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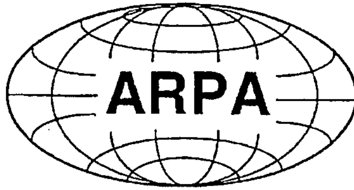

NOVEL LARGE AREA, HIGH THROUGHPUT, HIGH RESOLUTION, PATTERNING SYSTEM PROGRAM

PROGRAM STUDY

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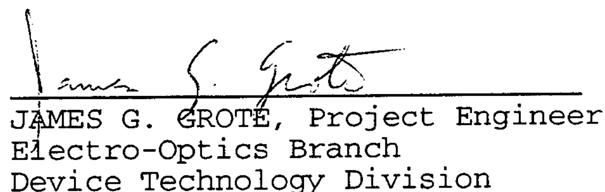

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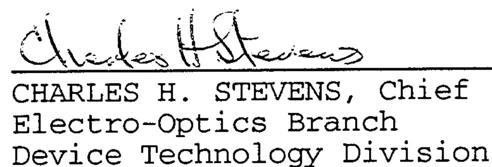

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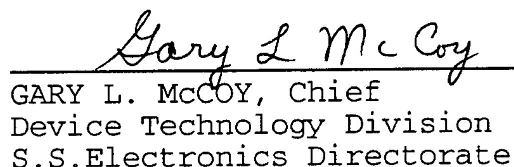

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13. Abstract (Maximum 200 words)
The objective of this phase ia program is to demonstrate a concept for a high resolution ultra violet (UV) based optical patterning system technology for production of both electronic and electro-optical multichip modules (MCMs) and flat panel displays.
The tasks identify patterning system requirements, investigate different optical and mechanical design options, perform comparativ analysis of design options, procure hardware, demonstrate large area patterning, procure masks, conduct via etching experiments, perform cost study, and determine limits of the system. A proof-of-concept patterning system was assembled. It was used to demonstrate large-area seamless patterning using multiple, partially overlapping scans. For patterning resists, the system demonstrated good resolution down to 3 µm . For ablation of polyimide, vias showed excellent resolution down to 10 µm. Ablation of 6 µm wide lines and spaces was demonstrated.

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1. INTRODUCTION

In the manufacturing of multichip modules (MCM's) and other high-performance electronic packages, patterning of the various resist, dielectric, and metal layers constitutes the most important segment of the total fabrication process. Currently used patterning and via-drilling methods suffer from several inherent disadvantages. Anvik's novel large-area patterning technology offers a breakthrough that overcomes the limitations of existing methods and achieves the combined capabilities of large field size, high resolution, and high throughput. The goal of this ARPA-sponsored TI-Anvik program is to develop Anvik's technology into advanced manufacturing equipment that will significantly improve the cost-effectiveness of high-volume manufacturing of MCM's, flat-panel displays, and printed circuit boards.

The key objectives of the Phase 1 program were to carry out risk reduction tasks and establish technical feasibility by designing, building, and demonstrating a proof-of-concept patterning and via-drilling system prototype, as well as conduct detailed experiments to demonstrate the full advantages of the new technology. This work is in preparation for Phase 2, which will be devoted to designing, building, and testing a production-worthy hardware prototype of the proposed system. At the conclusion of Phase 2, the patterning tool will be fully qualified as a beta-site manufacturing tool and installed at the TI-Microelectronics Packaging Systems MCM foundry.

This Technical Summary describes our prototype design approach and seamless scanning technique. We also present results from our extensive large-area imaging experiments with both patterning of photoresist and photoablation of interlayer dielectric materials. In the Phase 1 program, we achieved diffraction-limited resolution of 3 μm lines and spaces in photoresist over a full 5 x 5 inch substrate and demonstrated photoablation of 10 μm vias and 6 μm lines and spaces in polyimide.

2. SYSTEM DESIGN

At the beginning of this program, we conducted a comprehensive investigation to determine the system requirements for applications of the new patterning technology to fabrication of MCM's, flat-panel displays, and printed circuit boards. The requirements for both resist patterning of various materials as well as via-etching in dielectrics were investigated. With Anvik's technology, the fundamental system concept can be easily reconfigured for different product applications; however, the design of a specific system for each application will depend on the relevant patterning requirements, including minimum feature size, substrate size, and patterning materials. The prototype developed for Phase 1 was designed to demonstrate both resist patterning as well as ablation of dielectric materials over large-area substrates, with sufficient resolution to meet the requirements for fabrication of MCM's and most types of flat-panel displays.

We investigated several design options for the overall patterning system configuration, including different imaging systems, stage systems, and illumination systems. These design options considered different projection system configurations, different substrate and mask movement concepts, and different illumination system designs. These configurations each incorporated the two key elements of Anvik's novel patterning technology, namely: (a) batch processing instead of bit-by-bit serial writing, and (b) elimination of the resolution vs. field size trade-off by obtaining the desired resolution with a small-field imaging system and then delivering that resolution over the entire substrate area by a combination of continuous scanning and seamless joining of overlapping, adjacent scans.

The design concept chosen is based on the use of a single, planar scanning stage on which both the mask and the substrate are mounted. This configuration is shown in Fig. 1. The mask is illuminated with a hexagonal illumination pattern produced by an illumination system situated below the mask. The illuminated region of the mask is imaged with a projection lens and several beam-folding mirrors to produce an image of the illuminated mask region on the substrate.

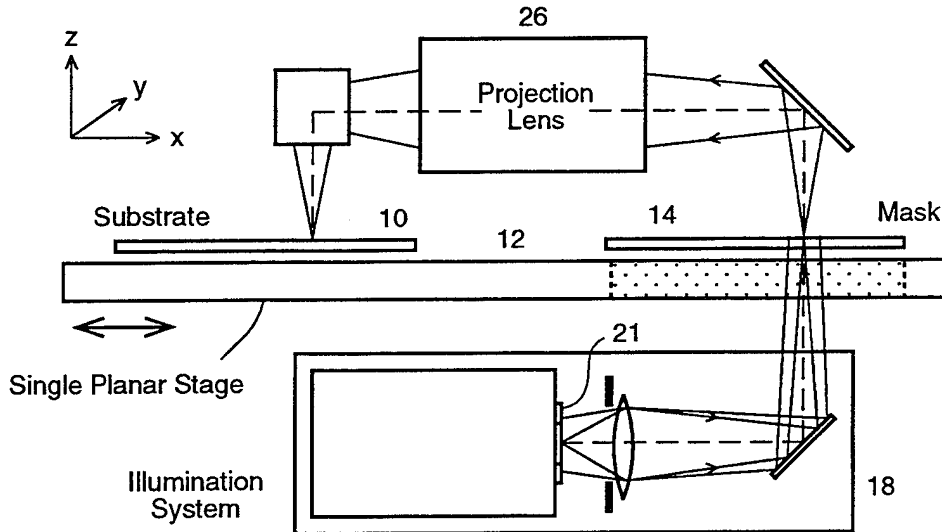

Fig. 1. A schematic illustration of Anvik's large-area, high-throughput patterning system, showing a board 10 and a mask 14 held rigidly on a single planar stage 12, an illumination system 18, and a projection lens assembly 26.

Note that the optical axis through the projection lens is in a horizontal plane, and a reversing assembly is used in the imaging path to undo the image reversal caused by the lens. This produces an image on the substrate in the same orientation as the mask pattern, which enables the use of a single stage. It is readily seen that this design approach is highly modular, in that each of the main subsystems, namely, the projection system, the illumination system, and the stage system, can be separately optimized and an overall system configuration most suitable for any given application can be assembled.

The details of the scan-and-repeat method are now described based on Fig. 1. The substrate 10 and the mask 14 are mounted on a single planar stage 12. The stage is capable of moving the substrate and the mask in synchronism in both x- and y-directions. The illumination system 18 is such that its emission plane 21 is in the shape of a regular hexagon. A 1:1 projection lens 26 images the pattern contained within the illuminated hexagonal region on the mask on to the substrate. The lens has a numerical aperture determined by the required resolution. The largest hexagon that can be inscribed within the circular image field of the lens is used as the corresponding exposure region on the substrate. The single planar stage causes the mask and the substrate to scan in unison (say, along the x-axis) across their respective illumination regions to traverse the substrate length. Following a scan, the stage moves along y by an amount called the effective scan width (shown as w in Fig. 2). The substrate and mask are again scanned along x as before, after which they are laterally moved along y, and the process is repeated until the entire substrate is exposed. The complementary overlap between adjacent scans is such that the transition, from one scan to the next, is totally seamless and uniform.

Figure 2 illustrates the mechanism of seamless, overlapping scanning. The hexagon 36 represents the illuminated region on the substrate when the scanning begins. The orientation of the hexagon is such that one of its sides is orthogonal to the scan direction. The scans along x are shown as scan 1 (50), scan 2 (54), and scan 3 (58). The movement along y after each x-scan is shown by w (52) and given by $w = 1.5\ l_h$, where l_h is the length of each side of the hexagon. The hexagon 38 shows the y-position of the beam during scan 2, and its spatial relation to hexagon 36 illustrates why the exposure overlap between adjacent scans is seamless.

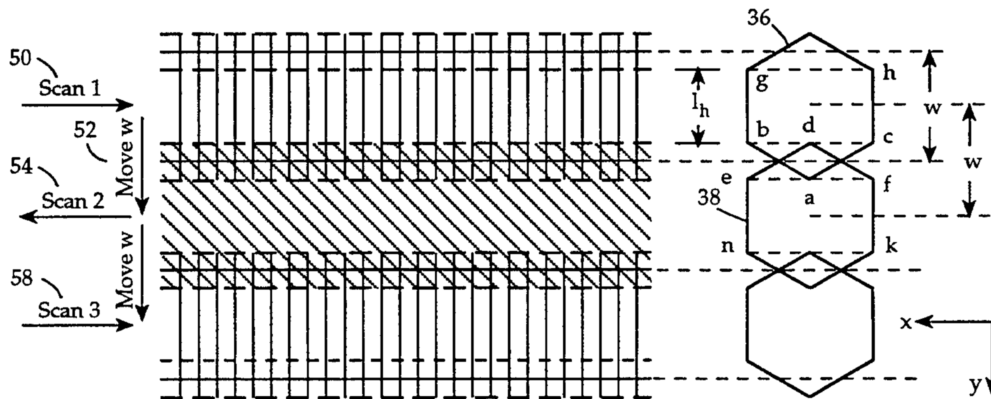

Fig. 2. The seamless scan-and-repeat mechanism, showing three successive scans and complementary exposure in the overlap area between adjacent hexagonal imaging regions.

In scan 1, the region swept by the rectangular portion b-g-h-c of hexagon 36 is not overlapped by any portion of scan 2. Similarly, in scan 2, the region swept by the rectangular portion e-f-k-n of hexagon 38 is not overlapped by any portion of scan 1. However, the region swept by the triangular segment a-b-c of hexagon 36 in scan 1 is reswept in scan 2 by the triangular segment d-e-f of hexagon 38. By integrating the dose received from each of the above triangular segments, it can be shown that the cumulative exposure dose received anywhere in the overlapping region is the same as in the nonoverlapping regions. Furthermore, the transition from scan 1 to scan 2 is seamless in exposure uniformity because the doses provided by hexagons 36 and 38 not only taper in opposite directions in the overlapping region, they taper to zero at apex a and apex d, respectively.

Thus, the Anvik system approach enables the designer to obtain the desired resolution by selecting a projection lens of a suitable numerical aperture, and deliver that resolution over very large substrate areas efficiently by the technique of hexagonal seamless scanning.

3. Experimental Results

3.1 Patterning in Photoresist

As part of the Phase 1 program, we conducted detailed experiments to study several different photoresists and optimize our processing parameters. Here, we present examples of the excellent results achieved using the Anvik lithography tool. We were able to obtain very good resolution down to the expected diffraction limit of the projection lens of approximately 3 μm.

Figures 3 and 4 show very good resolution of 5 and 3 μm lines and spaces, respectively, in 1.1 μm thick UCB-JSR TI 080 resist. These results are attained over the entire exposed area of 5 inch square glass substrates scanned at 25 cm/sec with our seamless scanning method.

In Figs. 5 and 6, we show scanning electron micrographs (SEM's) of features in 1.1 μm thick JSR IX 300 resist. Figure 5 shows very well resolved 6 μm lines and spaces, and Fig. 6 shows well resolved 4 μm features.

3.2. Photoablation in Polyimide

We have also conducted photoablation experiments with different types of polyimide. We were able to achieve excellent results for ablation of 10 μm vias. We have also obtained very good resolution of 6 μm lines and spaces. Below, we show results for photoablation of Dupont Pyralin 2611D polyimide, spin-coated on silicon substrates.

Figures 7 and 8 show ablation of 10, 20, 50, and 100 μm round vias and a checkerboard pattern of 10 μm square vias in 8.3 μm thick polyimide. Fig. 7 is focused on the substrate surface, showing that the 10 μm vias are just reaching bottom. Figure 8 is focused on the top of the polyimide coating.

We also present, in Figs. 9 and 10, scanning electron micrographs of these features. Figure 9 shows 100, 50, 20, and 10 μm vias along the bottom row and 100, 50, 20, and 10 μm pillars along the top row. There is a checkerboard pattern of 10 μm square vias at the bottom of the picture. This SEM shows very clean via-drilling, with the 10 μm via just reaching bottom. These vias have approximately a 30° wall angle from vertical. Figure 10 shows an enlarged view of the 20 μm via, which is cleared out to the bottom.

Figure 11(a) shows photoablation of 8 μm lines and spaces in 5.6 μm thick polyimide, and Fig. 11(b) shows an enlarged view of the 8 μm lines. The photograph is focused on the substrate surface, showing that the polyimide has been ablated through to the bottom. Figure 12 shows ablation of 6 μm lines and spaces. Since our slope angle is 30°, these do not reach bottom.

For ablation in Pyralin, we have measured an ablation rate of approximately 0.4 $\mu m/J/cm^2$. This ablation rate was found to be almost linear to a depth of at least 13 μm, and is consistent with other data reported in the literature.

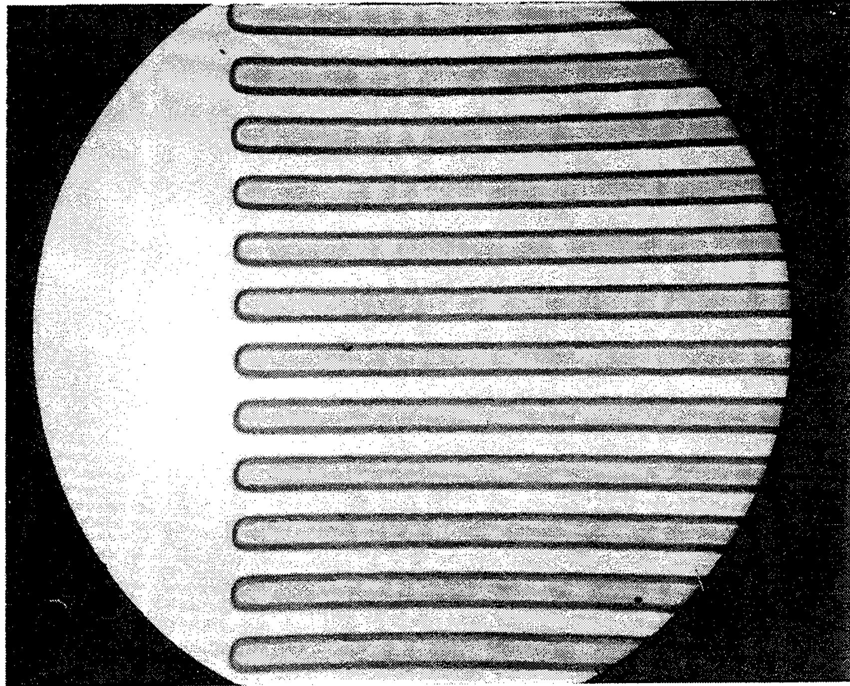

Fig. 3. Exposures in 1.1 μm thick UCB-JSR TI 080 photoresist with the Anvik patterning system, showing resolution of 5 μm lines and spaces.

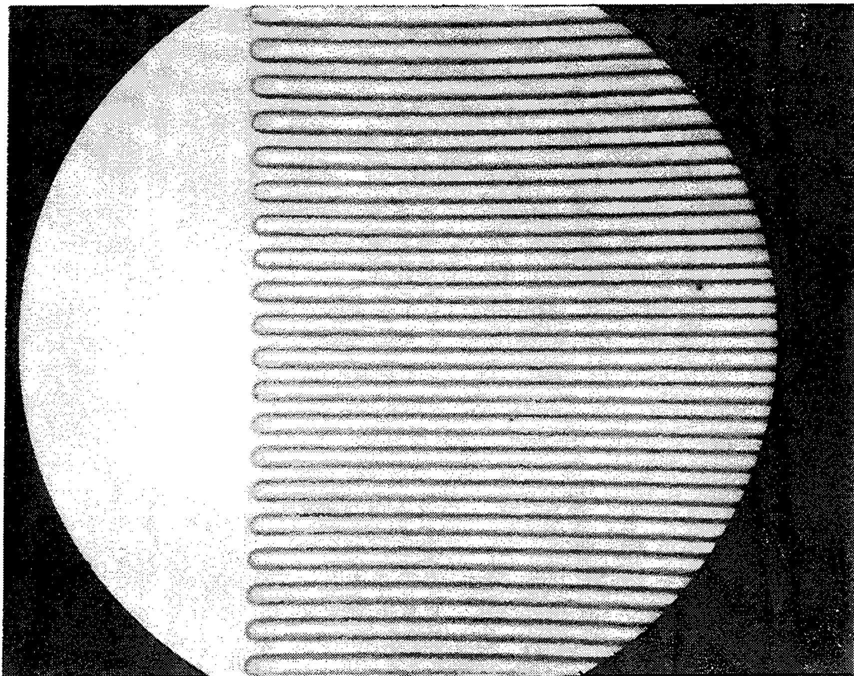

Fig. 4. Exposures in 1.1 μm thick UCB-JSR TI 080 photoresist with the Anvik patterning system, showing resolution of 3 μm lines and spaces.

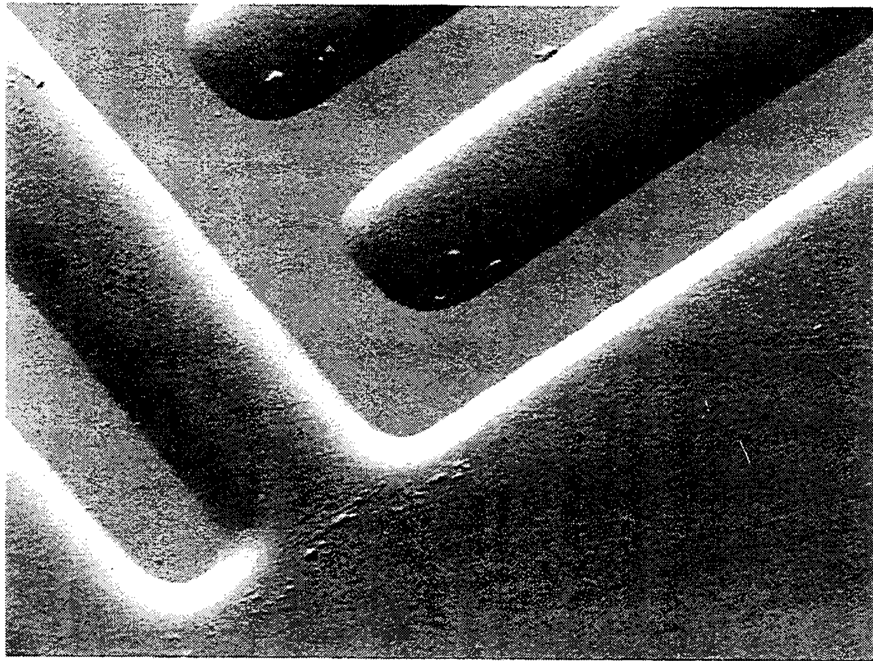

Fig. 5. Scanning electron micrograph of an exposure in 1.1 μm thick JSR IX 300 photoresist showing excellent resolution of 6 μm lines and spaces.

Fig. 6. Scanning electron micrograph of an exposure in 1.1 μm thick JSR IX 300 photoresist showing very good resolution of 4 μm lines and spaces.

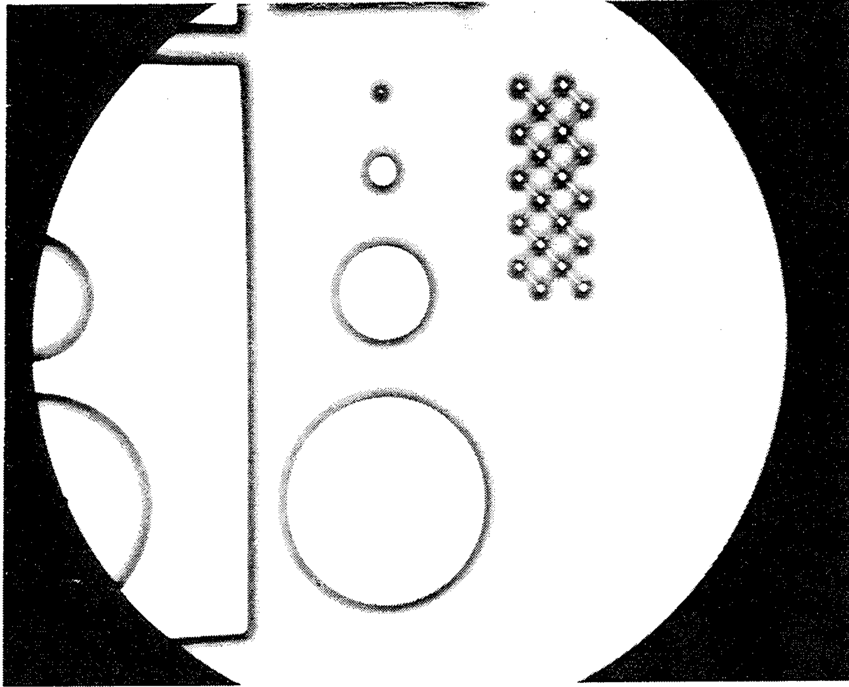

Fig. 7. Photoetching in 8.3 μm thick Pyralin PI 2611 polyimide by excimer laser ablation, showing patterning of 100, 50, 20, and 10 μm round vias and a checkerboard pattern of 10 μm square vias. The photograph is focused on the substrate surface, showing that the 10 μm vias just reach bottom.

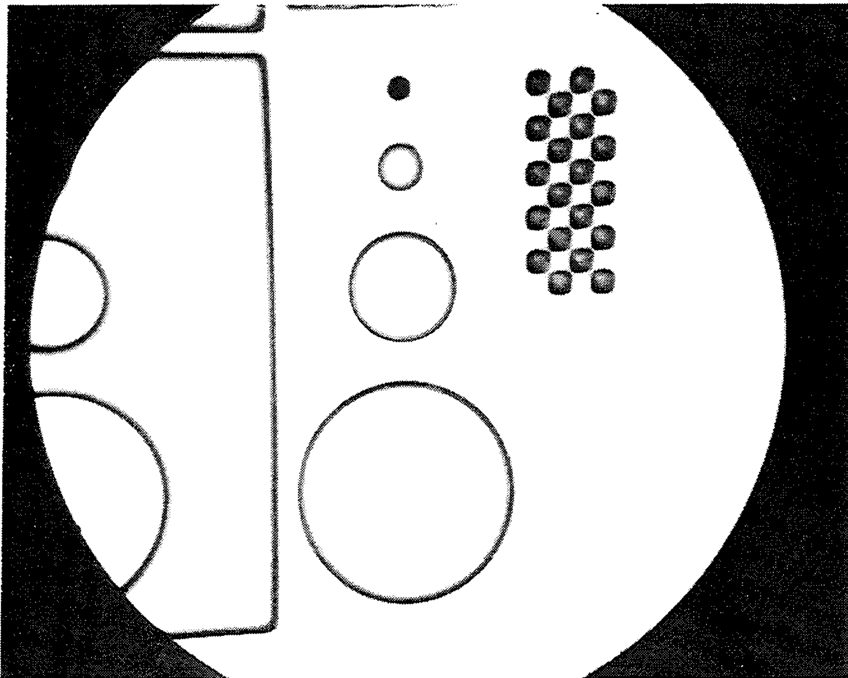

Fig. 8. Photoetching in 8.3 μm thick Pyralin PI 2611 polyimide by excimer laser ablation, showing patterning of 100, 50, 20, and 10 μm round vias and a checkerboard pattern of 10 μm square vias. The photograph is focused on the top of the polyimide surface.

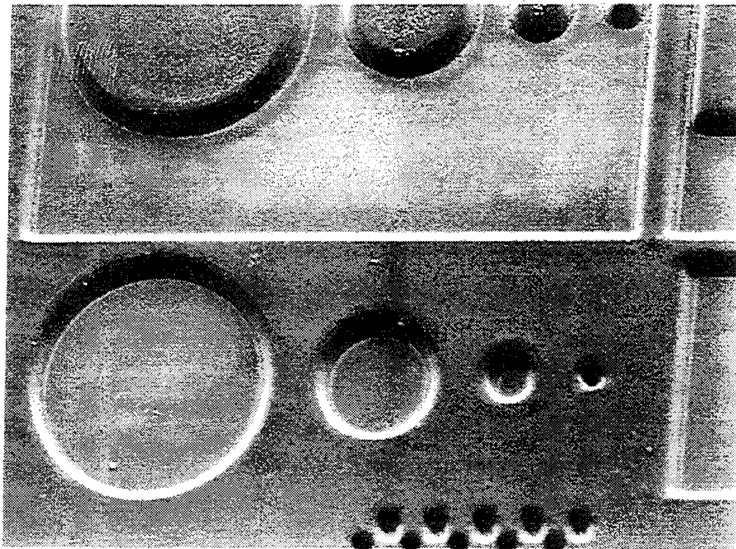

Fig. 9. Scanning electron micrograph showing patterns in 8.3 μm thick Pyralin PI 2611 polyimide photoetched by excimer laser ablation. The bottom row shows 100, 50, 20, and 10 μm round vias and the top row shows pillars of the same dimensions. At the very bottom is a checkerboard pattern of 10 μm square vias. The 10 μm round via can be seen to just reach the bottom of the substrate.

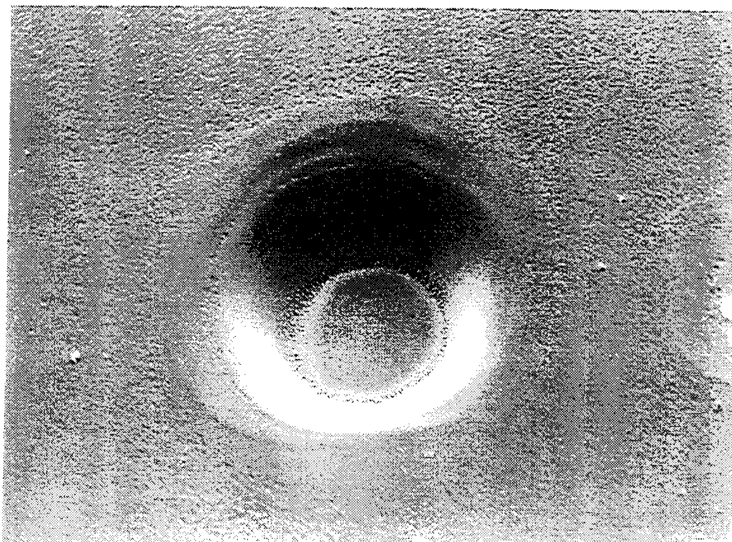

Fig. 10. Scanning electron micrograph showing an enlarged view of a 20 μm via drilled through 8.3 μm thick Pyralin PI 2611 polyimide by excimer laser ablation.

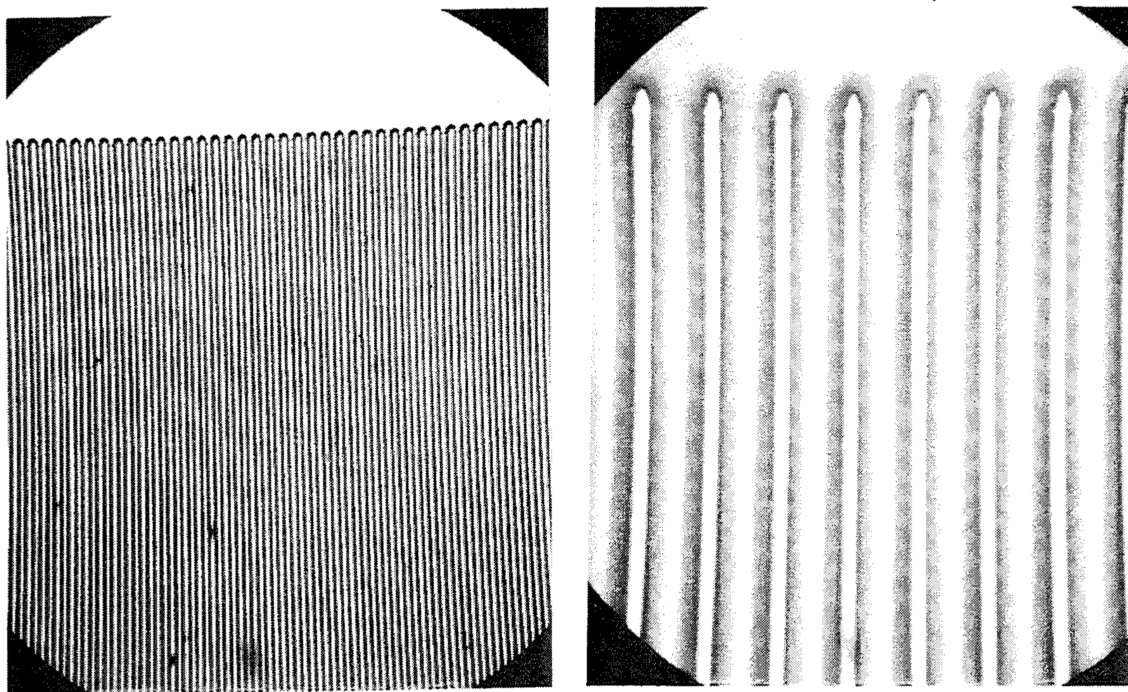

Fig. 11. Photoetching in 5.6 μm thick Pyralin PI 2611 polyimide by excimer laser ablation, showing patterning of 8 μm lines and spaces. The photograph is focused on the substrate surface. (a) A wide view of the features is given, showing excellent resolution and clearing to bottom. (b) An enlarged view of the 8 μm features is given.

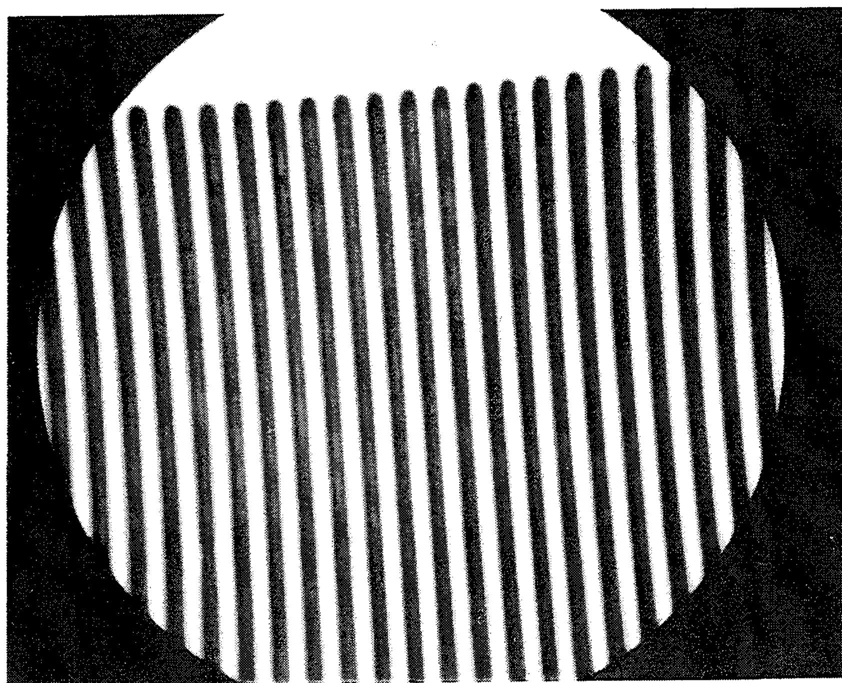

Fig. 12. Photoetching in 5.6 μm thick Pyralin PI 2611 polyimide by excimer laser ablation, showing well-resolved 6 μm lines and spaces, which do not reach bottom for this thickness. The photograph is focused on the substrate surface.

4. SUMMARY

In this Phase 1 program, we have successfully demonstrated the feasibility of Anvik's patterning technology. We have fully assembled a proof-of-concept patterning system and demonstrated large-area, seamless patterning using multiple, partially overlapping scans. We have also carried out seamless, scan-and-repeat exposure of polyimide to demonstrate large-area batch drilling of vias. For patterning in resist, we have demonstrated good resolution of 3 μm lines and spaces, and for via ablation in polyimide we have drilled 10 μm vias and 6 μm lines and spaces. We have carried out detailed experiments on large-area, seamless patterning of different photoresists and via etching in different interlayer dielectric materials.

The numerous advantages over other lithography systems by Anvik's patterning and via-drilling technology as demonstrated in this program are as follows:

(i) Being a projection system, it circumvents the traditional problems of contact and proximity printing: defect generation, mask degradation and limited resolution.

(ii) It eliminates the throughput bottleneck of laser direct-write machines by exposing very large numbers of pattern data in parallel rather than in a serial manner.

(iii) It enables patterning of substrates of practically any desired size with practically any desired resolution, eliminating field-size constraints of conventional projection tools.

(iv) Anvik's seamless scanning technique eliminates stitching errors and large overhead time, characteristic of step-and-repeat tools. It also provides greater optical efficiency and requires fewer scans, thus delivering significantly greater throughput.

(v) The single planar stage concept provides superior mechanical performance, remedying poor functional characteristics such as Abbe errors and flexure bending found in some other systems.

(vi) The desired resolution and substrate size handling capability can be delivered with off-the-shelf optical and mechanical components, thereby minimizing commercialization risks.

(vii) Its modular design permits rapid construction of the exposure system in different user-specified configurations, and provides upgradability without complete retooling.

(viii) The Anvik tool is highly versatile, providing high-throughput capability for both photoresist patterning and dielectric via drilling, thus lowering both capitalization costs and required cleanroom space.

This program has successfully demonstrated that Anvik's excimer laser exposure system delivers both large-area lithography capability with the desired resolution, and high throughput at a low cost of ownership. These performance breakthroughs are achieved using entirely off-the-shelf optical and mechanical subsystems, thereby minimizing development and commercialization risks.