan pattern in the fast scanning direction disappears for times greater than $100 \mu\text{s}$.

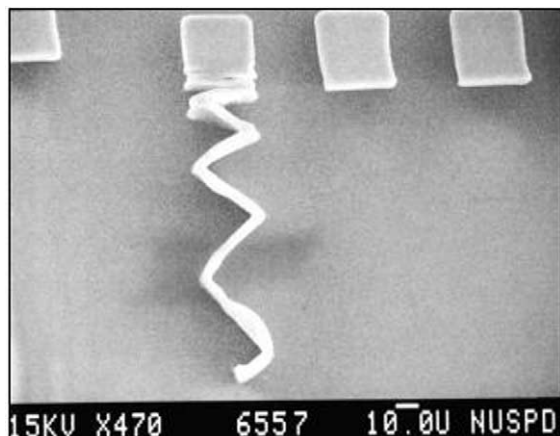


Fig. 3. Artifact caused by scanning too fast. Scan speed used in this exposure was 25 μs . The scan resolution was 512×512 pixels over a scan area of 400 μm .

Fig. 2 shows SEM images obtained from the raster scan squares at speeds of 1 and 100 μs . At 1 μs a contraction in the figure is observed in the fast scan direction. This distortion progressively decreases as slower scan speeds are used. At 100 μs the figures are distortion free which indicates that figures should be scanned at speeds slower than 8 nm/ μs for our current system. These distortion effects are due to hysteresis in the magnetic scan coils. It is anticipated that faster scan speed should be possible for electrostatic scanning.

Fig. 3 more clearly illustrates the hysteresis effect. This figure was exposed using *figure normalization* at an update time of 25 μs . When *figure normalization* is used, the beam is blanked at the end of each pass while the scan returns to the start of the figure. If the scanning system has not had enough time to settle, the beam will begin to scan the first shape again before the magnetic scan coils have reached the required field. What results after multiple scans of a figure is the tail which can be seen in Fig. 3.

5. Conclusion

The first version of *ionscan*, the new PBM scanning software designed at the RCNM has been implemented. The current version has the ability to scan an arbitrary shape or group of shapes up to a scan resolution of 16 bit per channel. Beam blanking and external dose normalization have been implemented. Pixel, shape and figure normalization can be used depending on the requirements of the exposure and the type of photoresist being used. Currently dose normalization is performed with RBS. Future studies will ascertain the feasibility of using either ionoluminescence or secondary electron signals to normalize the dose. Whether these alternative dose normalization methods are utilized depends on how predictable and reproducible these signals are during irradiation. Issues like beam damage and the surface roughness of the photoresist may need to be addressed.

The blanking voltage is currently obtained by directly amplifying the digital I/O line from the data acquisition card. This will soon be replaced by a high voltage transistor switch which will be driven by the same TTL level. The switch will reduce the noise which is commonly found on digital I/O lines and hence give a cleaner zero level. Future versions of the software will incorporate target stage movement and the ability of load multiple scan patterns. This will allow the user to define the exposure of a whole sample ahead of time or to stitch multiple patterns with a high degree of accuracy.

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