MERCURIC IODIDE IMAGING DETECTORS*

by

C. Ortale, L. Padgett, and W.F. Schnepfle
EG&G, Santa Barbara Operations
Goleta, California 93116

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ABSTRACT

Linear and two-dimensional monolithic arrays of different configurations have been fabricated using photolithographic techniques. The fabrication technology, electronic setup, and pinhole imaging experiments are described. Spatial resolutions of 1 to 2 mm have been achieved.

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ABSTRACT

Linear and two-dimensional monolithic arrays of different configurations have been fabricated using photolithographic techniques. The fabrication technology, electronic setup, and pinhole imaging experiments are described. Spatial resolutions of 1 to 2 mm have been achieved.

1. INTRODUCTION

The application of photolithographic techniques to high-quality room-temperature mercuric iodide detectors has allowed fabrication of position-sensitive arrays. These arrays have a wide variety of potential uses such as small-area gamma-ray cameras.¹ Since mercuric iodide detectors operate at room temperature and do not require photomultiplier tubes, this is an advantage over nuclear detectors such as Si(Li), Ge, and NaI(CTI).

2. DESCRIPTION OF PHOTOLITHOGRAPHIC TECHNIQUE

Single crystals of mercuric iodide grown by vapor phase techniques² are prepared for array fabrication in the following way. The crystal is first cut into

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blocks of ~ 20 mm x 20 mm x 20 mm and then sliced into ~ 2 -mm-thick pieces. After the thickness is reduced to ~ 0.5 mm by polishing and etching, the slice is then ready for deposition of a contact.

The desired electrode pattern consists of a series of parallel conducting stripes of metal, each separated from its neighbor by a small insulating gap. In order to form the desired electrode pattern, a photolithographic technique similar to that used in the processing of integrated circuits was developed. The technique makes use of a photoresist masking material, which allows for the selective removal or deposition of the contact material.

Initially both positive- and negative-type photoresists were explored with the positive-type resists proving to be more reliable. In addition, both "lift-off" and "etch" techniques were used to produce stripe electrodes. In the "lift-off" method, a polished slice is coated with a suitable photoresist material. The coated slice is then exposed (contact printed) through an appropriate photographic negative, using an ultraviolet light source. The film negative typically has a pattern of alternating clear and black stripes, in the shape and size desired for the array electrodes. After the photoresist layer has been exposed to such an alternating light/dark pattern, the slice is placed in a resist developer solution. For a positive resist, the exposed regions of the resist will be removed by the developer. The slice is thus protected where the resist pattern remains and is bare where the resist has been removed. The electrode material [e.g. palladium (Pd)] is then vacuum-evaporated over the entire slice. When the resist is later removed in a solvent, any Pd overlaying it is "lifted off"; the Pd in direct contact with the bare HgI_2 surface remains, forming the desired stripe electrodes.

The electrodes were also produced by an etch technique. In this method, the contact material is first vacuum-evaporated over the entire bare surface of the polished HgI_2 slice. The metallized slice is then overcoated with the photoresist

and exposed to ultraviolet light through a suitable photographic negative. The exposed photoresist regions are removed in a developer solution, just as for the lift-off processing. The regions of metallizing which now are unprotected by the resist can be removed with an appropriate etchant. After this, the photoresist covering the remaining metallization is removed with a solvent.

The first linear array was fabricated using a lift-off technique, but poor adhesion of the Pd contact made this technique unreliable. An etch technique developed for use with the thin Pd contacts allowed fabrication of functional linear arrays and two-dimensional 5 x 5 orthogonal arrays with 2.0-mm center-to-center spacings.

Continual problems with poor adhesion of the Pd contacts during processing led to use of other contact materials which could be deposited in thicker layers and showed better adhesion. Germanium (Ge) contacts produced by an etch method proved reliable for processing the 8 x 8 orthogonal arrays.

3. LINEAR IMAGING ARRAY

Figure 1 shows a photograph of a prototype 20-element linear array used for x- and gamma-ray imaging. Pd electrodes 0.75 mm wide with 0.25-mm inter-element spacings were deposited on the top surface of a 22 x 10 x 0.5 mm³ slice of mercuric iodide. The back electrode was a single, full-area Pd contact. This unit had a spatial resolution of 1 mm as set by the spacing between array elements.

The useful energy range of operation for this array extends from approximately 20 keV to 500 keV; however, all of the imaging data reported here was taken using 241 Am (E_γ = 59.6 keV). To test this array, the back electrode was biased with +500 V, and each top electrode element was connected to an individual

charge-sensitive preamplifier followed by an amplifier. The response from a particular element was measured by the number of counts in an energy region of interest on a multichannel analyzer. To obtain actual imaging data, a 10- μ Ci collimated ^{241}Am source was used to scan the array through a 0.3-mm lead aperture 12 mm above the detector. The position-sensitive response is shown in Figure 2. A spatial resolution at FWHM (full width half-maximum) of 1 mm is observed for element No. 3 in Figure 2. The maximum count rate from each element occurs when the radiation beam is centered on that element.

4. TWO-DIMENSIONAL IMAGING ARRAYS

Two-dimensional imaging arrays were fabricated by forming a linear array on one surface of a detector slice, as described above, and a second identical linear array orthogonal to the first, on the other surface. An array element is formed at each intersection of an upper surface stripe ("row") and a lower surface stripe ("column"). This arrangement requires only one preamplifier-amplifier chain per row and column stripe; an event is localized by time coincidence between row and column signals.

4.1 5 x 5 Monolithic Array

A two-dimensional, 5 x 5 orthogonal array with contact widths of 1.75 mm and spaces of 0.25 mm was fabricated on a 12 x 12 x 0.5 mm³ mercuric iodide slice using the photolithographic technique and Pd electrodes. The test arrangement is shown in Figure 3. Simultaneous row and column signals define the position of the photon interaction within the array. A 10- μ Ci uncollimated ^{241}Am gamma-ray source providing a uniform flood field illumination was used to determine uniformity of the array. The count rate response of each element, normalized to the count rate of the array element having the highest response, is shown in Figure 4. There is up to a 30% variation in count rate over the array area. However, 16 out of 25 elements in the array had counting rates greater than 90%, and only five had count rates greater than 80%. A fixed, collimated ^{241}Am source, using the aperture

described for the linear array, was used to irradiate the upper right hand corner (row 1, column 5) of the array. The normalized count rates of the corner element and its neighbors are shown in Figure 5. One can see that while the nearest neighbor elements show a count rate varying from 12% to 42%, the next nearest neighbors show count rates of only 1% or 2%.

Figure 6 shows the count rate response from a uniform flood field illumination when a 4- x 4- x 4-mm lead mask was placed over the four upper right corner elements. The mask shadow is clearly defined. Both of these experiments show the capability of this 5 x 5 orthogonal array to produce images with a position resolution equal to the center-to-center spacings between elements, i.e., 2 mm.

4.2 8 x 8 Monolithic Array

A two-dimensional, 8 x 8 monolithic array with Ge electrode widths of 1.8 mm and spaces of 0.2 mm was fabricated on a 20 x 20 x 0.7 mm³ slice of mercuric iodide.

The complete test arrangement is shown in Figure 7. Outputs from the array rows and columns are amplified by charge-sensitive preamplifiers and post amplifiers. Simultaneous row and column signals determine the position of the photon interaction within the array. The user has the option of varying the energy window by adjusting the lower- and/or upper-level discriminator. The presence in coincidence of more than one row or column signal defines an invalid event. The number of valid events for each array position is stored in memory by the Z-80 microprocessor. These array data are periodically transferred to the HP-35 desktop computer via a General Purpose Interface Bus (GPIB). The HP-85 can then manipulate and display the data in a suitable format.

A uniform flood field from a 100- μ Ci ²⁴¹Am source was used to check the array for uniformity (see Figure 8). Response of this array is fairly uniform with only 11 of the 64 elements having a count rate below 80% of the maximum response.

A pinhole imaging experiment was done where two 1-cm-diam ^{241}Am disc sources separated by a distance of 4 cm were imaged onto the element array through a 2-mm aperture. The sources were 40 cm above the detector. With this geometrical setup (see Figure 9) each 1-cm-diam source should form a geometrical image 2 mm in diameter, and the separation between the two images should be 8 mm. As shown in Figure 10, the actual response shows two images whose centers are 8 mm apart. The individual images are roughly 2 to 3 mm in diameter, thus showing a reasonably good correlation between the predicted geometrical response and the actual system response.

5. CONCLUSION

It appears that the photolithographic techniques outlined here are compatible with mercuric iodide detector technology. Although this paper only reported data on a few detectors, routine fabrication of these monolithic imaging arrays with spatial resolutions of 2 mm has become a reality.

In the future, this processing technique will be applied to the fabrication of a 16 by 16 element array. The 256-element array with 2.0 mm center-to-center spacing will be accommodated on one 35 mm x 35 mm piece of mercuric iodide.

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FIGURE CAPTIONS

1. Photograph of a 20-element linear array. Stripe widths are 0.75 mm with inter-element spacings of 0.75 mm. Thickness of the mercuric iodide detector is 0.5 mm.
2. Position-sensitive response of 20-element linear array to 59.4 keV peak from ^{241}Am . Radiation is collimated through a 0.33 mm in diameter lead aperture 12 mm above the detector.
3. Test arrangement for the 5 x 5 array.
4. Normalized count rate responses of each element in 5 x 5 array from a uniform flood field illumination using the 59.6-keV peak from ^{241}Am . Each element is 1.75 x 1.75 mm with 0.25-mm spaces between elements.
5. Normalized count rate responses obtained from irradiation of upper corner of 5 x 5 array. Irradiated element No. 5 (encircled) shows a counting rate of 100%. The other numbers represent the relatively decreased counting rate of the neighboring elements.
6. Normalized count rate showing the decrease in the count rate (circled numbers) when the four upper right corner elements are covered with a lead mask.
7. Test arrangement for the 8 x 8 monolithic array.
8. Normalized count rate responses of the 8 x 8 array from a uniform flood field illumination using the 59.6 keV peak of ^{241}Am . Each element is 1.8 mm x 1.8 mm with 0.2 mm inter-element spacings.
 - (a) Actual image
 - (b) Digitized intensities of individual elements

FIGURE CAPTIONS (continued)

9. Two ^{241}Am sources 10 mm in diameter separated by a distance of 4 cm placed 40 cm above the 8 x 8 array and imaged through a 2-mm aperture so that the image diameters are 2 mm.
10. Normalized image response when two Am sources were imaged as shown in Figure 9.
 - (a) Actual image
 - (b) Digitized intensities of individual elements

Figure 1

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Figure 2

S-207-TF

Figure 3

Figure 4

Figure 5

Figure 6

Figures 4, 5, and 6

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ORTALE FIG. 7

IMAG-2 SYSTEM OVERVIEW

Figure 7

ORTALE FIG. 8

a. ACTUAL IMAGE

b. DIGITIZED INTENSITIES OF INDIVIDUAL ELEMENTS

Figure 8

Figure 9

S-207-TP

a. ACTUAL IMAGE

b. DIGITIZED INTENSITIES OF INDIVIDUAL ELEMENTS

Figure 10