Charged Particle Technology for Ultra High Density Data Storage

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Abstract: Long term archival storage of valuable documents is rapidly approaching a critical juncture. The introduction of reliable and acceptable microfilm techniques over sixty years ago allowed preservationists to address the 'slow fires' of deteriorating, acid-based paper documents in a cost-effective manner. Since that time, microfilm standards and techniques have evolved to allow for a relatively secure manner in which to store a variety of document types, ranging from black and white texts to color photographs. However, the advent of digital information creation and retrieval has created numerous new problems that conventional archival storage techniques are hard-pressed to address. Most notably, the capability to create huge amounts of data, often stored only in electronic format, has led to a crisis not only in the need for preservation standards for digital documents, but as well has resulted in impossible demands upon the physical storage capabilities of microfilm storage vaults. With the limited lifespan of organic-based microfilms, particularly older films, the need to replace microfilm with a more durable and dense storage medium is acute.

Norsam Technologies is developing an ultra-long term storage solution in which analog, i.e. eye-readable, images are placed at unprecedented densities into nickel substrates, allowing for near geologic storage lives of data that, as eye-readable images, are not subject to the vagaries of changing formats and media to which digitally stored data is so susceptible. Specifically, using focused beams of Ga^{+1} ions, data can be written at pixel sizes as small as 25 nanometers (nm), allowing, for example, the storage of one million pages of data in less than a cubic inch of material. Readback of this data is direct, requiring no intermediate bitstream interpreter. This paper will outline the process by which the data is written and stored using focused ion beam (FIB) technology. In addition, Norsam is developing a digital product written using focused charged particle technology that will allow for the introduction of a digital technology capable of storing 165 GigaBytes (GB) of data on a CD-sized disc.

Technology

Ion irradiation is commonly used for surface modification of materials.[1] Of particular interest to data storage is ion implantation.[1] Because of fast write rates, implantation and subsequent etch-stop techniques have developed as the method by which data can be efficiently and rapidly written.

Ions are well suited to write data by implantation and etching techniques. Norsam's technology currently uses Ga^{+1} ions implanted at 30 keV into (100) silicon to write the data. By adjusting the ion beam current and the dwell time per spot, the size of the data spot and the dose of implanted ions can be carefully controlled. It has been determined that implantation doses of approximately 10^{13} - 10^{14} ions/cm^2 give a good combination of economical write times and sufficient implantation statistics to reliably and reproducibly write bits of data.[2] Under these conditions, gallium serves as an etch-enhancement dopant, with etchant exposure times as short as 1 minute. Figure 1 is a schematic of the ion implantation process. In this case, the spatial resolution is governed by the beam current, which is a function of the selected aperture. Typical spot sizes, which determine the pixel size of the written data, are about 50 nm. Depth of implantation is a function of incident ion energy, which for 30 keV is about 50 nanometers.

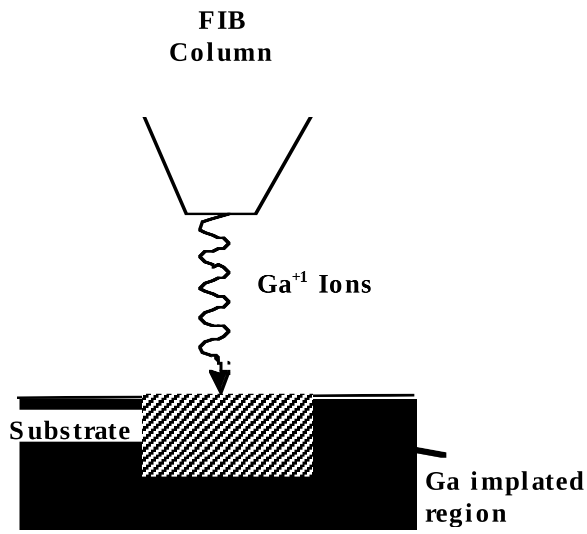

Figure 1

Following implantation, the wafers are transferred to an etch bath and processed for approximately one minute. The regions in which Ga^{+1} has been implanted etch more rapidly than the unimplanted regions, thus the data, in the case of text, is developed and is revealed as topologically distinct regions, essentially engraved into the substrate. Data writing is affected by additional process details. Anisotropic vs. isotropic etching and Si orientation dependency can be exploited to ensure a consistent pit wall profile. Implantation depth is a function of incident Ga^{+1} energy as well as substrate properties; this, combined with etch rate dependency on dose, allows for the writing of variable depth data pits. Different substrate materials can allow for even lower doses, though statistical variations in the number of particles will provide a lower limit to the dose.

The amount of data that can be written into a substrate is a function of spot size. Feature size, density and comparisons with other analog archival storage methods are given in Table I. The time to write each page of data is a function of the number of pixels to be written. For a typical 300 dpi document at 2550 x 3300 pixels, with 10% opacity, actual implantation times are around one second. Software overhead and stage motion increases the total implantation time per page to around two seconds per page. At this rate, nearly fifteen million pages of data per year can be written with each FIB machine. With further improvements in substrate design and software, write rates are expected to decrease to 0.2 seconds per page.

Table I
Comparative weight and volume of paper, fiche and archival substrate for 1M images, assuming Ni archival substrate @ 0.25 mm thickness, and 60 images per 4" x 6" fiche.

Spot size	Ni weight	Ni volume	Fiche weight	Fiche volume	Paper weight	Paper volume
1.0 micron	64 lb.	0.12 ft^3	[a] 93 lb.	[a] 1 ft^3	[a] 10,200 lb.	[a] 206 ft^3
0.2 micron	3.1 lb.	.005 ft^3	Invariant	Invariant	Invariant	Invariant
0.15 micron	1.8 lb.	.003 ft^3	"	"	"	"
0.1 micron	.79 lb.	.001 ft^3	"	"	"	"
50 nm	3.2 oz.	0.6 in^3	"	"	"	"
25 nm	0.8 oz.	0.2 in^3	"	"	"	"

Data writing by FIB implantation is essentially a mastering process. Thus the information on the Si master can be transferred to an archival substrate, such as nickel, by electroforming methods. Figure 2 is a schematic of the electroforming process, showing how the conformal capabilities of electroforming allow for the production of a freestanding substrate containing the data.

Some of the requirements of the archival substrate include: sufficient thickness for durability and strength when handled, mirror flatness, and reproduction fidelity. Electroforming has already been shown to be capable of reproducing features as small as 80 nm, and even better resolution is expected, while the excellent mechanical properties of nickel will allow for durability. Protection against oxidation, corrosion, and fire will require prudent encapsulation. Figure 3 shows a prototype design for a storage box, which, when purged with an inert atmosphere and constructed with sufficiently thick refractories, would allow complete protection against almost any disaster. Bearing in mind that this encapsulator design would replace entire buildings currently dedicated to microfilm preservation, the cost effectiveness of ultra-high density storage becomes apparent.

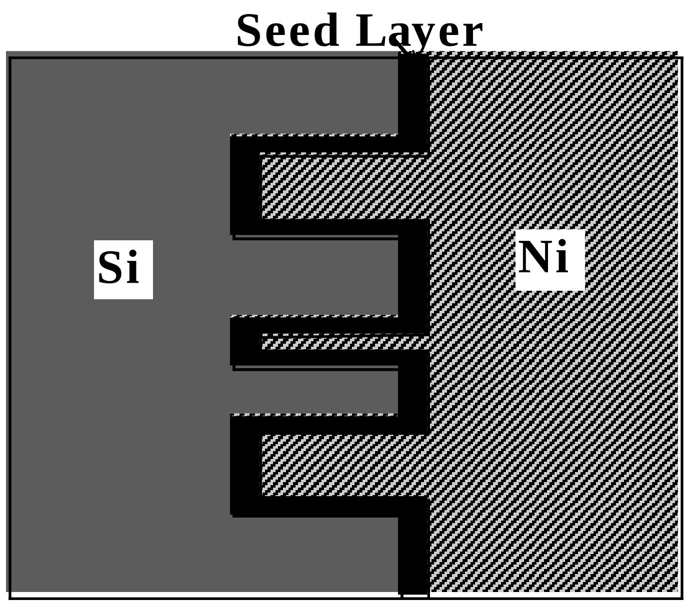

Figure 2

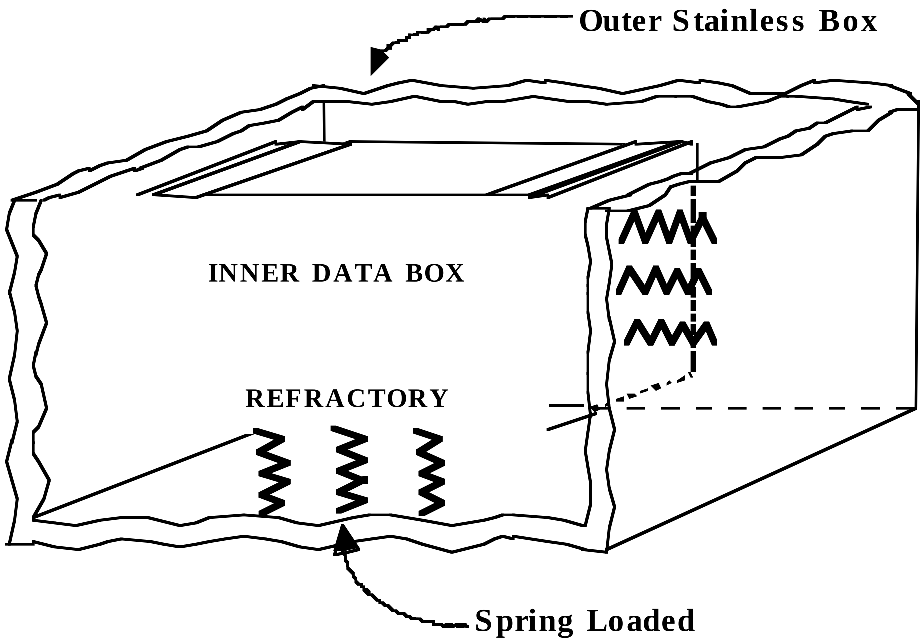

Figure 3

Readback of the data is accomplished by optical microscopy. Figure 4 is an illustration of data supplied by the National Library of Medicine, in this case a portion of a page of text from an electronic journal.[3] For this example, the resolution of the microscope is approximately 0.2 micron, which, in the case of data written at 500x, corresponds to nearly exact pixel by pixel recovery of data. Data written at finer pixel sizes can easily be read by optical techniques, since many hundreds of pixels make up each letter of text, allowing for excellent readability even when written at pixel sizes below the resolution limit of the microscope. However, if exact retrieval is required, scanned probe techniques, such as scanning electron microscopy, have been demonstrated.

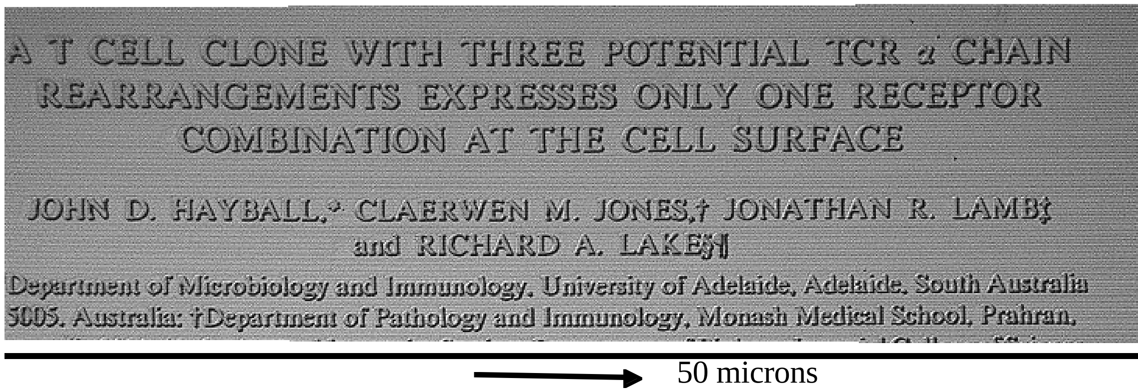

Figure 4

CONCLUSION

Norsam Technologies has successfully demonstrated all aspects of the production technology required to produce its initial analog product, and is planning to begin analog product manufacture by the end of Q2 1998. It is developing beta-site customers, providing initial data writing demonstrations, and proposing data management solutions to several very large clients. Norsam currently owns four FIB milling machines, and is in the process of setting up its first production facilities.

In addition, Norsam Technologies is developing an ultra-high density digital product, HD-ROM, which will use charged particle technology to write at pit sizes at 50 nm and below. Beam blanking technology will allow for write rates starting at 200 Mbps, while near field technology will permit read-back rates at 60 Mbps, at resolutions less than 5 nm.

References

1. Michael Nastasi, James W. Mayer and James K. Hirvonen, Ion-Solid Interactions : Fundamentals and Applications, Cambridge University Press, New York , 1996.

Footnotes

[1] Implantation means that the ions are physically placed into the substrate material under high accelerating voltage. The implantation depth depends upon the voltage.
[2] Writing rates are currently around 3 Mbps, and are expected to increase to about 20 Mbps.
[3] Note that this picture was captured using a 1k x 1k CCD camera. The data was written at 2550 x 3300 resolution, such that nearly 80% of the data was lost in this optical image capture. Regardless, excellent fidelity is still retained.