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Rapid Prototyping of Masks from Various 35mm Film Types for Use in Photolithography

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Abstract

Photolithography is a process by which a photoactive polymer material known as photoresist is deposited onto a substrate and exposed with ultraviolet (UV) light through a mask in order to replicate a pattern onto a substrate. Progress in lithography has been one of the most important technological advances in the miniaturization and efficiency of microelectronics during the last three decades. This paper reports an inexpensive approach to producing masks used in patterning substrates through photolithography with minimum feature sizes of approximately 100 µm. Patterns were created on the computer drawing program Corel Draw. Images were printed from the computer onto transparencies via laser printing and several different 35 mm film types. These masks were tested in the laboratory with varying exposure times and development times in order to determine the best technique for mask production. Exposure times ranged between 5 and 15 s with 7 s generally being the optimal time, depending upon which mask was being used. We report that masks produced with Kodak Kodalith film results in reproducible 100 µm features and can be readily generated in an undergraduate laboratory. This rapid approach for producing masks allows for an undergraduate research lab to engage in research involving photolithography at a fairly inexpensive cost.

1. Introduction

Photolithography is one of the most important processes in the microfabrication industry[1]. With the use of photolithography, submicron features can be patterned onto substrates for the production of microelectronic devices, flat panel displays, integrated circuits (IC), and many other devices. Photolithography involves a photoactive polymer material known as photoresist. This is exposed to ultraviolet (UV) light through a mask in order to create a pattern on a substrate. Masks used in optical photolithography are made from patterned chromium thin films on high purity quartz substrates. These typically cost about $80/in^2 which means that a 5 x 5 in. mask costs about $2,000.[2] This paper presents an inexpensive and rapid approach for producing masks with 100 µm feature resolution in an undergraduate laboratory setting.[3]

Black and white slide film offers a convenient alternative to designing and fabricating a chromium mask for structures at least 100 µm in size. The idea is to create a mask that is capable of blocking UV light in certain carefully defined areas while allowing UV light through other regions. Several different 35 mm black and white films, as well as laser printer transparencies were used to determine which provided the most clearly defined features and even exposure.

2. Experimental

2.1. Instrumentation and Materials.

A high resolution (2000 line per inch) screen capture camera (Polaroid Digital Palette CI-5000) was used to transfer images from a computer screen onto the 35 mm film. Deposition of photoresist was performed on a Laurell Technologies WS-200 spin coater. Photoresist was exposed using an Oriel Corporation 200-watt Hg flood exposure lamp. Transparency images were printed on a 1200 d.p.i. Hewlett Packard Laser Jet 2100TN printer. Optical microscopy was performed using a Nikon CCD camera with a PC video capture card.

Shipley 1818 Positive Photoresist was used as-received. P-type (100) silicon wafers were obtained from Virginia Semiconductor. Silicon wafers were deposited with Shipley 1818 Positive Photoresist at 4000 rpm for 60 s and baked at 115°C for 60 s, giving a photoresist thickness of about 2 μm. The samples were exposed for various times ranging between 5 and 20 s. All samples were then developed for 60 s in Shipley Photoresist Developer, rinsed with deionized water, and dried with compressed N_2. Polachrome Polaroid 100 film, Kodak TMY 200 and 400 speed black and white film, and Kodak Kodalith Ektagraphic HC slide film were used. Kodak Developer D-11 and Kodak Fixer were prepared and used as instructed by Kodak for the Kodalith development process. Chrome masks were supplied by MCNC in Research Triangle Park, NC.

2.2. Producing Mask Patterns.

Test pattern images were created using the computer drawing program Corel Draw 7. (See Figure 1) The original test pattern was drawn in a 1 cm^2 box on Corel Draw. Since the image produced on the slide film is a reduction of the image on the computer screen, the 1 cm^2 box was systematically enlarged from 125%-1000% in order to determine the enlargement that would create a 1 cm^2 box on the film. This was done for two reasons. First, this was necessary to determine what feature size produced the best resolution on film. Second, this was done to determine the smallest feature that could be patterned with each film type onto a substrate. It was determined that an 800% (8x) of the Corel Draw file to an 8 cm^2 box would reproduce a 1 cm^2 box onto the slide film when printed using the Digital Palette.

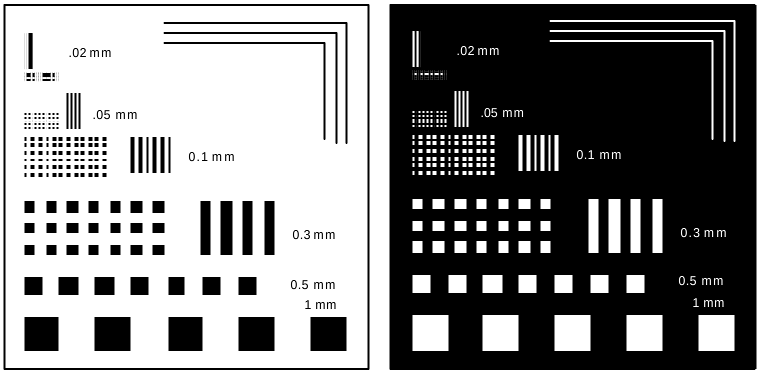

Figure 1: Test patterns drawn on Corel Draw. Each feature is drawn to the actual labeled size in Corel Draw.

2.3. Mask Production

2.3.1 Laser Printer Transparencies.

A separate heater pattern with feature sizes as small as 100 μm was designed on Corel Draw in the manner described previously, and printed to a laser printer transparency using the 1200 dpi laser printer. The transparency was then cut to about 1.5 in^2 for use as a mask in photolithography.

2.3.2 Polaroid Polachrome 100 Slide Film.

Several test pattern images were enlarged as described previously. The images were then printed to Polaroid Polachrome 100 Slide Film using the Polaroid Digital Palette CI-5000. A Polaroid development cartridge provided with the film was used to develop the film in 2 min. The film was cut into segments containing separate images and each image was placed into a slide frame. The slides were viewed on a screen using a projector. Three clean silicon wafers were spin coated with photoresist as described previously and developed under the same conditions. Exposure times were 5, 7, and 10 s.

2.4.3. Kodak TMY 400 film and TMY 200 black and white film.

Images were printed to Kodak TMY 400 film through the Digital Palette. There was no available setting for 400-speed film on the computer film tables used in setting the parameters for the Digital Palette, so a 200-speed setting was used. The film was developed locally[4]. The slide film was observed under an optical microscope to determine the minimum visible feature size, edge resolution, and pinhole resistance. A clean Si wafer was spin coated with photoresist as previously described, exposed for 7 sec, and developed.

Identical images were again printed to a roll of Kodak TMY 200 black and white film, and developed as previously described. The film was observed under an optical microscope. A clean silicon wafer deposited with photoresist at 3000 rpm (for a thicker layer) was used to test a mask from the roll of film. After an exposure time of 7 s and a development time of 60 s, the sample was observed under an optical microscope.

2.4.4. Kodak Kodalith Ektagraphic HC slide film.

Kodak produces a high definition black and white film with no gray scale known as Kodalith. This film is often used for high resolution applications such as astronomy and offers a great possibility for mask production in photolithography in an undergraduate laboratory. A disadvantage to using this film is that it must be self-processed in a darkroom. Multiple rolls of Kodalith were used. Several images were printed to the film using the Digital Palette. Brightness levels for exposure of the film were varied with the computer from a level of 50 to a level of 200 since there was no previously defined film tables for Kodalith film.

Kodak Developer D-11 and Kodak Fixer were prepared as directed on the packages and stored at 23°C. Rolls of Kodalith were put onto metal film reels in a darkroom under a red safe light. Two film reels were loaded into a metal developing tank. One reel containing the film was placed on the bottom while the second reel (empty) was placed on top. A black lid was snapped onto the tank. The lights in the darkroom could then be turned on. The tank was filled with tap water and left to soak for about 5 min. The water was then poured out and 8 oz. of developer D-11 was added to the tank. The tank was agitated for 2.5 min. followed by disposal of the developer. The tank was then rinsed several times with tap water. Rinsing was followed by the addition of 8 oz. of fixer. The tank was agitated for 5 s every 30 s for a period of 3 min. The fixer was disposed of after the 3 min. period, and the film was removed from the tank and the reel. The film was then placed into a tray with running tap water for approximately 10 min., then hung to dry. Images from the Kodalith film were cut into separate sections. Several clean silicon wafers were patterned using these masks. Exposure times varied from 5 sec. to 15 sec. Samples were observed under an optical microscope to determine the correct exposure time.

3. Results and Discussion

A summary of the results of each type of film is shown in Table 1. Edge and minimum feature resolution, ease of use, and pin hole resistance are compared with one another. The following describes in more details how each mask type compared.

Mask Type	*Minimum Feature (mm)*	*Edge Resolution*	*Pinhole Resistance*	*Ease of Manufacture*
Laser Transparency	100	Fair	Poor	Excellent
Polaroid	300	Poor	Poor	Good
Kodak 200	300	Fair	Good	Fair
Kodak 400	300	Poor	Good	Fair
Kodalith	100	Good	Good	Fair
Chrome/SiO_2	> 0.5	Excellent	Excellent	Poor

Table 1: Comparison of rapid prototyping mask types. Chrome/SiO_2 mask is to compare with commercially produced masks for photolithography.

3.1 Laser Printer Transparencies.

Laser printer transparencies produced minimum features of 100 µm after exposure and development of photoresist. The resulting edge resolution was fair as shown in Figure 2. Pinhole resistance was poor. It was noted that "dark field" masks (masks with a black background and white features) were subject to overexposure in the black regions. This happens because the laser printer does not completey block the UV light, and leakage exposes the photoresist. There is no doubt that pinhole resistance will improve as higher resolution printers are produced. Laser printer transparencies offer an easy and inexpensive approach to performing photolithography in an undergraduate laboratory. In fact, we have introduced a freshman chemistry laboratory[5] using this technique for mask production modeled after the work of Gwozdz.[3]

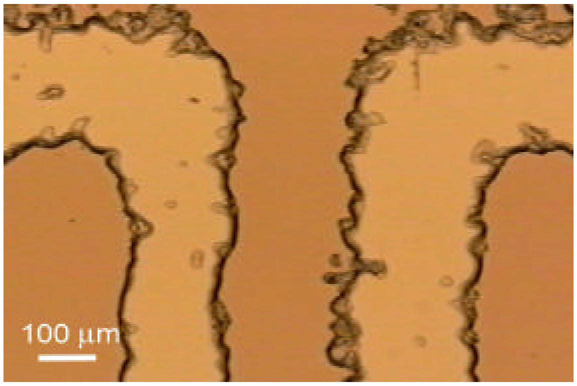

Figure 2: Photoresist after exposure and development through laser transparency mask

3.2. Polaroid Polachrome 100 Slide Film.

Polaroid Polachrome film images appeared fuzzy and not well defined, however there was little to no gray area around the features. The grains appeared to be large when observed under the optical microscope. This large grain size in the film explain the undefined features. The Si wafers exposed through Polaroid Polachrome masks were also viewed under an optical microscope. The film did not appear to give clearly defined features. In areas of the “unexposed” photoresist, development had occurred, leading to the possibility of UV light leaking through dark areas of the film. The mask itself was observed under the optical microscope to determine the cause of the UV leak. The grains in the film appeared to be large allowing for small pinholes in the mask and undefined features. (See Figures 3 and 4) It was determined that this film type, while easy to use, is not adequate for use in mask fabrication.

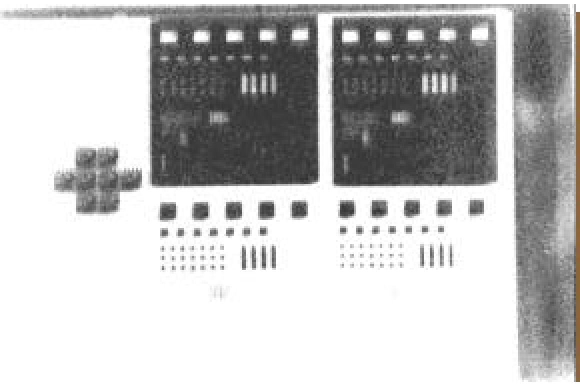

Figure 4: Polaroid Polachrome test pattern mask: Features are not defined and gray areas are apparent

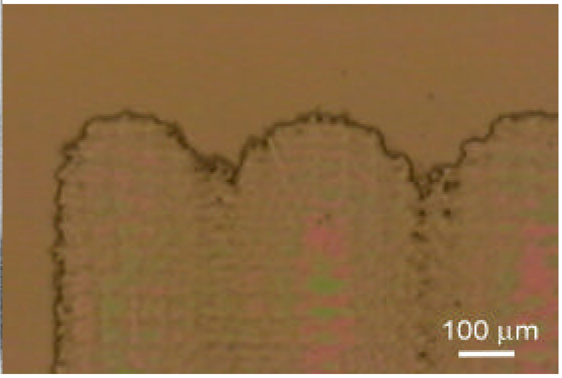

Figure 5: Optical micrograph of photoresist after development with exposure through Polachrome mask. Features are not developed to substrate

3.2. Kodak TMY 400 Film and Kodak TMY 200 Film.

Kodak TMY 400 black and white film produced clear images, however there is a grayscale evident around the edges of features (See Figure 5). Optimal exposure times ranged between 10 and 15 s. Photoresist exposure around these features was uneven due to this gray scale. The 400 setting for the film was also not available in the film tables accompanying the software for the Digital Palette. This could be a possible reason for such a large gray scale around the features of the images. The Kodak TMY 200 film produced clearer images with more subtle gray areas around the features (See Figure 6). Samples of Si wafers deposited with photoresist and exposed through the 200 and 400 masks were unevenly exposed around the features due to the gray areas of the masks. This is shown in Figure 7.

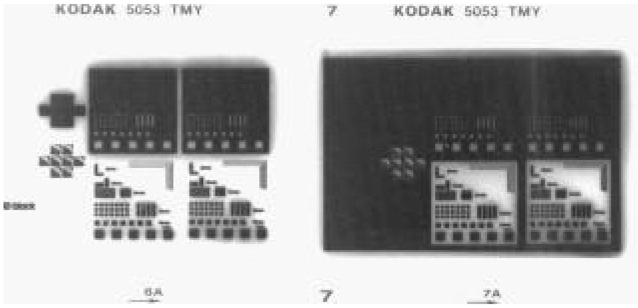

Figure 5: Kodak TMY 400 test pattern mask: Gray areas are apparent around features.

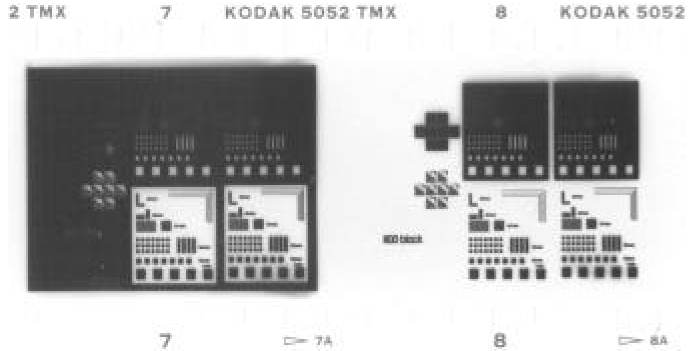

Figure 6: Kodak TMY200 film test pattern mask. Less pronounced gray scale in clear regions.

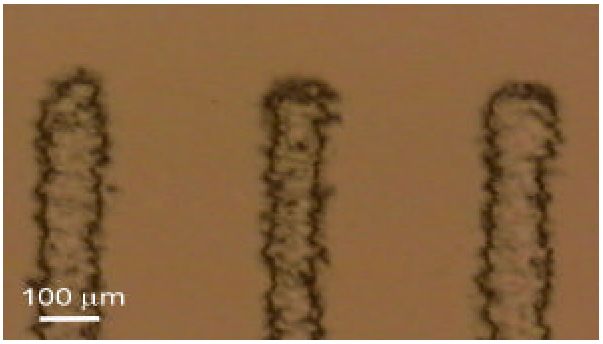

Figure 7: Optical micrograph of photoresist after exposure and developmentthrough Kodak TMY200 mask

3.3. Kodak Kodalith Ektagraphic HC Slide Film.

Developed Kodalith film gave well-defined images with no gray scale. Optimal exposure times ranged between 5 and 7 s. The film surrounding the features was completely clear to provide a better exposure. The best brightness level during exposure was found to be 100. Samples of Si wafers deposited with photoresist and exposed using these masks demonstrated clear features as small as 100 µm on the test pattern. (See Figures 8 and 9.) We directly compared the same 100 µm features of the Kodalith and the TMY 200 film in Figure 10. One can clearly see that the Kodalith film results in a greatly improved pattern transfer and edge resolution.

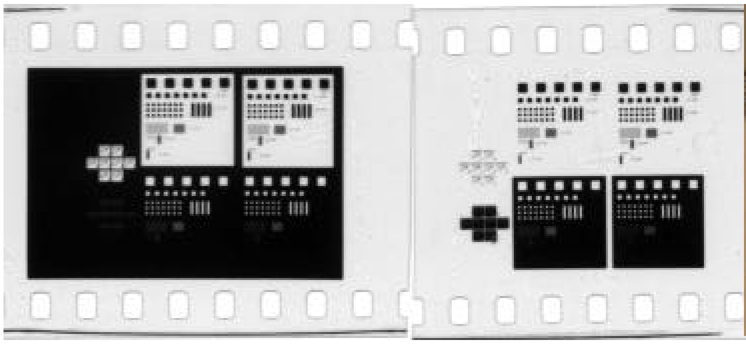

Figure 8: Kodak Kodalith test pattern mask

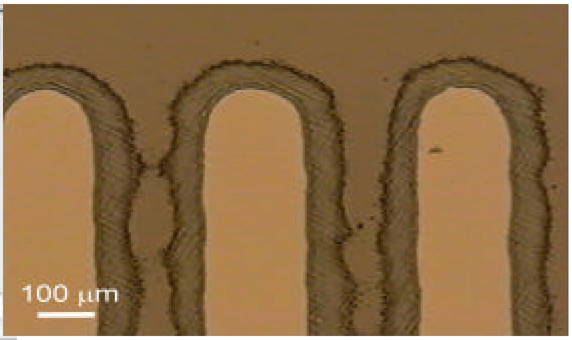

Figure 9: Photoresist after exposure and development through Kodak Kodalith mask

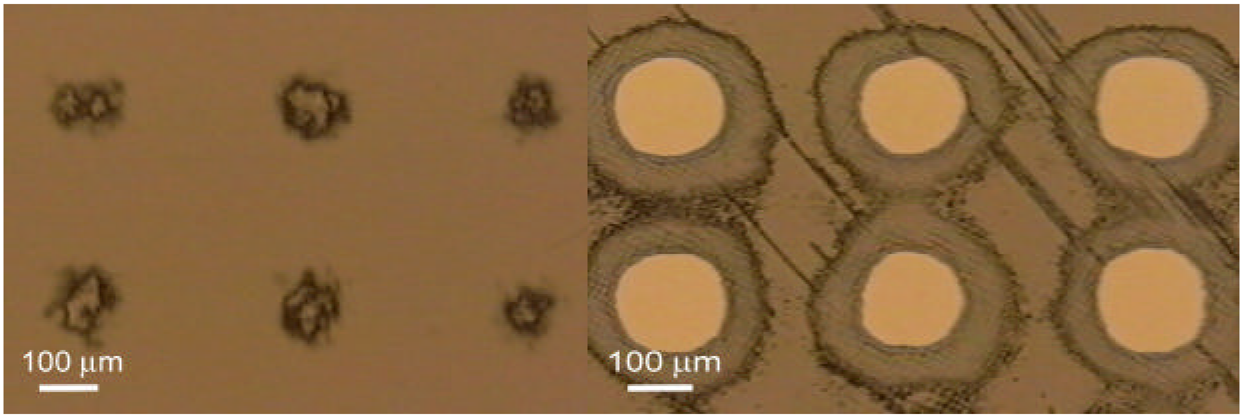

Figure 10: Comparison of exposed and developed photoresist through a Kodak TMY 200 film mask (left) and a Kodak Kodalith mask (right). Both show identical 100 µm features from the test pattern.

4. Conclusion

Using film for the production of masks offers a rapid and inexpensive approach to photolithography. It is fairly simple to create the designs on any computer drawing program. A Polaroid Digital Palette or any other digital camera capable of taking images from a computer and transferring them to film can be used. Laser printer transparencies offer a quick, easy, and inexpensive option for producing photolithography masks. Though the edge resolution is not particularly good, it is predicted that will improve as printer technology continues to advance. The Kodak TMY 200 and 400 films are accompanied with gray scales that are not beneficial to photolithography. Well-defined features with no gray scale are best achieved with the use of Kodalith film. Though this film must be self-processed, it offers great possibilities for rapid prototyping masks for photolithography in an undergraduate setting.

5. Acknowledgments

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6. References

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[5] A. M. Christensen, T. C. DeVore and B. H. Augustine, Chemical Educator (to be submitted) (2000)