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1991-11-01

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Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Physics Division

Presented at the IEEE Nuclear Science Symposium,
Santa Fe, NM, November 5–9, 1991, and to be
published in the Proceedings

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S. Holland

November 1991

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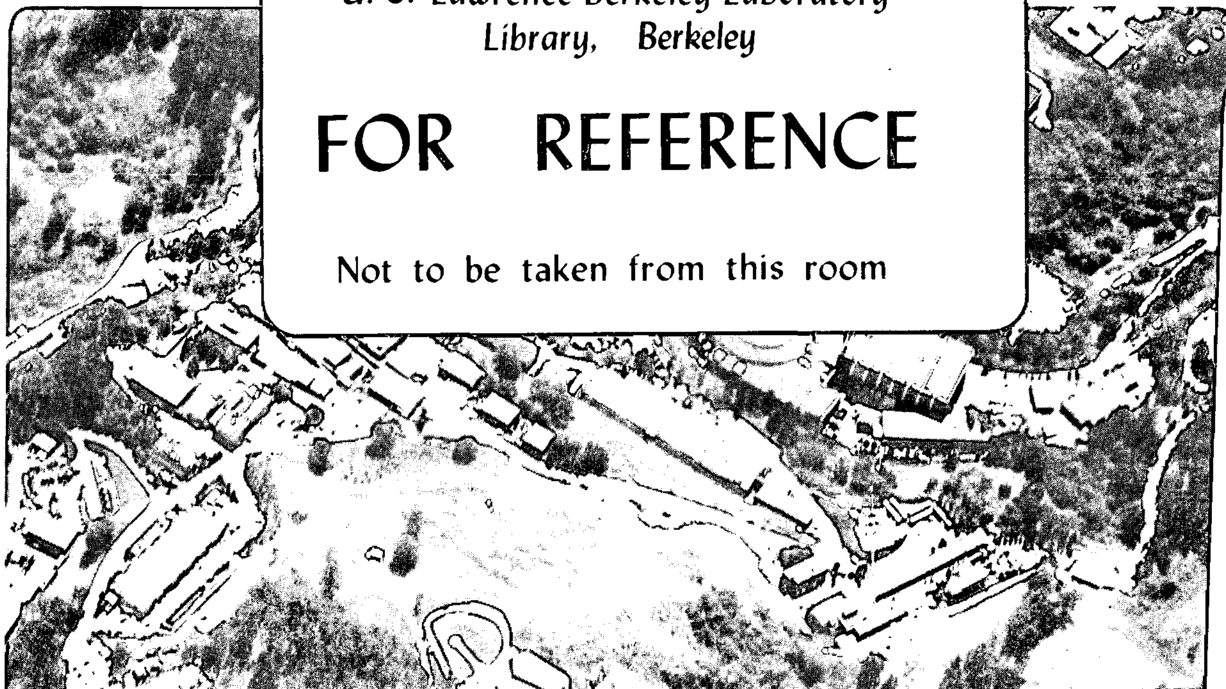

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LBL-31595

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This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Fabrication of Silicon Strip Detectors Using a Step-and-Repeat Lithography System

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Abstract- In this work we describe the use of a step-and-repeat lithography system (stepper) for the fabrication of silicon strip detectors. Although the field size of the stepper is only 20 mm in diameter, we have fabricated much larger detectors by printing a repetitive strip detector pattern in a step-and-repeat fashion. The basic unit cell is 7 mm in length. The stepper employs a laser interferometer for stage placement, and the resulting high precision allows one to accurately place the repetitive patterns on the wafer. A small overlap between the patterns ensures a continuous strip. A detector consisting of 512 strips on a 50 μm pitch has been fabricated using this technique. The dimensions of the detector are 6.3 cm by 2.56 cm. Yields of over 99% have been achieved, where yield is defined as the percentage of strips with reverse leakage current below 1 nA. In addition to the inherent advantages of a step-and-repeat system, this technique offers great flexibility in the fabrication of large-area strip detectors since the length and width of the detector can be changed by simply reprogramming the stepper computer. Hence various geometry strip detectors can be fabricated with only one set of masks, as opposed to a separate set of masks for each geometry as would be required with a contact or proximity aligner.

1. Introduction

Silicon strip detectors have been extensively used for vertex detection and tracking in high-energy physics. In order to cover the entire interaction region at colliding-beam accelerators, the detectors are typically several cm to 10's of cm in length [1]. The lithography system used for detector fabrication normally consists of a contact or proximity printer which uses a mask with feature sizes identical to those desired on the silicon wafer (1:1 system). The major drawback of contact printing is that repeated contact between mask and wafer results in defects on the mask which are obviously undesirable for large-area devices. Proximity printing, in which the mask is separated from the wafer by a small distance (typically 10–20 μm), eliminates the mask-wafer contact but resolution is sacrificed. Diffraction effects cause the minimum linewidth which can be printed in proximity mode to be significantly degraded from that possible with contact printing. However, the decrease in resolution is usually not of concern in detector fabrication since the typical linewidths are much larger than the resolution limit of the lithography tool, even when proximity printing is used. Nevertheless, future designs of strip detectors that monolithically integrate readout electronics with the detector would benefit from high-resolution lithography [2].

Step-and-repeat lithography systems (steppers) utilizing high numerical-aperture lenses and short exposure wavelengths can achieve linewidths in the submicron range and are extensively used for high-performance microelectronics manufacturing. In such a system the mask contains the pattern for one die, and the pattern is repeatedly printed on the wafer which is located on a movable stage. This type of system has numerous advantages when compared to contact or proximity printing.

To minimize the effects of flatness variations of the wafer, an automatic focus system maintains the correct focus for each step-and-repeat location. The autofocus system thus can maintain high resolution even in the presence of some wafer distortion. Also, a reduction lens is used to reduce the pattern on the mask to the desired size on the wafer and hence the mask does not come into contact with the wafer. Typically the reduction ratio is 5:1 or 10:1. This simplifies mask making since the features on the mask are scaled by a factor of 5 or 10 compared to what is actually printed on the wafer. In addition, the sensitivity of the process to particles on the mask is reduced since they in turn are reduced in size at the wafer plane. However, the field size of a wafer stepper is limited by the availability of reduction lenses with acceptable performance. Field sizes are usually 10 to 30 mm in diameter which is much smaller than a typical strip detector.

We have utilized a technique which overcomes the field size limitation and allows one to fabricate large-area strip detectors with a wafer stepper. This technique essentially consists of the precise, repetitive placement of strip patterns on the wafer. Prototype detectors using this method has been fabricated and tested. In addition to the inherent advantages of a stepper described above, the technique will be shown to offer much greater flexibility in the geometry of detectors which can be fabricated from a single mask set. The next section describes the technique in detail, followed by experimental results from the first prototype.

2. Experimental Technique

Figure 1 shows the mask design used in this work. A GCA Model 6100 stepper with a 5X reduction lens was used for this investigation. The mask layout consists of two arrays, one with just strips (128 strips on a 50 μm pitch) and the other with strips and bonding pads. Guard ring structures and alignment fiducials are also included in the layout. The strip length is 7 mm at the wafer plane. The mask patterns shown in Figure 1 fit comfortably within the 20-mm diameter field of the stepper (100-mm diameter at the mask plane). For this application a 5X stepper is preferred over a 10X since more layout artwork can be accommodated on a 5X mask.

The strip detector pattern shown in the upper portion of Figure 1 is the basic unit cell used in this work. This pattern is precisely placed on the wafer in the areas where strips are desired. Overlap of the patterns results in a continuous strip whose length is a multiple of the unit cell length of 7 mm. The pattern including bonding pads can be placed wherever bonding pads are required, and the entire structure can be enclosed by a guard ring.

In order for this technique to be viable, one must have the capability to expose only the desired pattern on the mask while the remaining patterns are covered by a light shield. This is accomplished with the use of a programmable aperture system (Silicon Valley Associates, Inc. Model 101). This device is positioned between the mask and light source of the stepper and consists of 4 independent knife blades driven by stepping motors. The aperture opening can be programmed to any size from 5 mm square to 100 mm square and thus fulfills the need to selectively expose various parts of the mask. All masks used in this work are dark field, i.e. the patterns are clear areas and the remainder of the mask is opaque. Hence the mask itself functions as a fine aperture. An image reversal photoresist is used for those mask layers where the mask image must be inverted on the wafer (KTI Chemicals, Inc. 875 Dualtone Resist).

The resulting image on the wafer must be placed in the precise location where it is needed. The wafer stepper uses a laser interferometer for highly accurate positioning of the wafer. The wafer is held on a stage under vacuum, and a two-frequency laser system monitors the location of the stage by measuring interference signals from a fixed reference point and the stage. We have measured the precision of stage placement to be better than ± 0.3 μm ($3\ \sigma$). Compared to normal strip detector geometries, this number is negligible. Precision of this magnitude allows one to form continuous strip detector structures by overlapping successive patterns by a small amount. To minimize any effects at the overlap area, the length of the overlap is only 0.5 μm, which is comparable to the measured error in stage placement.

For the mask layout shown in Figure 1 a total of 10 passes are required to print the first layer of the detector. A pass is defined as a set of exposures at a given aperture setting. The only operator intervention required for this process is the changing of the aperture position after each pass. The wafer remains on the stage for all 10 passes and no alignment between passes is required. Operator intervention can be eliminated entirely by interfacing the aperture system directly to the stepper computer.

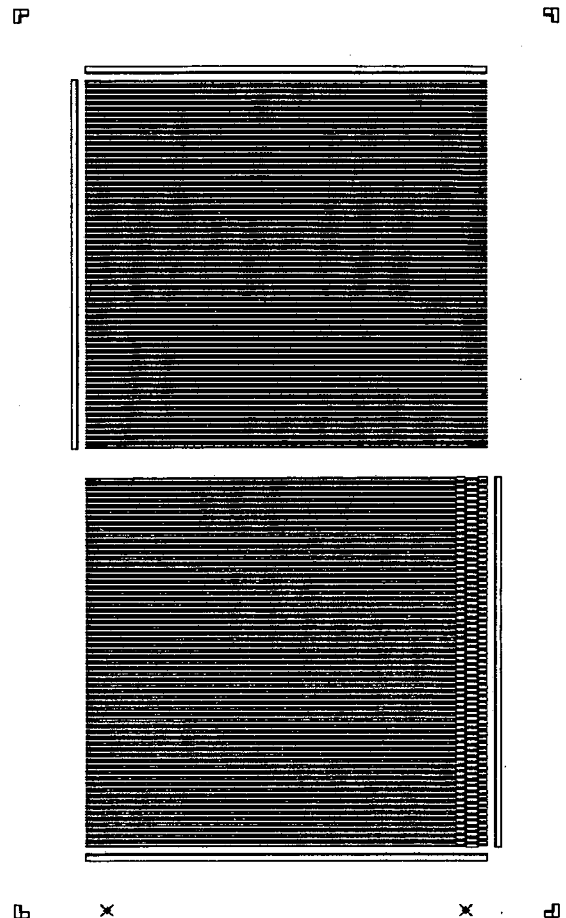

Figure 1. The mask layout used to fabricate strip detectors in this work. The upper array consists of 128 strips on a 50 μm pitch. The lower array includes bonding pads. Guard ring structures and alignment fiducials are also shown. The outermost features are at a diameter of 16.2 mm, well within the 20-mm field size of the stepper.

Once the first layer of the detector is processed, successive layers must be aligned to the first layer. A global alignment technique is used to allow for large-area devices. Global alignment refers to a method in which the second and higher mask levels are aligned to one set of alignment fiducials on the wafer. Once the wafer is aligned at this site, one relies on the stage precision to maintain alignment across the remainder of the wafer. This eliminates the need for alignment fiducials at every step-and-repeat location on the wafer. Figure 2 shows the typical location of global alignment fiducials for the GCA Model 6100 stepper. For the 100-mm diameter silicon substrates used in this work the fiducials are spaced 7.62 cm apart and occupy an area of approximately 200 μm square. The fiducials are present on the first layer only and essentially the entire remaining area of the wafer is available for the placement of strip detector patterns. The fiducial locations shown in Figure 2 are for standard fiducials. Nonstandard fiducials can be placed in alternate locations for applications requiring

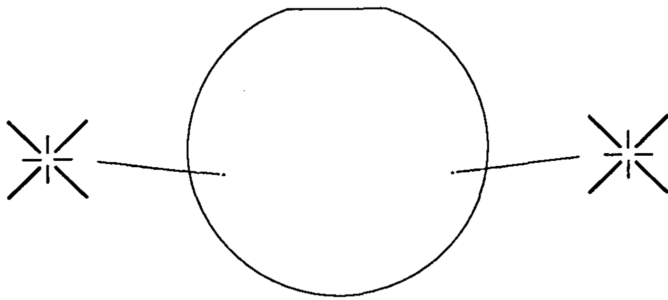

Figure 2. Location of standard global alignment fiducials on a 100-mm diameter wafer. The horizontal spacing between alignment fiducials is 7.62 cm.

strip patterns which would otherwise infringe on the location of the standard fiducials.

In the next section experimental results from the fabrication of a prototype detector are described.

3. Fabrication/Experimental Results

Silicon strip detectors have been fabricated using the techniques described in the previous section. The starting substrates were 100-mm diameter, <100> float-zone refined silicon. The conductivity is n-type and the resistivity is approximately 8000 Ω–cm. A gettering layer consisting of in-situ doped polysilicon was employed to minimize the detector leakage current as described previously [3]. Figure 3 shows a photograph of a 100-mm diameter wafer containing two strip detectors. The detectors are 6.3 cm long (9 unit cells in X) by 2.56 cm wide (4 unit cells in Y). The total number of strips in each detector is 512 and the strip pitch is 50 µm. Each detector is completely surrounded by a guard ring and contains bonding pads at one end of the detector for electrical probing.

The detector process requires three masks. The first mask defines openings in the thermally grown oxide where p^+ junctions are formed by ion implantation of boron. The implants are thermally annealed at 900C in steam. Contact openings are formed with the second mask, followed by metal deposition (Al - 2% Si) and patterning of the metal using the third mask. The wafers are sintered in forming gas at 400C for 20 minutes to complete the processing.

Figure 4 shows a histogram of measured reverse leakage current at 60V of substrate bias. The depletion voltage for these 300 µm -thick devices is approximately 40V. The data shown is a compilation of measurement results from two 6.3 cm-long detectors. Of the 1024 strips probed, 98.3% had currents below 200 pA. Of the strips exceeding 200 pA, all but 2 were below 1 nA. The maximum measured current on any strip was 16 nA. Neglecting the upper 1.7% of the distribution results in a standard deviation in leakage current of 5.8 pA. The approximate mean value of 150 pA corresponds to a current per unit area of approximately 5 nA/cm^2. These results are consistent with high-quality strip detectors.

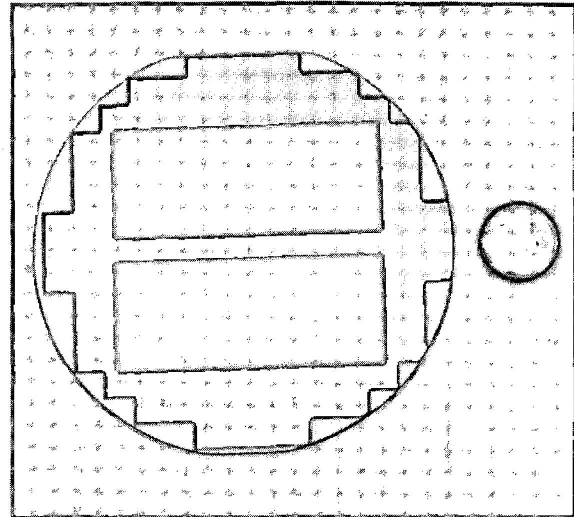

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Figure 3. Photograph of a 100-mm diameter wafer including 2 strip detectors of dimensions 6.3 cm by 2.56 cm.

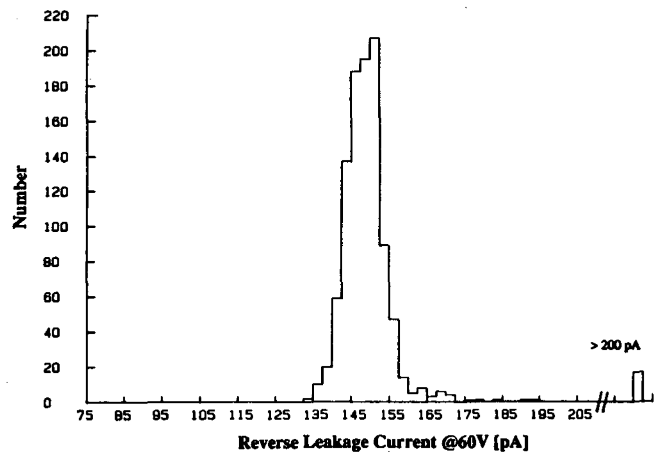

Figure 4. Histogram of measured reverse leakage current for the detectors shown in Figure 3. The substrate bias was 60V.

4. Discussion

The experimental results presented in the previous section validate this approach to large-area detector fabrication. The technique allows both high-resolution lithography and large-area device fabrication with the same lithography tool. The strip width in these detectors is 16 µm. The precision of this technique allows narrower strips (2–4 µm) even with multiple process steps as needed for ac-coupled detectors. The mask does not contact the wafer and defects on the mask are reduced by a factor of 5 at the wafer plane, both of which are desirable for a high yield process. The major drawback is reduced wafer throughput due to the step-and-repeat nature of the technique and the requirement for changing aperture settings during the lithography process.

However, these disadvantages are offset somewhat with respect to the flexibility possible with this approach. Figure 5

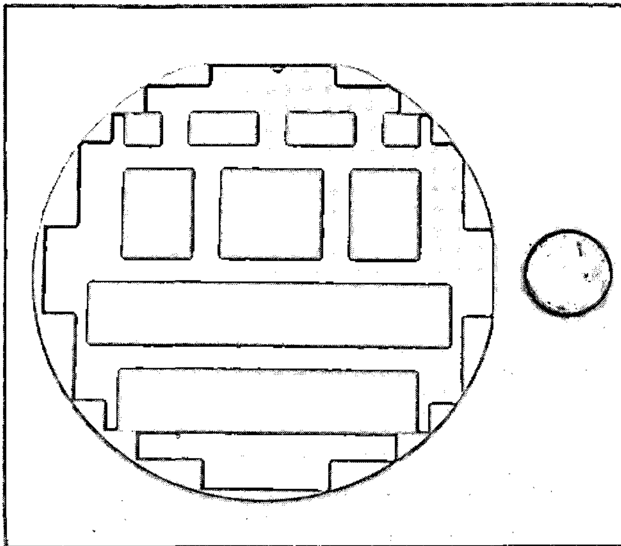

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Figure 5. Photograph of a metal-mask pattern on a 100-mm diameter wafer. The pattern was generated from the basic layout of Figure 1.

shows a metal mask pattern fabricated on a 100-mm diameter silicon substrate. The mask set used was the same as used to fabricate the detectors shown in Figure 3. By simply reprogramming the stepper computer, various geometry detectors are realized from the basic mask layout shown in Figure 1. Detector patterns ranging from lengths of 7 mm to 70 mm are shown. The only constraints in detector geometry are the unit cell size and the need for a set of alignment fiducials on the wafer. A smaller unit cell will increase the flexibility at the expense of throughput. The conventional approach of fabricating strip detectors using contact or proximity printing requires a separate set of masks for each geometry. Hence this approach can be used for inexpensive, rapid prototyping of devices since several geometry detectors can be fabricated from the same mask set. The approach might also be amenable to the generation of 1X masks using a step-and-repeat camera although we have not investigated this possibility in any detail.

While the detectors fabricated in this work are single-sided, we believe that this technique could also be applied to double-sided detectors. Wafer steppers in general do not have the capability for backside alignment, but an inexpensive technique for generating alignment marks on both sides of the wafer has been described in Ref [4].

5. Summary

A technique for the fabrication of large-area strip detectors exploiting the advantages of a wafer stepper has been described. Strip detectors 6.3 cm long by 2.56 cm wide have been fabricated using a stepper with a 20-mm diameter field. The use of a programmable aperture system in conjunction with precise stage placement and a global alignment strategy allows one to fabricate detectors much larger than the field size. This approach yields a more flexible alternative to conventional 1:1 printing and should be useful for rapid, inexpensive prototyping of silicon detectors. In addition the technique allows high resolution lithography for other structures on the detector such as high density electronics.

6. Acknowledgements

This research was sponsored by the U.S. Department of Energy under contract number DE-AC03-76SF00098. Part of the device fabrication was performed at the University of California-Berkeley microfabrication facility. Discussions with Helmuth Spieler and Nick Palaio of the Lawrence Berkeley Laboratory and Steve Hurtado of Silicon Valley Associates are gratefully acknowledged.

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