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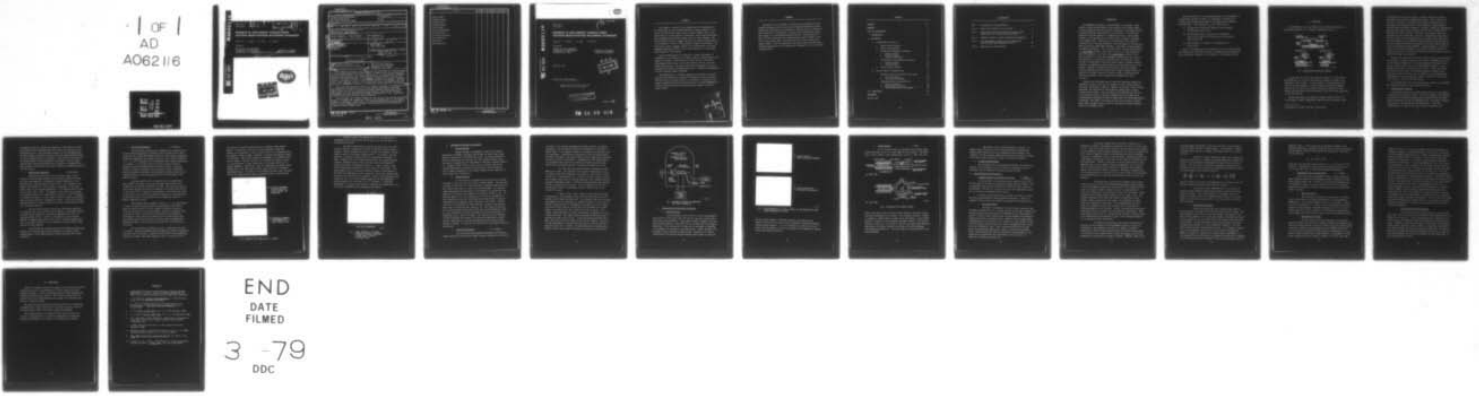
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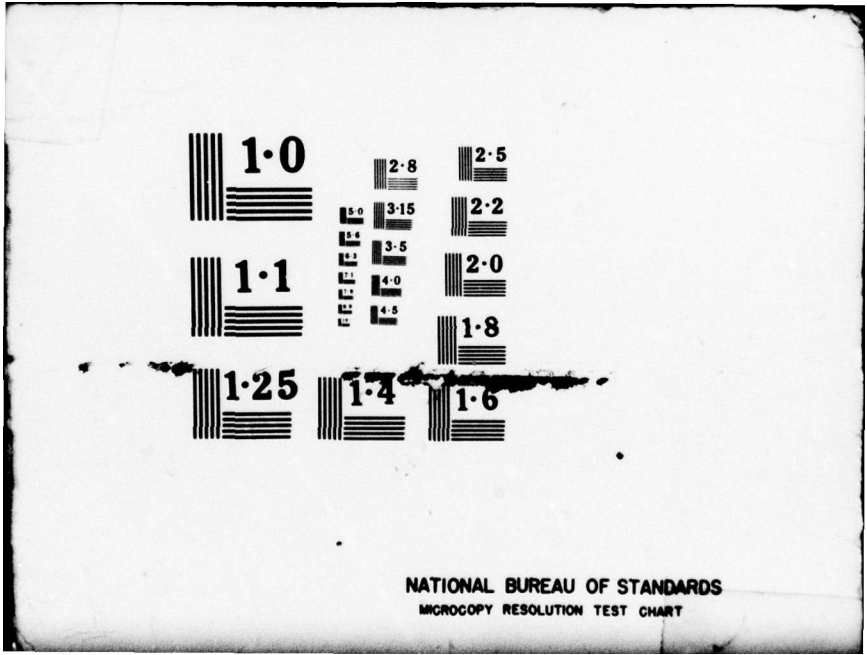
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# RESEARCH IN HIGH-DENSITY STORAGE USING ELECTRON BEAM-ACTIVATED MACHINING TECHNIQUES

Edited by: K. T. ROGERS    D. R. CONE    L. N. HEYNICK

Prepared for:

OFFICE OF NAVAL RESEARCH  
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13. ABSTRACT

This program is devoted to the preparation and investigation of two novel kinds of electron-beam-addressable storage elements of submicron size and densely packed arrays of these elements; also to the construction of a large-capacity, high-speed, electron-beam-addressable, data-storage system utilizing regular arrays of these elements. One kind of element, called a  $\mu$ -cap, consists of an isolated microcapacitor at the bottom of a hole in a metal/dielectric/metal film sandwich. The other kind, called a  $\mu$ -ring, consists of an isolated metal film ring embedded concentrically with a hole in the dielectric of a multilayer metal/dielectric film sandwich.

Work on storage mosaics was devoted to further development of techniques for the preparation of regular arrays of densely packed  $\mu$ -cap elements including: investigations of other resists besides tetrakis(triphenyl)siloxytitanium, such as KPR, Shipley's AZ 111, and poly(methyl methacrylate); argon-ion sputtering of molybdenum films; and lead-fluoride etching of aluminum-oxide films. Appropriate combinations of these techniques appear promising.

The development of a computer program for the design of electron-optical systems capable of scanning  $10^8$  elements per field for mosaic fabrication and for element address is continuing. Concurrently, the present molybdenum-lens electron-optical system is being reassembled to include a velocity-selector/electron-multiplier readout unit and a bakeout heater.

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Microstructures						
Microminiaturization						
Micromachining						
Thin films						
Microcapacitors						



March 1968

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Report No. 4  
Final Report

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Approved: C.A. ROSEN, MANAGER  
✓ APPLIED PHYSICS LABORATORY

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## FOREWORD

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The purpose of this program is to produce and investigate the performance characteristics of novel types of high-packing-density binary information storage mosaics, consisting of regular arrays of elements of about micron size. The program is directed toward producing an experimental model of a data-processing system having a storage capacity of about  $10^8$  bits accessible with a high-resolution electron beam at less than 10  $\mu$ sec access times to subfields and faster than 10 MHz serial readout speeds. Thin-film deposition and electron-beam-activated micro-machining techniques are to be adapted and integrated to form the desired storage mosaics.

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## I INTRODUCTION

This program is devoted to the development of high-speed, large-capacity storage systems based on novel kinds of data storage elements of about micron size and the effective utilization of the high-resolution and rapid-switching capabilities of electron beams. It includes the preparation and investigation of high-density arrays of such storage elements to be addressed with an electron beam of diameter comparable to the element size. These arrays of storage mosaics are formed by developing and/or adapting appropriate thin-film deposition and electron-beam-activated micromachining techniques. Two kinds of storage elements are under investigation. One is an electrically isolated microcapacitor or  $\mu$ -cap element formed at the bottom of a hole in a metal/dielectric/metal film sandwich. The other, the  $\mu$ -ring element, consists of an isolated washer or ring of metal embedded concentrically with a hole in the dielectric of a multilayer metal/dielectric film sandwich. Data writing is accomplished by using the electron beam to produce secondary electrons or bombardment-induced conductivity (BIC) selectively at each element. Readout is obtained with the beam by detecting secondary electrons emerging from each element hole, using an energy selector to ascertain the element state and a closely coupled, continuous-dynode electron multiplier to drive appropriate high-speed data-output circuitry.

Research and development work on such data-processing concepts was originally started at SRI under two separate contracts having distinct objectives and methods of approach. However, as the work on each contract progressed, the advantages of continuing the program under a single contract became evident. This unification was formalized near the end of the present quarter by closing out ONR Contract Nonr 3449(00) and correspondingly enlarging the scope of ECOM Contract DA 28-043 AMC-01261(E). Accordingly, this report constitutes the last of the series of reports issued under the ONR contract as well as the regular quarterly progress report for the ECOM contract.

The basic objective of the combined program is the development of an operational feasibility model of a high-speed, large-capacity, alterable data-storage system based on the submicron-size elements described above. The design goals of this system include:

- (1) Storage mosaics having  $10^8$  regularly spaced elements per electron-optical field
- (2) Electron-beam access to subfields of appropriate size in less than 10  $\mu$ sec with accuracy and stability better than  $1:10^4$
- (3) Serial readout of subfields at 10 megabit/sec or faster rates.

Work on the organization of the memory and on the interface equipment required for utilizing this kind of storage system in conjunction with conventional computers is also planned at the appropriate time.

## II DISCUSSION

For convenience, the  $\mu$ -cap element and the nominal potentials and beam energy parameters for writing are reproduced in Fig. 1.

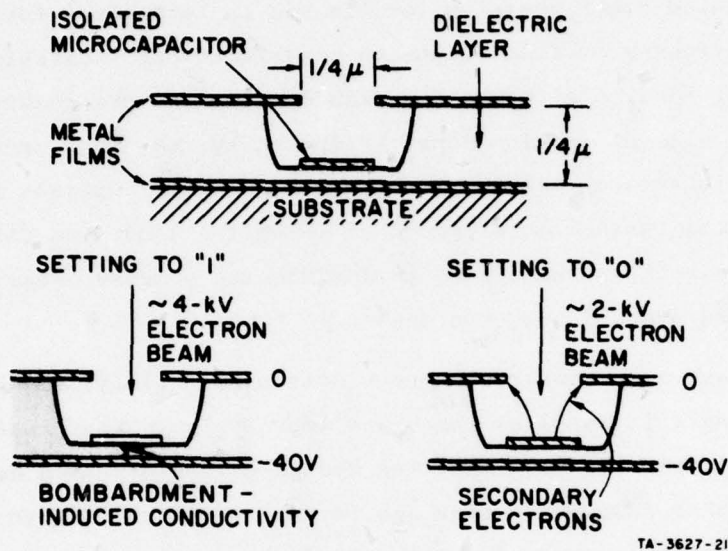


FIG. 1 MICROCAPACITOR STORAGE ELEMENTS

As described in the previous quarterly reports,<sup>1\*</sup> we have shown experimentally that the basic operations of storage and readout can be performed on such elements. For this purpose, we used the brass lens and its ancillary equipment to address randomly distributed elements produced by utilizing micron-diameter polystyrene spheres as contact masks, selective aqueous-etching techniques, and post-etching depositions to form the elements.

We have also begun the formation of regular arrays of about  $10^4$   $\mu$ -cap elements, using a JEOLCO Model JEM-30 electron microscope, which

\*References are listed at the end of the report.

we converted into an electron probe, for resist exposure in patterns consisting of two mutually perpendicular rasters. Recent results indicate that in addition to the field size limitations imposed by this instrument, our electron-sensitive resist material tetrakis(triphenyl)siloxytitanium (hereinafter referred to as STER, standing for siloxytitanium electron resist) may not have adequate sensitivity for forming  $10^8$  bit arrays by such serial exposure. Therefore, investigations have been undertaken on other resist materials and on techniques for obtaining the desired patterns by flood-exposing resists through suitable mesh grids. The raster results with the JEM also confirm the previously anticipated limits on element packing density imposed by the usual undercutting that occurs with aqueous-etching techniques. Greater emphasis is now being given to the further development of selective localized film-removal techniques such as the lead-fluoride etching process described in earlier reports and argon-ion sputtering.

We have also constructed an electron-optical system having molybdenum lens elements to supplant the brass lens system. Measurements thus far on both systems indicate that the design parameters used herein, which had been chosen several years ago in semi-empirical fashion, are not optimum with regard to off-axis spot distortions. These lens systems will continue to be useful for developing important storage system operations on  $10^4$  bit mosaics, but the design of a more sophisticated lens/deflector system is required in order to achieve the  $10^8$  bit per field objective, and this has been started.

The considerations above and other important aspects of the program are discussed in detail in the following sections.

#### A. Storage Mosaic Formation

The general procedure for forming regular arrays of  $\mu$ -cap elements involves the following basic steps. A thin-film sandwich of Mo/ $Al_2O_3$ /Mo is deposited on a sapphire substrate and an electron-sensitive resist layer is deposited over the top molybdenum film. The resist is exposed to electrons in the desired pattern and developed. (For STER, polymerization is caused in the areas exposed to electrons, and

development consists of heating the substrate to about 350°C in vacuum, which converts the polymerized areas into silica and vaporizes the un-polymerized resist.) The unprotected areas of the top molybdenum film are then removed, followed by etching of the Al<sub>2</sub>O<sub>3</sub> areas exposed thereby, to form the element holes in the sandwich. The isolated microcapacitors are formed therein by using appropriate techniques to stop the Al<sub>2</sub>O<sub>3</sub> etching before the base molybdenum film is reached or by redeposition of Al<sub>2</sub>O<sub>3</sub> material at the bases of the holes, followed by molybdenum deposition into the cavities.

1. JEM-30 Resist Exposures

E. Westerberg

STER was used this quarter as an electron resist to form matrices of 1000 and 5000 elements with the modified JEM-30 microscope. The resist was deposited on substrates by vacuum sublimation of the material from a crucible source at 350 to 370°C. The thickness of the deposit was monitored by a quartz crystal microbalance, which allows close control of the thickness parameters. The thickness generally used at this time is 800 - 900 Å. The exposure of the resist by a rastered ~7-kV electron beam with a charge density of about  $1.5 \times 10^{-10}$  coulombs/ $\mu^2$  converted the resist to a state where it did not resublime when heated above the usual sublimation temperatures (~350°C). Such resist patterns have been heated to as high as 950°C prior to the etching process without loss of pattern integrity.

The most recent results indicate that the minimum resolvable line spacing that can be obtained with the JEM-30 is about 8000 Å center-to-center, which represents a significant improvement over the 1.4- $\mu$  spacing achieved earlier. However, as indicated in the last report (QPR 10) it appears impractical at this time to undertake further reduction of the field distortion of this instrument to obtain 10<sup>8</sup>-bit/field mosaics by serial exposure.

The specimens now being produced with the JEM-30 are being used primarily for investigating etching techniques near maximum element packing density, where undercutting and related problems would be most significant.

The resolution capabilities and compatibility of STER with the present etching techniques are excellent, but the sensitivity is undesirably low for forming  $10^8$ -element mosaics by serial exposure techniques. Preliminary experiments this quarter indicate a lower limit of exposure of  $\sim 1 - 2 \times 10^{-11}$  coulombs/ $\mu^2$  may be achievable, but a greater sensitivity is necessary. If a suitable additive activator could be found to enhance the electron-polymerization efficiency of STER, it might be possible to reduce the exposure times by several orders of magnitude. Several preliminary experiments were performed with benzyl peroxide and aluminum chloride as possible polymerization activation agents, with negative results.

The high sensitivities of photoresists such as Kodak Photo Resist (KPR) to electrons as well as light make them attractive for consideration as possible alternatives to STER. Some tests were made on the electron exposure of KPR with the JEM-30, and electron sensitivities of the order of  $10^{-13}$  coulombs/ $\mu^2$  were obtained. No matrices were ruled on this resist as yet because the present technique for obtaining proper electron-beam focus on the substrate surface apparently results in general fogging of the KPR.

Both STER and KPR are negative resists, i.e., the areas exposed to light or electrons become protective layers against film removal. There are positive resists that are rendered selectively soluble or otherwise removable over the areas exposed, leaving the unexposed areas as protective layers. Such positive resists would be particularly advantageous in the formation of regular arrays of holes because fine-mesh screens could be used directly as contact masks or appropriately demagnified images of such screens could be used for flood exposure of the resist.

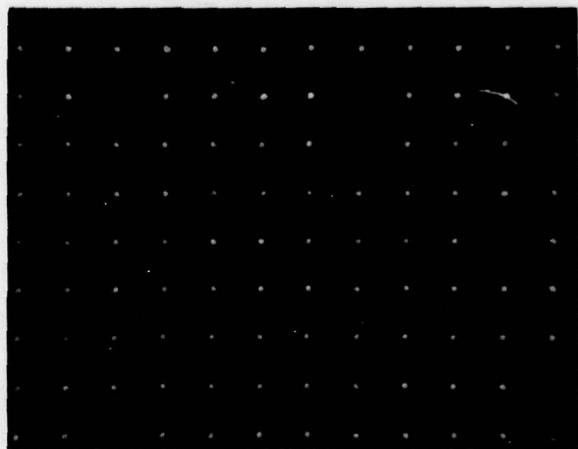
One such material is Shipley's AZ 111, a light-sensitive positive resist. Several experiments were performed this quarter to determine its sensitivity to electrons. Shipley's resist proved to have negligible sensitivity; however, when light exposure is used, it may prove to be

very useful for producing regular arrays of somewhat lower packing density. Figure 2(a), taken by reflection microscopy, shows the results of an experiment in which a layer of AZ 111 on a molybdenum film was exposed to light through a 2000-mesh, 22 percent transmission screen and developed. These screen parameters correspond to 6- $\mu$  diameter holes on 12- $\mu$  centers. However, the hole size obtained was reduced to about 1  $\mu$  by the presence of light diffraction and the proper choice of exposure parameters. Figure 2(b), taken by transmission microscopy, shows another area of the same specimen after being subjected to an aqueous molybdenum etchant; the holes in the molybdenum are about twice the diameter of the original resist holes, presumably because of undercutting.



(a) REFLECTION MICROGRAPH OF RESIST IMAGE AFTER OPTICAL EXPOSURE AND DEVELOPMENT

→ | ← 12 $\mu$

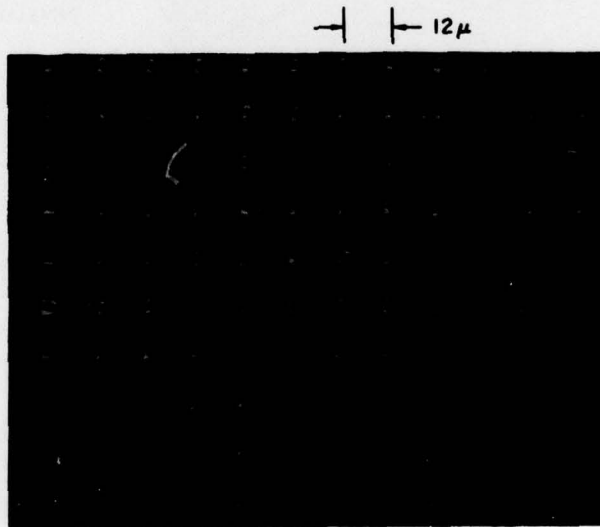


(b) TRANSMISSION MICROGRAPH OF MOLYBDENUM FILM AFTER AQUEOUS ETCHING

FIG. 2 RESULTS WITH SHIPLEY'S AZ 111 RESIST

Shipley's resist also appears useful for the protection of molybdenum contact areas during the etching of the matrices per se, as described later herein.

One means of generating a positive electron resist is to use a material that has a predominant reaction of degradation upon electron exposure. Several polymers are known to exhibit this tendency, the most common of which is poly(methyl methacrylate).<sup>2</sup> An attempt to use this material as a positive electron resist was immediately successful. A 2000- to 3000-Å film of poly(methyl methacrylate) was electron-exposed through a 2000-mesh screen, after which the resist was developed in alcohol to dissolve the degradation products. Figure 3 shows a dark-field-illumination micrograph of an area treated in this manner. (The double image is due to accidental substrate movement during exposure.) The edges are highlighted by the illumination, indicating excellent edge definition and high resolution capability. Based on the preliminary data obtained so far, the electron exposure required for this degradation process appears to be less than  $8 \times 10^{-13}$  coulombs/ $\mu^2$ . Additional experiments to determine lower limits of exposure and compatibility with film removal processes will be performed next quarter.



DARK FIELD ILLUMINATION

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FIG. 3 IMAGE FORMED BY ELECTRON EXPOSURE THROUGH A 2000-MESH SCREEN ONTO A POSITIVE ELECTRON RESIST

### 3. Molybdenum Film-Removal Techniques

#### a. Aqueous Etching

Aqueous etching of molybdenum is done with a solution consisting of 50%  $\text{HNO}_3$ , 30%  $\text{H}_2\text{SO}_4$ , and 20%  $\text{H}_2\text{O}$  (or acetic acid) using STER or a photoresist as the protective layer. The major difficulties are with undercutting and with the fact that etching continues after the mosaic is removed, both of which make it difficult to obtain uniformity. Another problem is that a small fillet is usually left by the electron-beam exposure (because of beam profile or back scattering), and the unequal permeation of the etchant through the thin edges of the resist causes more irregularity.

#### b. Gaseous Etching

In this process, the substrate with the film to be etched is placed on top of a silica tube inside a vacuum chamber. The substrate is raised to about  $500^\circ\text{C}$  by a heating element contained within the silica tube, which also serves as a small inner vacuum chamber. For etching, oxygen and hydrogen-chloride gases in approximately 5:4 proportions are admitted to the outer vacuum chamber at a pressure of about 2 torr. The reaction appears to be a two-stage process in which the molybdenum is first converted to an oxide, which then reacts with the  $\text{HCl}$  to form an oxychloride such as  $\text{MoO}_2\text{Cl}_2$ , which vaporizes at about  $200^\circ\text{C}$ . Etching rates of  $0.2 \mu$  per minute are easily obtained. Various other etchants were tried, including pure  $\text{HCl}$ , pure  $\text{Cl}_2$ ,  $\text{O}_2 + \text{CCl}_4$ ,  $\text{H}_2\text{O}_2$ , and pure  $\text{O}_2$ , but all were rejected either because they did not etch appreciably ( $\text{HCl}$ ,  $\text{O}_2 + \text{CCl}_4$  below  $600^\circ\text{C}$ , and  $\text{O}_2$ ) or because the results were erratic or rough ( $\text{Cl}_2$ ,  $\text{CCl}_4$  at  $950^\circ\text{C}$ , and  $\text{H}_2\text{O}_2$ ). With resists that can withstand the  $500^\circ\text{C}$  necessary for etching, this process has been shown to yield uniform, deep holes with much less undercutting than aqueous etching produces. However, it cannot be used directly with the higher-sensitivity photoresists.

#### c. Argon-Ion Sputtering

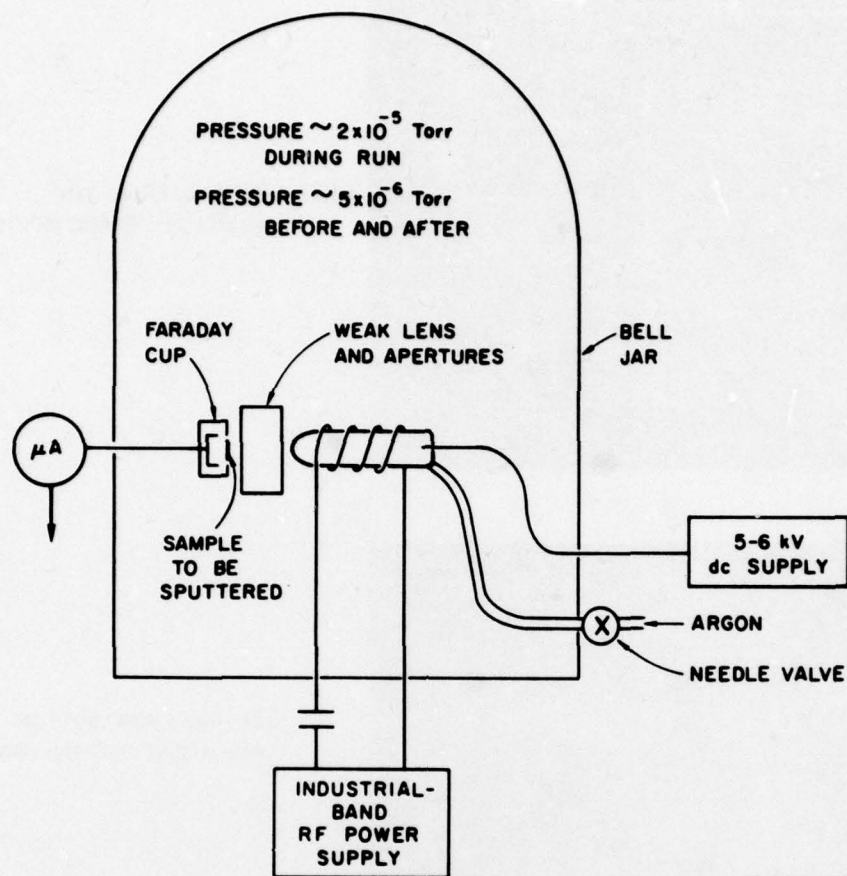
K. T. Rogers

One of the potential problems associated with the use of higher-sensitivity resists such as KPR for mosaic formation is that their

resistance to our present molybdenum and alumina etchants is marginal, especially in the thicknesses required for resolutions in the 1000- to 2000-Å range. It now appears possible to circumvent this problem by ion-beam sputtering. High-resolution sputtering of gold has been obtained by Broers,<sup>3</sup> who used a 5-kV beam of argon ions on a gold-coated substrate covered with lines of photoresist. He demonstrated that sputtering of the unprotected gold areas occurs whereas the insulator resist lines remain intact, presumably because of charging and repulsion effects.

We tried this sputtering technique on molybdenum, using STER as the resist. The apparatus used is shown schematically in Fig. 4. In essence, an RF argon discharge is produced in a tube within a vacuum station, and a probe operated at 5 to 6 kV dc is used to impel the argon ions through a weak lens and limiting apertures to the specimen with the requisite bombardment energy. A Faraday cup mounted behind the specimen is used to monitor the ion current. With this apparatus we can etch through almost 1000 Å of molybdenum in about 4 minutes with a 6 kV, 25  $\mu\text{A}/\text{cm}^2$  ion beam.

Figure 5 shows a small, regular array produced by argon-ion sputtering. The perimeter of the array was defined by the use of Shipley's AZ 111 positive photoresist. The procedure used was as follows. A molybdenum film was deposited on a sapphire substrate, a thin layer of STER was evaporated onto the molybdenum, the JEM-30 was used to expose the STER in raster fashion, and the resist was developed in the usual manner. The specimen was then coated with a layer of AZ 111. The roughly circular perimeter in Fig. 5 was produced by imaging the iris of a light microscope. The image produced was observed optically prior to exposure by using a yellow filter. After the desired adjustments were made, the yellow filter was removed to perform the exposure. The AZ 111 was then developed in an aqueous alkaline solution, which removed the exposed circular area. Finally, the molybdenum areas not protected by STER (or AZ 111) were argon-ion sputtered to produce the result shown.



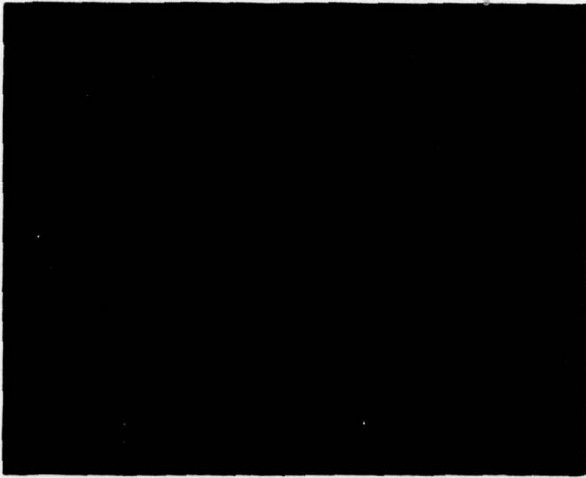
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FIG. 4 SCHEMATIC DIAGRAM OF ARGON-ION-SPUTTERING APPARATUS

#### 4. Aluminum-Oxide Film-Removal Techniques

##### a. Aqueous Etching

Using molybdenum as the resist we can use orthophosphoric acid at 95°C to etch  $Al_2O_3$  films that have not been heat treated above about 800°C after deposition. Bulk alumina ceramic, sapphire, and films that have been baked out above 800°C are not attacked by 95°C orthophosphoric acid. This selectivity is being used to advantage in producing  $\mu$ -cap elements, as described in previous reports. Again, the basic disadvantage of this technique is undercutting. Fabrication of uniform storage arrays with spacing between element centers equal to twice the



(a) LIGHTING FROM TOP  
(BRIGHT AREAS ARE MOLYBDENUM)



(b) LIGHTING FROM BOTTOM  
(DARK AREAS ARE MOLYBDENUM)

TA-5444-93

FIG. 5 PHOTOMICROGRAPH OF REGULAR ARRAY ON MOLYBDENUM HAS BEEN ARGON-BOMBARDMENT ETCHED

storage element diameter (and depth) requires that there be less undercutting than half the wall-to-wall thickness of material remaining between storage elements. It is not possible to do this with an isotropic etching process so its use is confined to the formation of mosaics having lower packing densities.

To avoid undercutting, the vaporized lead fluoride ( $\text{PbF}_2$ ) process described in the last report (QPR 10) was developed. The apparatus in use at present, shown schematically in Fig. 6, works very well.

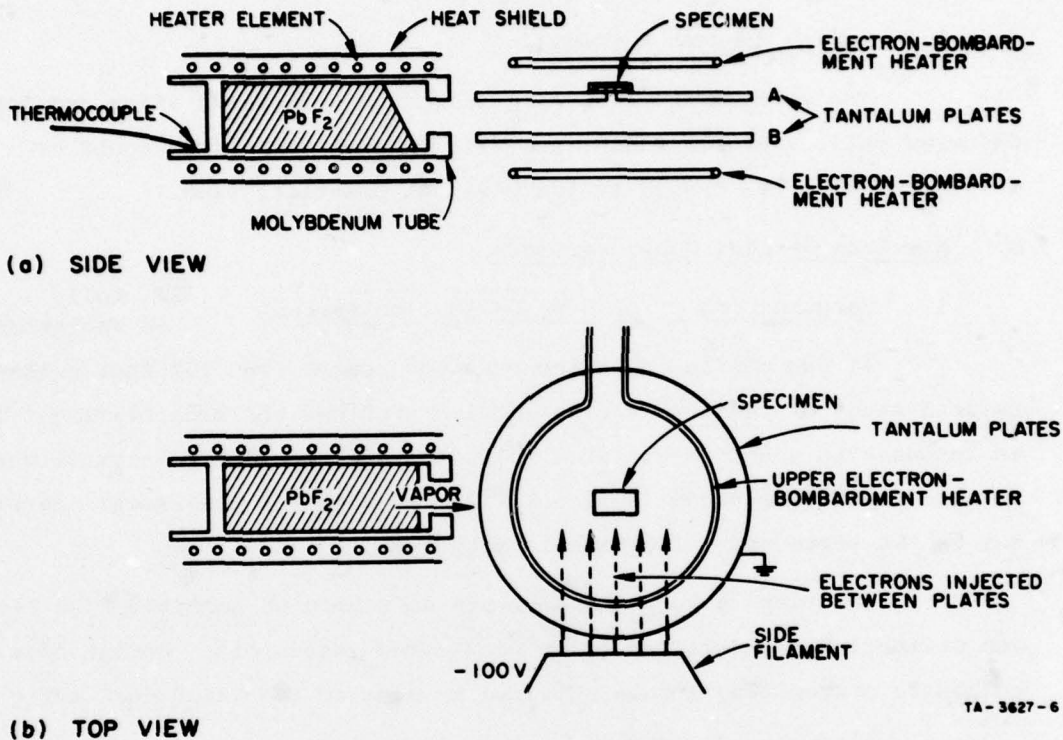


FIG. 6 APPARATUS FOR VACUUM ETCHING

Clean, controlled alumina etching has been obtained, and under suitable conditions molybdenum did not appear to be attacked noticeably. However, in attempts at making regular storage arrays this quarter, a new problem appeared. Etching of the molybdenum film edges adjacent to the alumina occurred in some runs. This seems to indicate that under some conditions,  $\text{PbF}_2$  and/or its reaction products with  $\text{Al}_2\text{O}_3$  can attack molybdenum, whereas  $\text{PbF}_2$  alone does not. The exact cause of the problem has not yet been determined.

The effect is most strongly observed, of course, in a regular array, and the fact that we have successfully produced some regular arrays indicates that this molybdenum etching problem is not insoluble. We are currently making runs with wider variations of parameters than we would otherwise, in order to isolate the problem.

5.  $\mu$ -Ring Storage Elements

The development of  $\mu$ -ring formation processes, which had been deferred until suitable resist and film-removal techniques could be developed, will be resumed at the earliest practical time.

B. Electron-Optical Considerations

1. Computer Design of Lens/Deflection System

J. Kelly  
E. Westerberg

It was mentioned in the previous report (QPR 10) that a theoretical study of the lens and deflection problems had been started. This is intended to provide data from which the electron-optical system can be optimized. The study is closely tied in with the experiments carried out on the brass and molybdenum lens systems.

In order to keep the analysis as simple as possible, the lens and deflection problems are being considered separately. Design of a composite system can then be obtained by summing the individual effects.

a. The Lens Problem

The theory of aberration for electrostatic lenses has been thoroughly developed for only a limited variety of electrode configurations. The most detailed treatments deal with unipotential and single-aperture lenses,<sup>4,5</sup> because these configurations are most amenable to mathematical analysis and can be constructed easily. However, even for these simple configurations little information is available for those aberrations that vanish for points along the lens axis, such as astigmatism, coma, distortion, and curvature of field. This is because these lenses are used mainly in narrow-angle applications, such as in electron microscopes, and in these cases the main factors limiting the resolving power of the lenses are the aberrations that are nonzero on the lens axis, i.e., spherical and chromatic aberrations.

To produce storage arrays with  $10^8$ -bit capacities it is necessary to design a lens capable of resolving 1 bit out of a linear field of  $10^4$ . Since the configurations analyzed in the literature are so limited, we are producing a digital-computer program that will derive the aberrations for an axially symmetric potential distribution with arbitrary boundary conditions. Furthermore, since we are interested in knowing the effect of large angles of deflection on spot size, we will need to calculate the off-axis aberrations. Finally, we may want to use the lenses close to unity magnification or even to magnify rather than demagnify, due to the fact that our field-emitter electron source has an apparent size very much smaller than the nominal  $2500 \text{ \AA}$  we require. The effect of magnification on the aberrations is not obvious and is not well treated in the literature, but we should be able to study this effect directly with the aid of the computer.

The properties of various lens structures will be calculated with the aid of the potential-determining program discussed below. A ray-tracing program, previously written by one of the authors for electrons in an axially symmetric magnetic field,<sup>6</sup> is being modified to enable the trajectories in electrostatic fields to be calculated. These trajectories will supply design information in two forms. First, spot diagrams representing the aberration figures in image space can be derived, thereby allowing the spot shape to be determined for planes other than the paraxial focus plane. This representation will also enable us to examine the effects on the spot due to variations in aperture placement on the lens axis. Second, the third-order aberration coefficients will be calculated for each potential distribution. These coefficients should allow us to categorize the different potential fields by the aberrations that predominate in each, thus yielding information on the optimum potential distribution.

To determine the potential field within the lens and its environs, we have adapted an existing FORTRAN program to fulfill our requirements. This program was written by V. Hamza<sup>7</sup> at Stanford University to determine space-charge solution for electron and ion guns. It has proved to be a simple matter to adapt the program to one of our computers for the solution of Laplace's equation. However, input of the

electrode shapes and boundary conditions constitutes a major problem since the format required is rather clumsy. In consequence a separate program has been written to assemble the boundary data with a minimum of effort.

Testing of the main program has begun, and it appears to work very satisfactorily. However, the planned aberration calculations require that the potentials be determined to high accuracy (0.01% or better). For this reason an additional subprogram is being written to calculate the error due to the finite difference approximation by using the fourth-order finite difference equation,

$$\frac{\partial^2 \varphi}{\partial r^2} = \frac{1}{h^2} \left[ \varphi_1 + \left(1 - \frac{h}{2r}\right) \varphi_2 + \varphi_3 + \left(1 + \frac{h}{2r}\right) \varphi_4 - 4\varphi_0 \right] - \frac{h^2}{12} \frac{\partial^4 \varphi}{\partial r^4}$$

This will indicate the location and magnitude of the largest errors and provide a means of obtaining a more accurate solution.

The writing of this subprogram will be followed by an overall accuracy check by comparing some problem solutions with known analytical results. One further addition is envisaged, which will enable the relaxation net to be expanded towards infinity at the boundaries. In this way inaccuracies due to the finite extent of the net will be avoided.

#### b. The Deflection Problem

Deflection problems have been studied by many authors, but the results are usually rather nebulous and difficult to apply. The basic problem is very similar to the lens problem; but because of the lack of axial symmetry, it is rather more complex. Considerable analysis will be required in the first place before the method of calculation can be determined. An interesting and more practical approach was adopted by Haantjes and Lubben<sup>8</sup> in a study of magnetic deflection. This has since received further considerations by Wang.<sup>9</sup> It is thought at present that our best approach will be to follow the method of Haantjes and Lubben, but applied to electrostatic systems rather than magnetic. In this approach the field equations are simplified by using the X-Y symmetry of the deflection system to eliminate as many terms as possible from the

expansion series. It was found that the aberration formulae can be expressed sufficiently accurately using the first two terms in the series for the magnetic deflection field  $H_x$  and its derivatives. The series used has the form

$$H_x = H_0 + H_2 y^2 + H_4 y^4 + \dots,$$

where  $H_0$  is the deflection field on axis ( $x = 0$ ,  $y = 0$ ) and is in the  $x$  direction. Consideration of the electrostatic problem will start as soon as the first tests on the potential program are complete.

## 2. Experimental Lens and System Work

K. T. Rogers

We are carrying on experimental work on the brass and molybdenum lenses and their associated pumping systems in parallel with the above computer design work. The aim is to correlate measurements with the theoretical results as they are obtained, as well as to continue measuring the properties of mosaics and developing the beam access and readout circuitry.

### a. Brass Lens System

The field-emitter brass-lens system housed in a conventional vacuum station has already provided most of the experimental parameters of  $\mu$ -cap storage elements (see Ref. 1 for details). Future uses for this system are as a vehicle to test techniques for deflection, stigmatism, beam chopping, flood-beam restoring, etc. This is a convenient system for initial evaluation of new techniques and apparatus since changes can be made far more easily than on the molybdenum system.

### b. Molybdenum Lens System

Over the course of the runs described in the previous quarterly reports, the central lens element developed field emission that caused local high pressure (since this system has not been baked) leading to arcing. We had not electropolished the lens elements after fabrication, therefore the observed field emission was apparently due to the growth of small irregularities during operation. We attempted to round these irregularities back with high voltage at  $10^{-4}$  torr<sup>10</sup> with some

degree of success. We finally disassembled the lens and examined the components carefully. The aperture region of the central lens element had the roughness characteristics of a lightly polished machined surface polish plus some evidence of lamination. We did some further light mechanical polishing and a very light electropolishing (attempting to maintain the tolerances). The electropolishing was done in an electrolyte consisting of 1 part sulphuric acid and 8 parts ethanol with about 8 amps/in<sup>2</sup> for 10 seconds in a holder that shielded the outer lens edge. The cathode used was a screen parallel to the lens piece. Thus the polishing was quite uniform and so brief as to remove only protuberances. We are in the process of reassembling the system now, including a velocity-selector/electron-multiplier detection unit and heaters for baking out the the lens. The next series of runs will be devoted to tests and calibrations of the detection unit and to remeasurements of spot size, to check the effects, if any, of the above lens polishing on performance, and any tendency toward buildup of undesirable field emission with operational time. Mild lens bakeouts will then be performed, followed by comparative spot size measurements, to determine how well molybdenum lenses retain their tolerances and alignment. We will also begin storage and readout measurements on regular arrays of  $\mu$ -cap elements, including further investigation of data retention or restoration by the use of flood-beam techniques.

c. Electron-Multiplier Developments

The velocity-selector/electron-multiplier unit mentioned above uses two of our present strip multipliers placed symmetrically with respect to the lens axis. Their signal-output-current capabilities are of the order of microamperes and are quite adequate for present requirements. Therefore, the further development of multipliers having higher output-current capacities, based on the use of sapphire or polycrystalline alumina dynode substrates and appropriate heat sinks, was deferred. Work will be resumed when related developments provide more insight into the desired physical and electrical parameters for the readout unit of the final operational system.

### III CONCLUSIONS

STER in its present form does not appear to have sufficient electron-sensitivity for use in the preparation of  $10^8$ -bit mosaics by serial exposure techniques. However, flood-beam exposure through appropriately demagnified screens may be feasible. Other resists, particularly the positive resist poly(methyl-methacrylate), appear very promising alternatives or adjuncts to STER.

The argon-ion-beam technique developed this quarter for sputtering molybdenum films without marked effect on insulator (resist) films will probably supplant aqueous and gaseous etching of molybdenum.

The computer program for designing  $10^8$ -bit/field lens/deflector systems is proceeding well, and plans are being made for appropriate supportive experiments with the brass and molybdenum lens systems.

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