



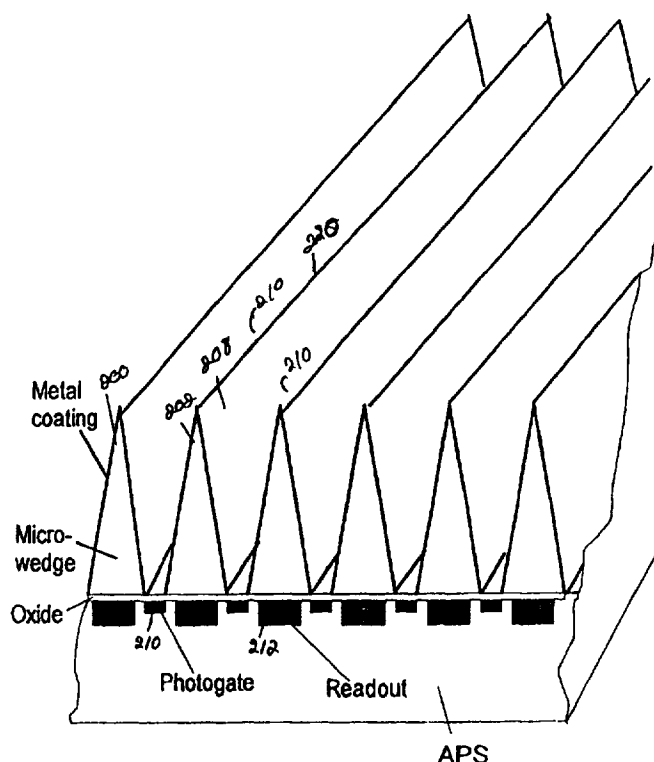
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(21) International Application Number: PCT/US97/15032 (22) International Filing Date: 25 August 1997 (25.08.97) (30) Priority Data: 08/708,075 27 August 1996 (27.08.96) US (71) Applicant: CALIFORNIA INSTITUTE OF TECHNOLOGY [US/US]; 1201 East California Boulevard, Pasadena, CA 91125 (US). (72) Inventors: WANG, Yu; 3151 Fairmont Avenue, La Crescenta, CA 91214 (US). FOSSUM, Eric, R.; 5556 Pinecone Road, La Crescenta, CA 91214 (US). (74) Agent: HARRIS, Scott, C.; Fish & Richardson P.C., Suite 1400, 4225 Executive Square, La Jolla, CA 92037 (US).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i>

(54) Title: REFLECTING OPTICAL CONCENTRATORS FOR SOLID STATE DETECTOR ARRAYS

(57) Abstract

Wedge-shaped optical reflectors (200 and 202) are used to reflect optical energy. Certain optical energy is incoming toward an area of the chip that is housing the non-photosensitive electronics (212). Wedges are used to reflect that radiation toward the photosensitive electronics (210).



Structure of Micro-wedge Reflectors for APS

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REFLECTING OPTICAL CONCENTRATORS FOR SOLID STATE DETECTOR ARRAYS

FIELD OF THE INVENTION

The present invention describes control of channeling of light in a pixel-sensing device.

5 BACKGROUND AND SUMMARY

Active Pixel Sensor ("APS") technology represents a second generation image sensor technology. An Active Pixel Sensor includes image acquiring structure, including an amplifier, in each pixel.

Each pixel has a limited light gathering capability that is proportional to the size of the
10 light gathering structure. However, this image acquiring structure has previously taken up some of the otherwise available area, or "real estate" on the image sensor substrate, "the chip". The so-called "fill factor" is a measure of how much of the chip is used to gather incoming light. Fill factor is degraded by this associated image acquiring structure. The fill factor of active pixel sensors has been as low as 20 to 30 percent.

15 One possible solution to this problem is the use of microlenses, such as described in co-pending patent applications, e.g. no. 08/558,521. Microlenses have been used in an attempt to refract some of the light impinging on the active pixel sensor to a photoreactive location. For example, if the light impinges on an area of the real estate that holds the amplifier, that light may be refracted to the area of the photosensitive
20 element.

However, the inventors noticed problems with using the microlenses. The shape of the microlens is very difficult to control. Rays having large incident angles may be shifted to the neighboring pixels by the microlenses. The inventors hence found that introducing the microlenses may increase the crosstalk and noise level.

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Figure 1 illustrates this occurrence. A ray 100 off the optical axis of photogate A is shown being reflected at the air/microlens interface. A portion 102 of that incoming ray enters the neighboring microlens B, thereby increasing crosstalk and noise level.

For example, a ray at 60 degrees off the normal will have over 10% reflected at the air/microlens interface to generate the crosstalk. Moreover, about 20% of the s-polarized light will be reflected and create crosstalk, while only less than 1% of p-polarized light is reflected. This may be unacceptable for certain applications.

The inventors recognized the need for a different technique of channeling light to a desired area on a light sensitive device. The preferred technique of the present invention uses light channelling without lensing effects to avoid this problem.

The preferred system uses small sized wedge-shaped reflectors ("micro wedge reflectors") to accomplish this goal. These reflectors can increase the photon collection efficiency without generating crosstalk.

The micro-wedge reflectors preferably cover the area of the associated image structure of the APS. This channels many of the image photons into the photosensitive areas, to thereby enhance the photon collection efficiency.

Another aspect of the invention limits the photons to movement in one direction. This further decreases the crosstalk.

For small pixel sizes close to the diffraction limit, for example, microlenses may not work. All lenses have inherent properties. For example, a lens cannot focus more distinctly than its diffraction limit. A lens also cannot focus with better resolution that its space- bandwidth product will allow. The quality of a lens is usually inversely proportional to its cost. This has provided a lower limit on the size of pixels that can be used with microlenses.

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The wedge reflectors of the present invention are reflective, not focusing, structures. Hence, there is no limits on size or resolution.

The micro-wedge structure described herein is based on the inventor's recognition of the crosstalk and other drawbacks with microlenses. This structure uses the reflection effect
5 to avoid the undesired refraction effect. This structure may allow better efficiency than the microlens. It can be precisely fabricated by micro-fabrication technology, it can work well for very small pixels, and there is smaller ray shifting for large incident angle rays. Since substantially all of the photons are limited to redirection in one direction, the crosstalk can be minimized.

10 BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will now be described in detail with reference to the accompanying drawings, wherein:

Figure 1 shows how reflection from refracting microlenses can cause crosstalk among the pixels;

15 Figure 2 shows a preferred embodiment of the present invention using reflective micro-wedges;

Figure 3 shows how the Figure 2 micro-wedges are used on a pixel device;

Figure 4 shows operation of high-profile reflectors with large incident angle radiation;

Figure 5A shows a cross section of a second embodiment of the present invention;

20 Figure 5B shows that second embodiment of the invention used with a pixel device; and

Figure 6 shows a two-dimensional wedge structure.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

The active pixel sensor chip includes two distinct areas in each pixel. The photosensitive area of each chip includes the photogate 210 which collects and integrates the light that is incident on the surface area of the photogate. Readout circuit 212 includes the
5 associated amplifier and other electrical structures which are associated with each readout area. Only that light which is incident on the photogate 210 is collected; light that is not incident on the photogate is not sensed. The light that is incident on the area of the readout circuit 212, therefore, is not sensed. That readout circuit, therefore, occupies real estate on the chip that cannot be used for light integration.

- 10 Figure 2 shows the first embodiment of the light channelling structures. Those structures are formed by reflective micro-wedges 200, 202. The micro-wedges each include two light-reflecting surfaces 208, 210 which face in directions generally opposed to one another. The two light-reflecting surfaces 208, 210 meet at angled area 220.

The reflection operation of these coatings operate as shown in Figure 3. Incident image
15 light 300 incident on the device includes a first portion 302 which will naturally impinge on the photogate area 210, and a second portion 304 which would, if unreflected, impinge on the readout areas 212. The photons 304 which would fall outside of the photogate areas are reflected by the micro-wedge surfaces 208, 210. For example, light ray 304 is reflected at point 306 to be incident on photogate 210. In this way, many of
20 those photons which impinge from outside the photogate area can be collected by reflection. This allows a more efficient collection of incident light.

The preferred embodiment uses a high-reflection metal coating of 500-1000 Å in thickness. Higher reflectivities provide a higher photon collection efficiency. However, less expensive techniques, including white coloring of the surfaces can be used with less
25 optical efficiency traded off against the higher cost.

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The micro-wedges used according to the present invention can be used with any radiation that is capable of being reflected. The preferred radiation bands include ultraviolet, visible and infrared.

The lateral aspect ratio of this reflector element is dependent on the height/width ratio of these wedges. This ratio preferably ranges between 1:1 to 5:1. A ratio which is high enough, e.g., greater than 3.5:1 can collect photons with large incident angles, as shown in Figure 4.

Ray 431 with a large reflective surfaces of the incident angle will be reflected several times between the two micro-wedges 400, 402 before reaching the photogate area 210. Even rays at extremely high incident angles, like ray 432, will be reflected many times between two wedges and finally either reach the photogate or be reflected back toward the incident direction as ray 433. High incident angle rays can become problematic in microlenses as described above. Those rays that are at high incidence angles can be refracted by the microlens to the wrong pixel. This pixel crosstalk can create smearing in the detected image.

The wedge reflectors of the present invention include edge-defining surfaces 410, 412. These edges define boundary edges between for the pixel. The ray 432 impinging on the pixel 420 side of boundary 410 is intended for pixel 420. The ray 435, on the other hand, impinges on the other side of the boundary 410 and hence is intended for the pixel 422. Theses edge defining surfaces hence demarcate the areas where the incoming radiation will be reflected.

A second embodiment of the radiation-reflecting devices of the present invention is shown in Figures 5A and 5B. Figures 5A is the cross section of an internally-reflecting plastic film used to according to the second embodiment. The film is preferably a polyamide film with the wedges described herein formed as microstructures thereon.

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The light receiving side of the film 500 is intended to receive incoming beams. The reflecting side 502 includes a number of wedge-shaped air gaps 504.

Figure 5B shows the plastic film 500 placed over the APS chip 206 in the preferred way. The film 500 is mounted such that each photogate area 210 is connected to or physically
5 coupled to a lower end portion 510 of the plastic part 502 of film 500. The air gaps 504 are located to cover the readout circuits 212. These rays do not reach the neighboring pixels to generate crosstalk.

When the image light is incident on the plastic film, the photons moving toward the readout area are reflected by the plastic-air interface of the wedge-shaped air gap by total
10 internal reflection to impinge on the photogate area. This embodiment is susceptible of being formed by semiconductor formation techniques, and hence this design is well suited for mass production. Moreover, proper selection of materials can make this photon collection efficiency even better than the micro-wedge reflector, if the total internal reflection is more efficient than reflection from metal coating. This selection
15 process would be understood by a person having ordinary skill in the art.

In order to effectively collect all of the image photons, the lateral ratio of these micro-wedges should be at least 2:1. Higher ratios may provide a larger photon collection angle. Recently, a micro-fabrication technology called LIGA (a German acronym for Lithographic, Galvanoformung, Abformung -- in English, lithography, electroforming,
20 molding) has been reported to form tall structures with submicrometer resolution. The structures have large vertical aspect ratios -- lateral dimensions of a few micrometers and vertical dimension up to 1000 μ m. Metal-coated silicon tips with dimension of 1 μ m wide and 3 μ m high also have also been reported. This process is preferably used to make the micro-wedges and the micro-wedge air gap plastic films.

25 A third embodiment modifies either of the above two embodiments to make a two dimensional micro-wedge well as shown in Figure 6. The two dimensional embodiment

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in the Figure 6 is shown as a plastic reflector, but the structure can also operate with reflectively lined micro-wedges of the Figure 1 embodiment.

The two dimensional system includes edges 600, 602, 604, 606 which define edges of pixel area. All of the photons falling into the well between these edges will end up at the photogate area. This device will have even higher light collection efficiency and less crosstalk.

Although only a few embodiments have been described in detail above, those having ordinary skill in the art will certainly understand that many modifications are possible in the preferred embodiment without departing from the teachings thereof.

- 10 For example, the surface of the micro-wedges do not have to be planar in shape. A curved surface could also work for desired applications.

The materials described herein, of course, are susceptible of modification. All such modifications are intended to be encompassed within the following claims.

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WHAT IS CLAIMED IS:

1. An optical detector, comprising:
an image receiving surface, including a first photosensitive area and a second non-photosensitive area;
5 a light collecting element, collecting light impinging on said photosensitive area and not collecting light impinging on said non-photosensitive area; and
at least two light reflecting surfaces, adjacent said light collecting element, and reflecting at least a portion of light which would otherwise impinge on at least one non-photosensitive area towards the photosensitive area.
- 10 2. A detector as in Claim 1 wherein said photosensitive area includes a photogate and said non-photosensitive area includes an area of the substrate integrating an amplifier associated with the photogate.
3. A photodetector, comprising:
a substrate, including a first photosensitive area and a second non-
15 photosensitive area; and
a reflective element, located in a location to reflect at least a portion of incident radiant energy that would otherwise impinge on said second area to said first area.
- 20 4. A photodetector as in claim 3, wherein said substrate includes an active pixel sensor.
5. A method of acquiring radiation over an area, comprising:
positioning a radiation sensitive element in an area where it can receive
25 radiation; and
reflecting at least a part of the radiation that is incident in a direction where it would not impinge on said radiation sensitive element, toward said radiation sensitive element, without a lensing operation.

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6. A method as in claim 5, wherein said reflecting is carried out by total internal reflection.

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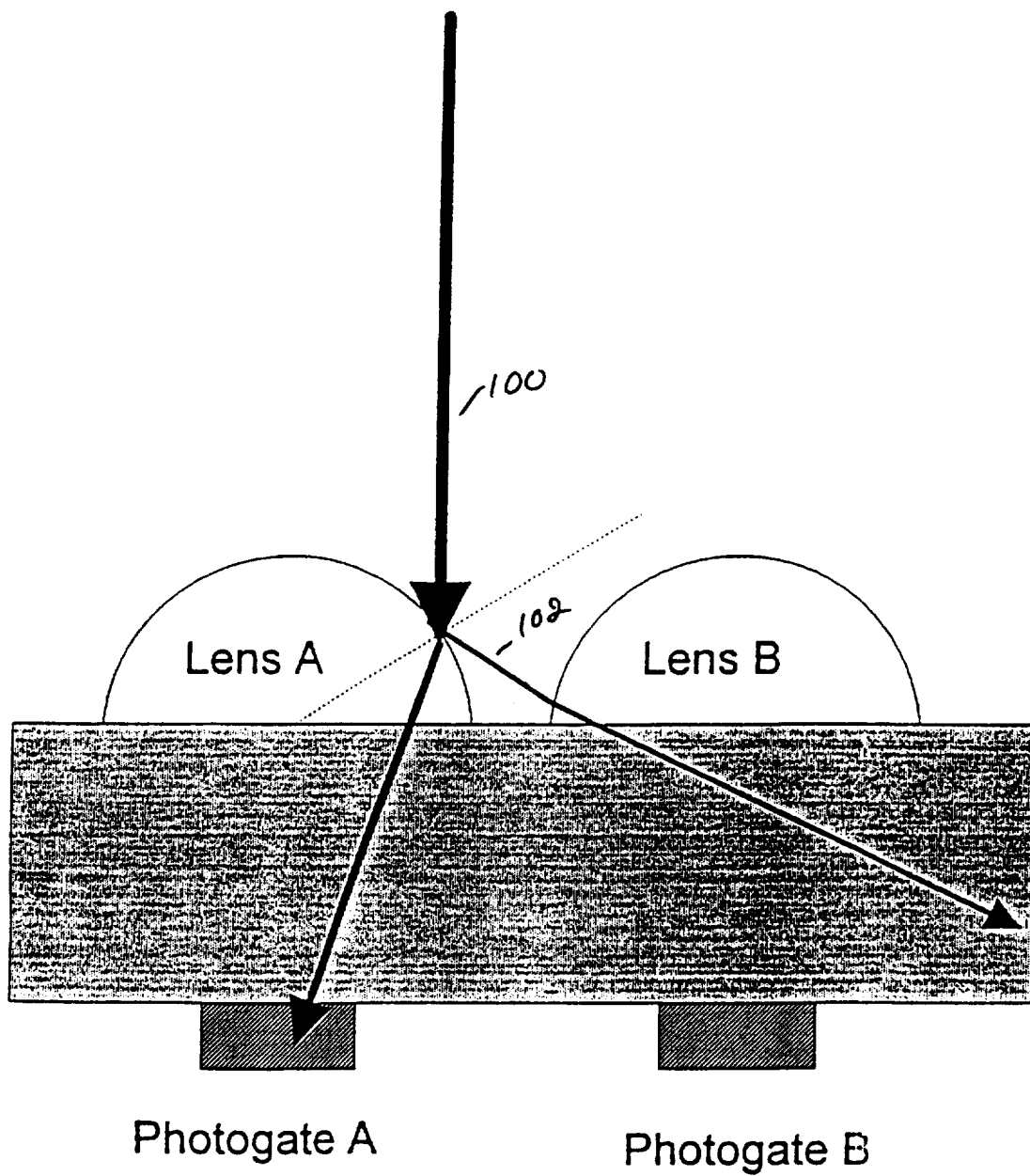


Fig 1. Reflection from microlenses will cause cross among pixels.

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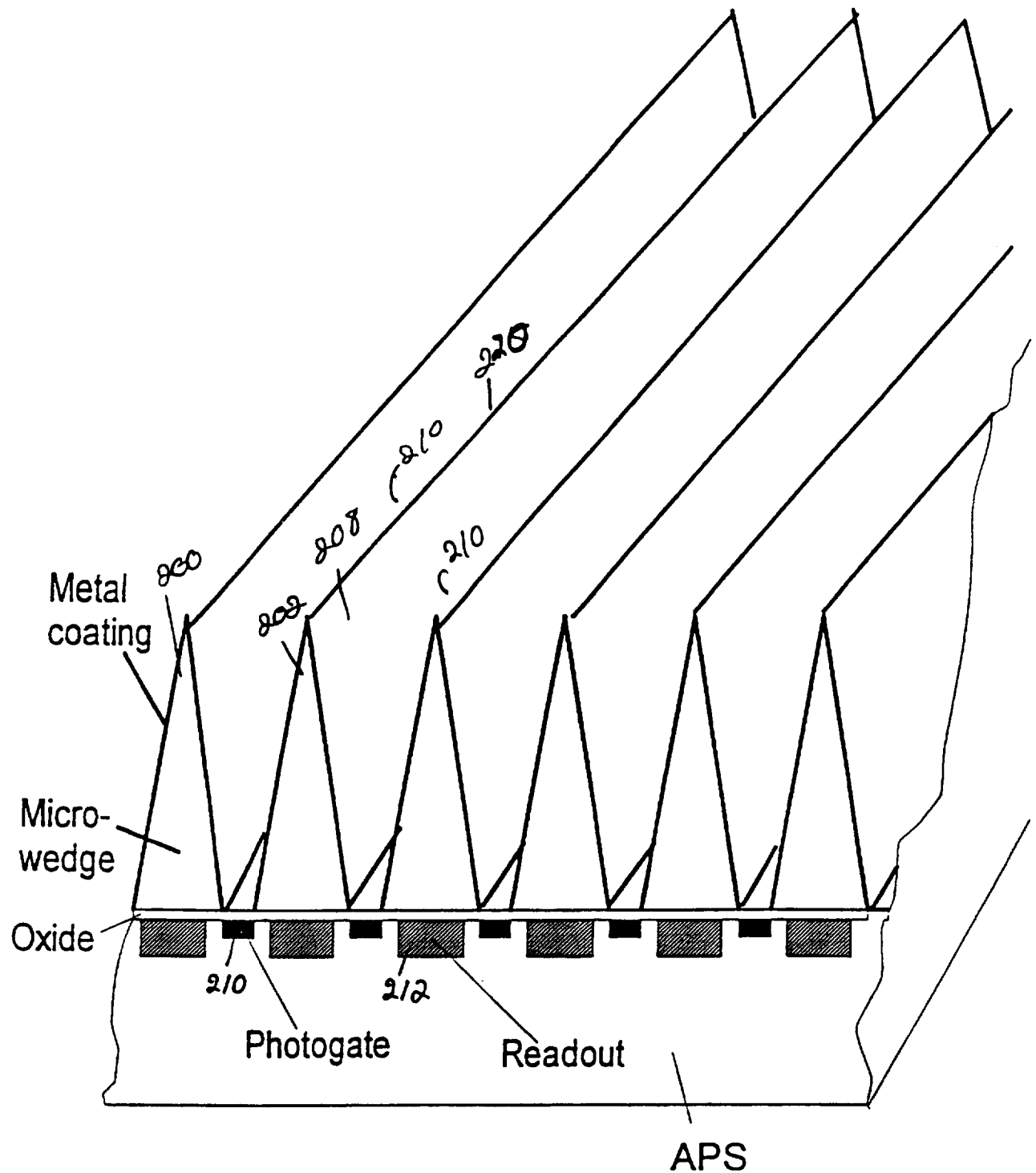


Fig. 2 Structure of Micro-wedge Reflectors for APS

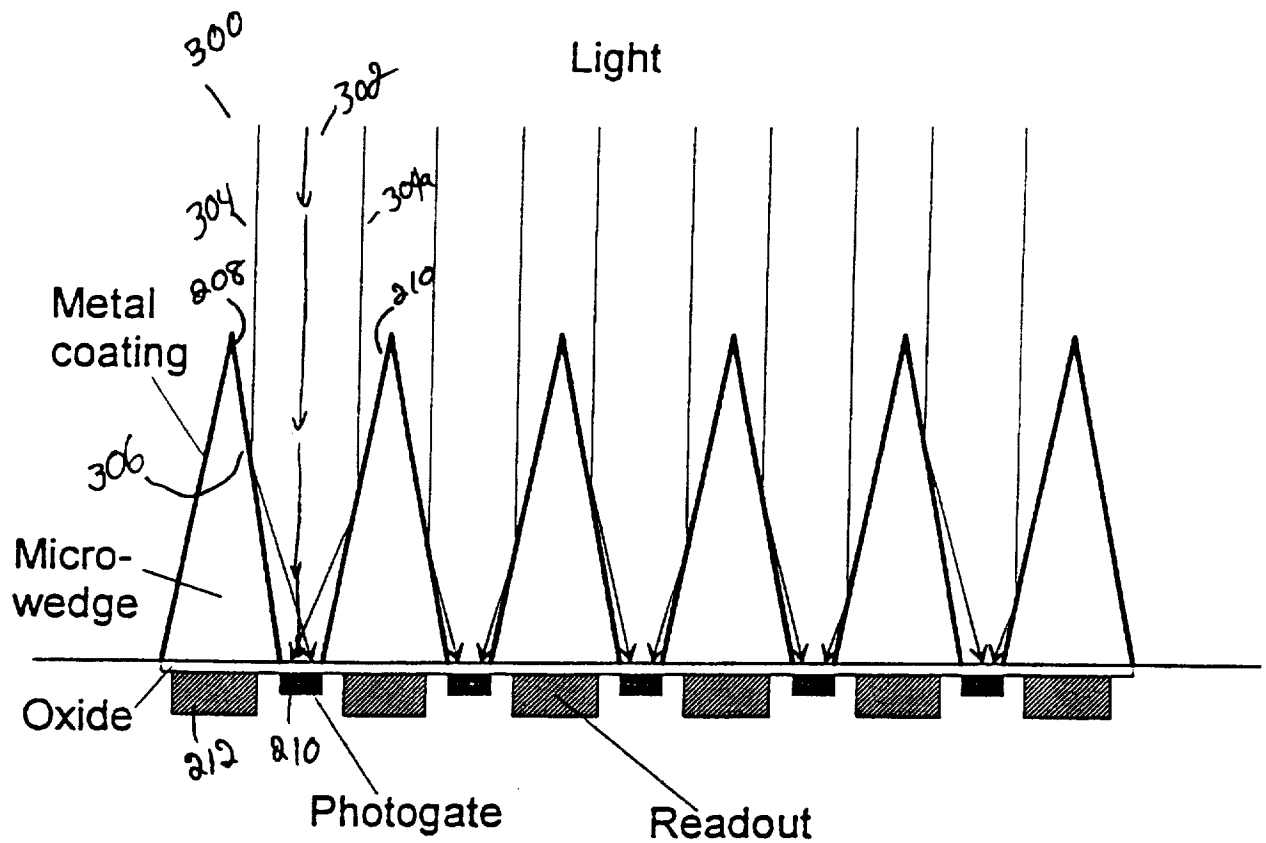


Fig 3. All of the incident photons fall into the photogate area due to the reflection by the micro-wedge reflectors.

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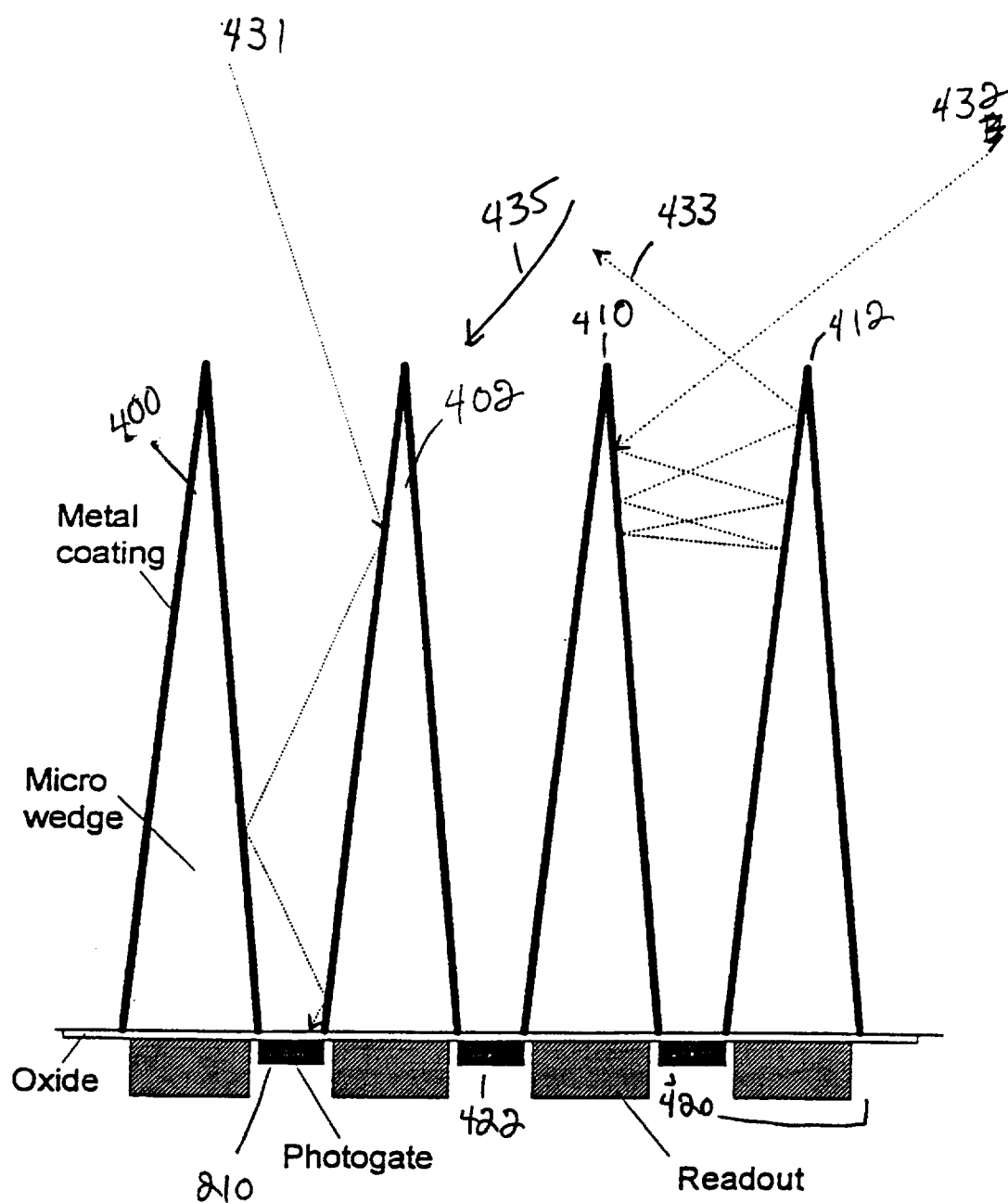


Fig. 4 Wedgereflectors work well with rays at big incident angle.

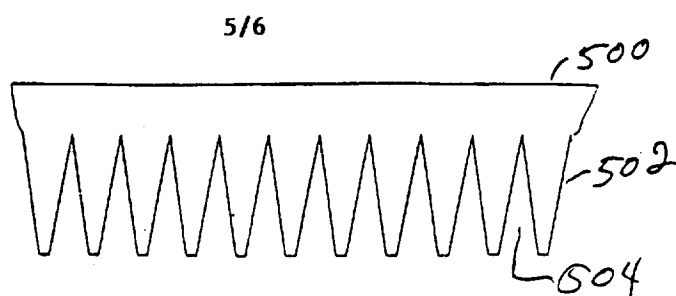


Fig. 5-a Cross-section of the plastic film

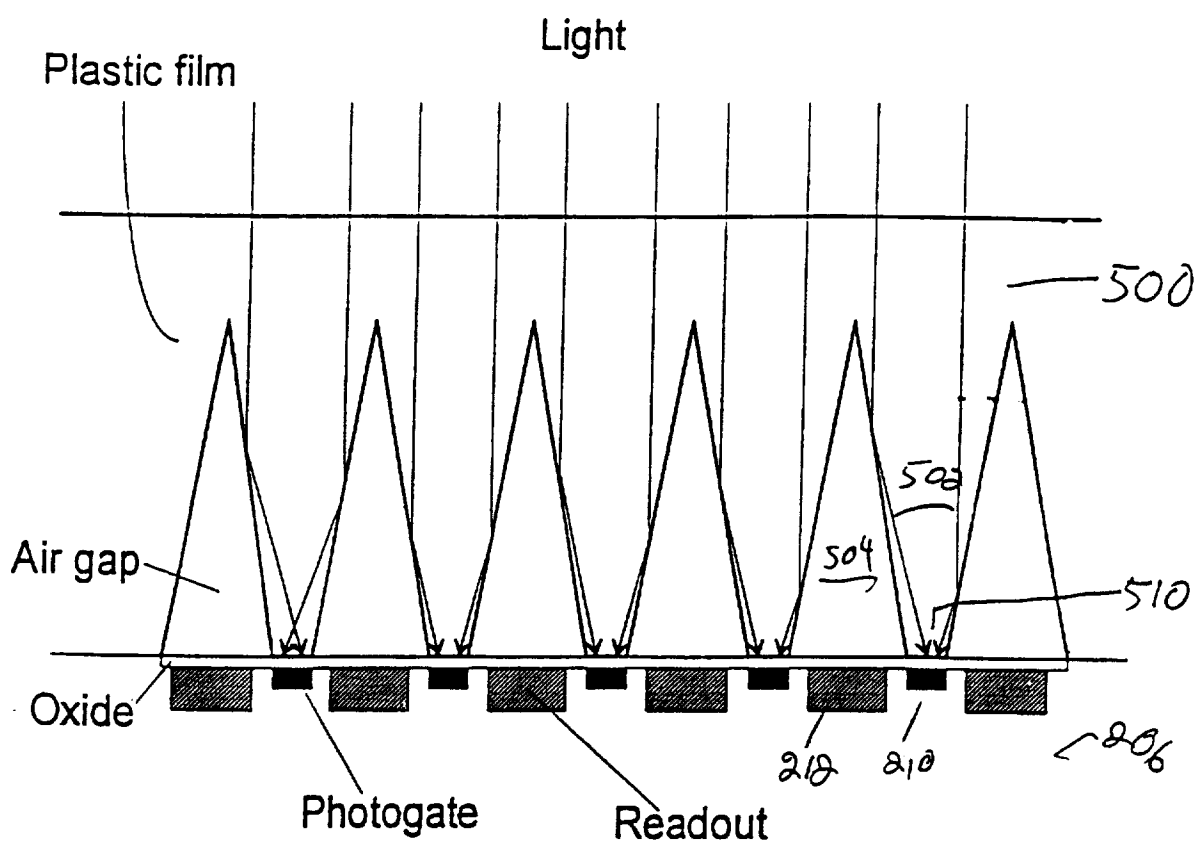


Fig. 5-b Plastic film with wedge shaped air gaps for APS.

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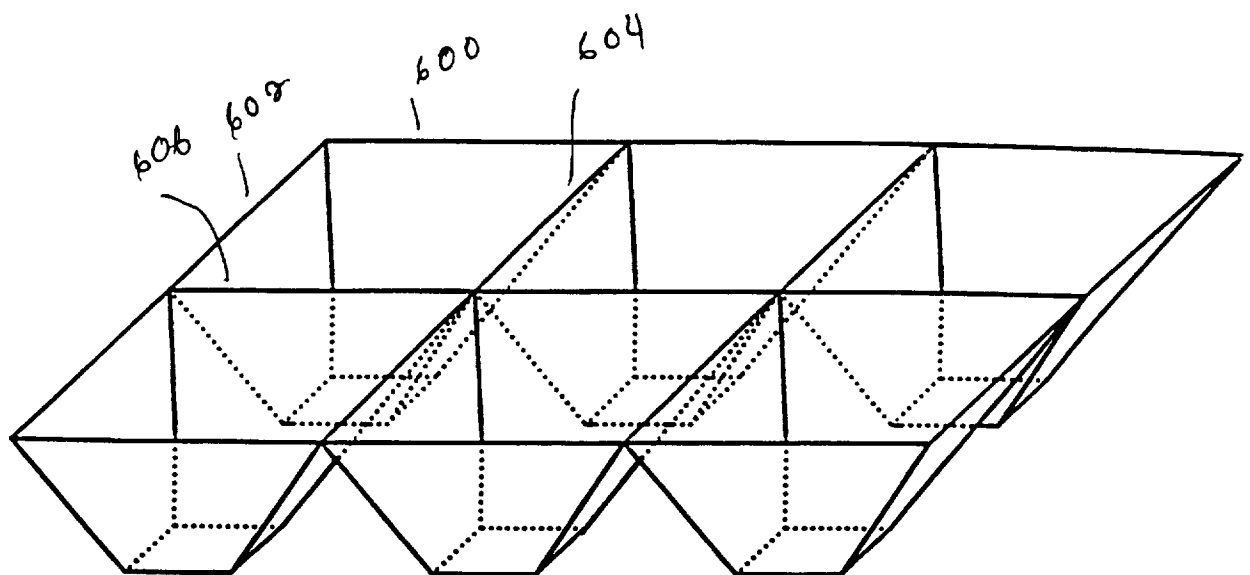


Fig. 6. Two dimension micro-wedge well optical concentrators for solid state detector arrays.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/15032

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H01L 31/0232; H01L 27/00

US CL : 250/208.1, 214.1; 257/294, 435

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 250/208.1, 208.2, 214R, 214.1, 559.15; 257/292, 294, 434, 435, 436

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

search term: wedge shaped, reflector, active pixel sensor

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	US 4,745,451 A (WEBB ET AL) 17 May 1988 (17/05/88), see entire document, especially column 2, lines 62-65.	1, 3, 5, 6 ----- 2, 4
Y	US 5,471,515 A (FOSSUM ET AL) 28 November 1995 (28/11/95), see figure 3.	2, 4
A	US 5,055,667 A (SAYAG) 08 October 1991 (08/10/91).	1-6

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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