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CA 2139108 C 2003/08/19

(11)(21) 2 139 108

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 1993/06/23
(87) Date publication PCT/PCT Publication Date: 1994/01/06
(45) Date de délivrance/Issue Date: 2003/08/19
(85) Entrée phase nationale/National Entry: 1994/12/23
(86) N° demande PCT/PCT Application No.: US 1993/006012
(87) N° publication PCT/PCT Publication No.: 1994/000781
(30) Priorité/Priority: 1992/06/25 (07/904,316) US

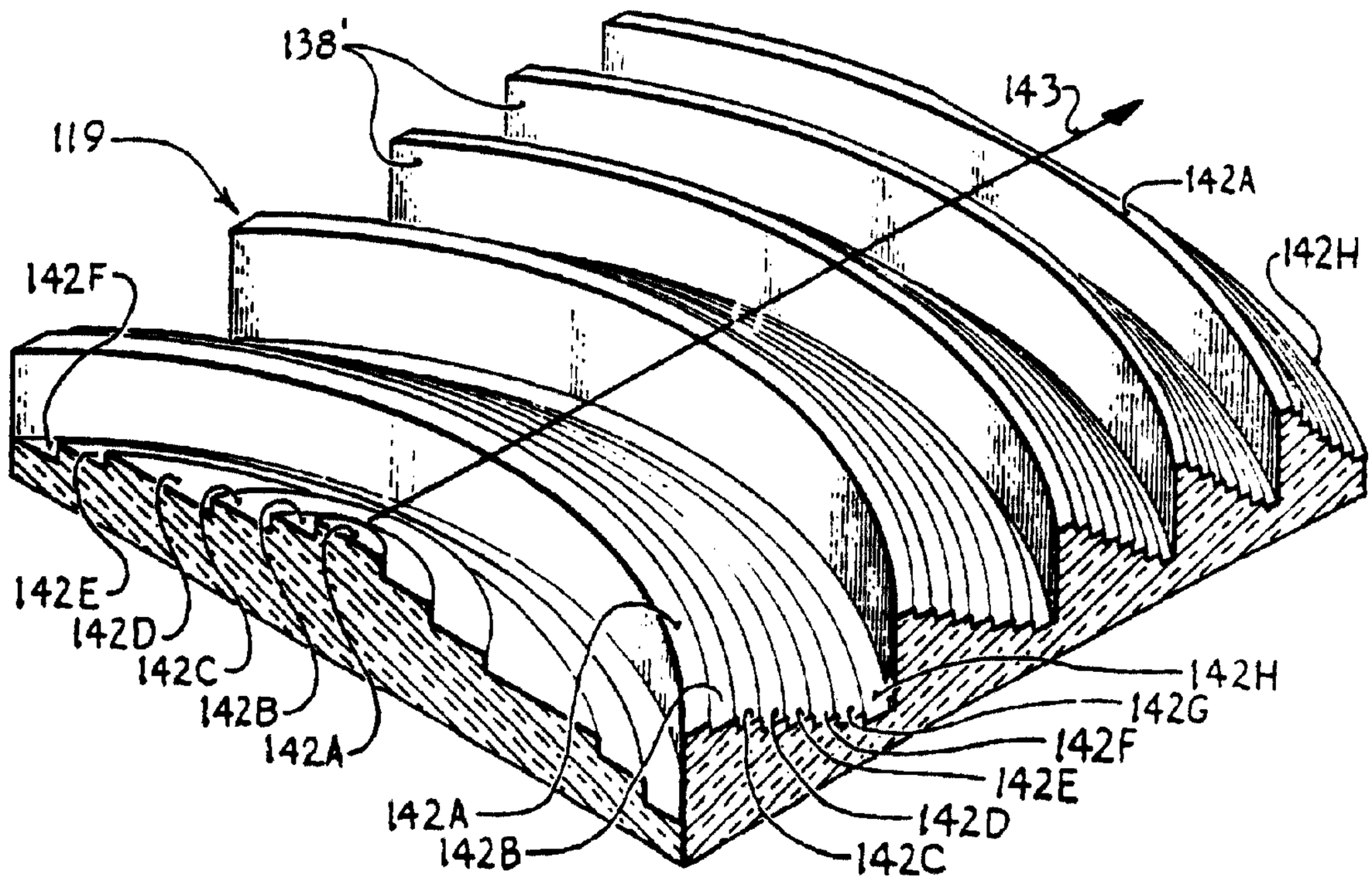
(51) Cl.Int.^{5}/Int.Cl.^{5} G02B 3/00, G02B 27/10, G02B 3/10, G02B 3/08, G01J 1/04

(72) Inventeur/Inventor:
GAL, GEORGE, US

(73) Propriétaire/Owner:
LOCKHEED MISSILES & SPACE COMPANY, INC., US

(74) Agent: SMART & BIGGAR

(54) Titre : MICROLENTILLE DISPERSIVE
(54) Title: DISPERSIVE MICROLENS



(57) Abrégé/Abstract:
Dispersive microlens apparatus (119) and methods are used in one mode for detecting multiple, different wavelengths (124A, 124B, 124C) from a bandwidth of wavelengths (existing within an image plane blur spot) and are used in another mode for combining a plurality of different, emitted wavelengths (151A, 151B, 151C) into a bandwave of wavelengths (at a blur spot in an image plane).

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G02B 5/04, 27/10

A1

(11) International Publication Number: WO 94/00781

(43) International Publication Date: 6 January 1994 (06.01.94)

(21) International Application Number: PCT/US93/06012

(22) International Filing Date: 23 June 1993 (23.06.93)

(30) Priority data:
07/904,316 25 June 1992 (25.06.92) US

(71) Applicant: LOCKHEED MISSILES & SPACE COMPANY, INC. [US/US]; 1111 Lockheed Way, Sunnyvale, CA 94089 (US).

(72) Inventor: GAL, George ; 4172 Donald Drive, Palo Alto, CA 94306 (US).

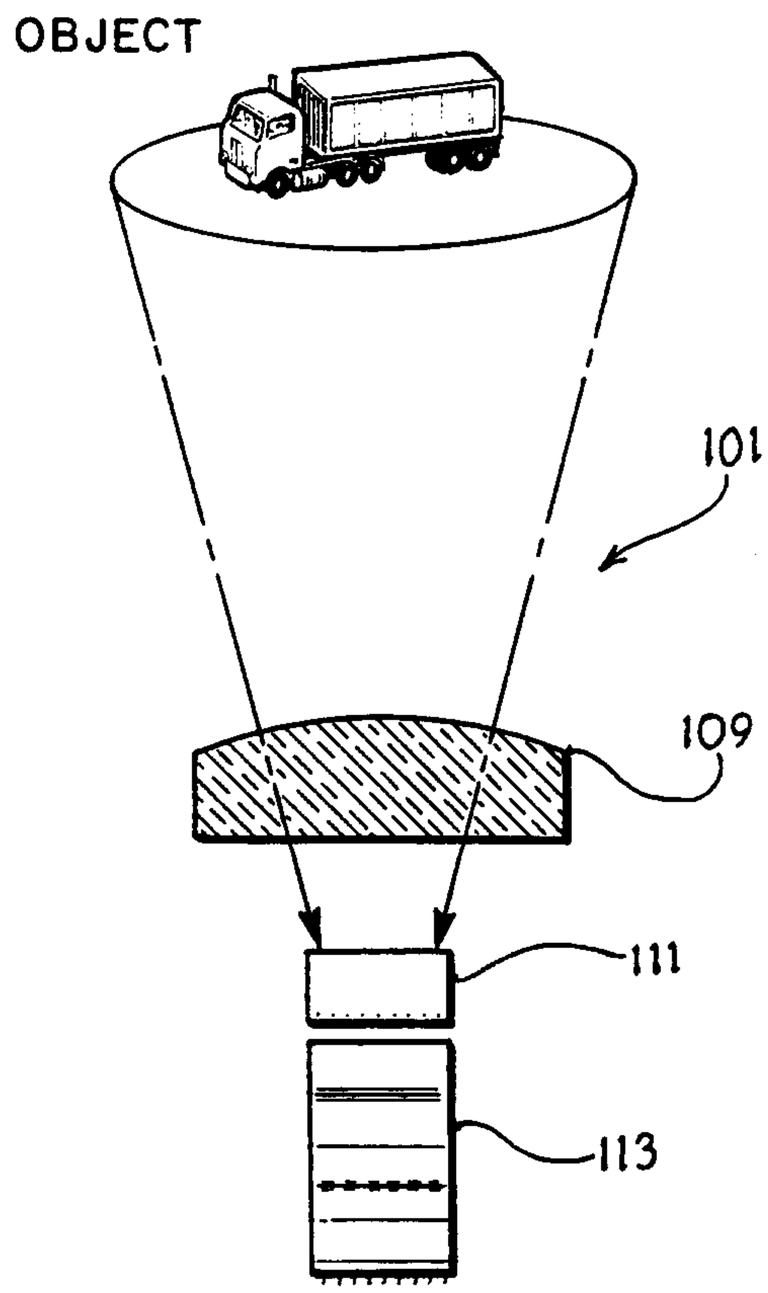
(74) Agents: IMAI, Keiichiro et al.; 4500 Park Granada Boulevard, Calabasas, CA 91399 (US).

(81) Designated States: CA, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

2139108

(54) Title: DISPERSIVE MICROLENS



(57) Abstract

Dispersive microlens apparatus (119) and methods are used in one mode for detecting multiple, different wavelengths (124A, 124B, 124C) from a bandwidth of wavelengths (existing within an image plane blur spot) and are used in another mode for combining a plurality of different, emitted wavelengths (151A, 151B, 151C) into a bandwave of wavelengths (at a blur spot in an image plane).

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DISPERSIVE MICROLENS

BACKGROUND OF THE INVENTION

This invention relates to microlens arrays and associated detector/emitter pixel arrays.

This invention relates particularly to dispersive microlens apparatus and methods which can be used in one mode for detecting multiple, different wavelengths from a bandwidth of the wavelengths (existing within an image plane blur spot) and which can be used in another mode for combining a plurality of different, emitted wavelengths into a bandwidth of the wavelengths (at a blur spot in an image plane).

The individual microlenses of the present invention may typically range in size from a diameter of 50 microns to 1 millimeter. Related detectors may be fabricated from bulk material that is thinned to a thickness associated to fast optical design *f*/1 in the substrates. The microlenses are located, usually in one dimensional or two dimensional arrays, at an image plane, and associated detectors/emitters are located in pixels in a detector/emitter plane which is spaced from the image plane.

The individual microlenses of the present invention may be Fresnel or non-Fresnel microlenses, and may be fabricated by binary or non-binary fabrication techniques, may have a variety of geometric shapes, such as, for example, circular, square, hexagonal, and rhombic.

SUMMARY OF THE INVENTION

In one embodiment of the present invention the microlens method and apparatus are used in a detector mode in focal plane arrays of an optical sensor system.

In this embodiment the focal plane arrays include an array of microlenses at an image plane and an array of detector pixels at a detector plane. Each individual microlens transmits and concentrates a bandwidth of light

(existing in a the incident blur spot) to a much smaller blur spot in an associated pixel in the detector plane. The area of detector plane blur spot is thus decoupled from the area of the pixel. The concentration of the optical information into the much smaller pixel plane blur spot produces a high contrast ratio, high fill factor and high optical gain of the optical information in the detector plane blur spot with respect to any existing, unwanted noise present at the detector plane. This concentration into the small detector plane blur spot also frees up relatively large adjacent areas (real estate) in the pixel which can be used for other purposes, such as, for example, the use of multiple detectors in a single pixel and/or micro-channel cooling, or for analog signal processing circuits.

In this embodiment certain ones of the individual microlenses are formed with dispersion means effective to produce, in relation to the bandwidth of light in the image plane blur spot, a controlled dispersion of the bandwidth of light and an elongated detector plane blur spot in which the wavelengths are varied in a progressive way from one end to the other of the elongated blur spot. This dispersion enables more than one wavelength and/or bands of wavelengths to be detected and/or located within the elongated pixel plane blur spot.

The dispersion means comprise a configured, prismatic surface which is formed integrally with and in a regular pattern on the individual, dispersive microlens.

Multiple detectors are positioned in the elongated detector plane blur spot to detect multiple, different signals from the optical information in the elongated blur spot. This permits real time discrimination of the optical information for certain qualities, such as, for example, the color and/or temperature of an object or objects generating or reflecting the optical information into the sensor system.

The multiple detector signals can be summed in an acquisition mode to obtain an increased signal. The multiple signals can be used in a discrimination mode to evaluate color contrast (to determine object temperature) and also to discriminate for temperature on the basis of the ratios of

the detected energies. This enables the use of a few spectral bands to suppress background.

Two detectors looking at the same instantaneous field of view (IFOV) get the energy from the same object space and get perfect background registration.

The multiple detectors are associated with a related microlens in an array of microlenses in which there is no dead space so that one hundred percent fill factor is obtained.

No scanners or beam splitters are required, so the dispersive microlens provides spatial and temporal registration without incident energy loss.

The multiple, separate detectors can be selectively sized and positioned in the elongated blur spot to pick up different, selected sets of information, dependent upon the sizes and positions of the detectors in the elongated blur spot.

In another embodiment of the present invention dispersive microlens apparatus and methods are used for combining a plurality of different emitted wavelengths of light, emitted from a plurality of emitters within a single emitter plane blur spot, into a bandwidth of light at an image plane blur spot.

In this embodiment a plurality of emitters are positioned at selected locations within an emitter plane blur spot and emit separate, different wavelengths or wavebands of light which are to be combined into a single bandwidth of light at an image plane blur spot.

In this embodiment a dispersive microlens is positioned at the image plane at a distance from the emitter plane which is effective to permit the microlens to receive the light from the plurality of emitters and to form the light into an image plane blur spot at the location of the microlens.

The dispersive microlens includes dispersion means which are effective to combine all of the separate, emitted wavelengths or wavebands into a single bandwidth of light into the image plane blur spot so that the multicolor emitted wavelengths appear as a single, composite color at the surface of the microlens.

In this embodiment the emitter plane blur spot is an elongated blur spot which is so related to the dispersion means of the associated microlens that the wavelengths of emitted light can be varied in a progressive way from one end of the elongated blur spot to the other.

In this embodiment each emitter generates a selected wavelength and/or band of wavelengths which is unique to that emitter and which is within the bandwidth. Each emitter is positioned in the elongated blur spot at a location correlated to the wavelength emitted by that emitter. The output of the emitters are modulated to control the energy level associated with the wavelengths present in the bandwidth at the image plane blur spot and also the relative energy levels of the different wavelengths which are combined into the single bandwidth at the image plane blur spot.

These two embodiments of the present invention can be used separately or in combination with one another for a variety of color detecting, displaying, transmitting and/or generating apparatus and methods, such as, for example, computer flat screen color television, color recording, color facsimile, and color printing.

Microlens apparatus and methods which incorporate the features described above and which are effective to function as described above constitute specific objects of the present invention.

Other and further objects of the present invention will be apparent from the following description and claims and are illustrated in the accompanying drawings, which by way of illustration, show preferred embodiments of the present invention and the principles thereof and what are now considered to be the best modes contemplated for applying these principles. Other embodiments of the invention embodying the same or equivalent principles may be used and structural changes may be made as desired by those skilled in the art without departing from the present invention and the purview of the appended claims.

BRIEF DESCRIPTION OF THE DRAWING VIEWS

Figure 1 is a side elevation view in cross section of an optical sensor system which utilizes dispersive microlens apparatus and methods of the present invention.

Figure 2 is a diagrammatic view showing how each of three adjacent microlens has an individual instantaneous field of view (IFOV) and showing how the energy (or object) in that individual IFOV is transmitted to the detectors associated with the particular microlens.

Figure 3 is an enlarged, schematic, fragmentary, isometric view showing how individual microlenses (in an array of microlenses located at an image plane) transmit energy and optical information (contained in individual blur spots in the image plane) to related individual pixels in a detector plane.

Figures 4A, 4B and 4C are enlarged, fragmentary views, partly in cross section, showing how multiple detectors are associated with non-Fresnel dispersive microlenses (Fig 4A) and Fresnel dispersive microlenses (Figure 4B) and showing how a single detector is associated with a wide-band non-dispersive microlens (Figure 4C).

Figure 5 is an enlarged, fragmentary, plan view showing details of how, in detector arrays (without any associated micro-lenses) used prior to the present invention, two images in blur spots of two instantaneous fields of view could fall, at least in part, upon dead zones between the detectors. Figure 5 illustrates, in double cross hatched portions of one image, how a large portion of one image could be lost when there are dead zones between such prior art detectors.

Figures 6 and 7 are related views showing, respectively, a fragmentary, enlarged plan view of a portion of the image plane and a fragmentary, enlarged view of a related portion of the detector plane.

Figures 6 and 7 show how an image, or information, in a blur spot at the image plane is transferred to a much smaller area in a related pixel in the detector plane by a microlens positioned at the blur spot in the image plane.

Figures 6 and 7 also show how a blur spot which spans four adjacent microlenses in the image plane can produce

four, small fragments of that image in the four related pixels of the detector plane to conserve all of the energy in the image plane blur spot (when there is no dead zone between any of the four adjacent microlenses in the image plane, i.e. when there is a 100% fill factor).

Figures 8A and 8B are elevation views showing how each individual microlens at a blur spot in the image plane reduces the size of the image transmitted to the detector plane so that there is space, or real estate, available at the detector plane which can be used for other purposes. Both Figures 8A and 8B show how micro cooling channels can be located in such available space in the pixels to provide cooling for adjacent heat producing components.

Figure 8B shows how multiple detectors can be used in each unit pixel to obtain more than one signal from the information in a blur spot at the image plane when a dispersive microlens of the present invention is positioned at the image plane blur spot.

Figures 9 and 10 are enlarged, fragmentary, plan views of a portion of the detector plane showing how multiple detectors can be located in individual pixels in the detector plane. Figure 9 shows two detectors in each pixel. Figure 10 shows three detectors in each pixel.

Figures 11, 12 and 13 are related views showing how a dispersion producing surface configuration (Figure 11) is associated with a plano convex microlens (Figure 12) to form a dispersive non-Fresnel microlens (Figure 13) in accordance with one embodiment of the present invention. The dispersion producing configured surface of Figure 11 comprises a series of identically sized, identically spaced, individual prisms arranged in a grating arrangement and effective to produce dispersion by prismatic, geometric refraction (and not by wave optics diffraction of a diffraction grating).

Figures 14, 15 and 16 are related views showing how a dispersion producing surface configuration (Figure 14) is associated with a Fresnel type plano convex microlens (Figure 15) to form a dispersive Fresnel microlens (Figure 16) in accordance with another embodiment of the present invention. The dispersion producing configured surface of Figure 11

comprises a series of identically sized, identically spaced individual prisms arranged in the grating arrangement effective to produce dispersion by prismatic, geometric refraction (and not by wave optics diffraction of a diffraction grating).

Figure 17 is an isometric view of a dispersive, Fresnel microlens constructed in accordance with one embodiment of the present invention. The microlens shown in Figure 17 has a rectangular topology (is in the shape of a rectangle as viewed in plan view), and the axis of the grating of the prisms is not skewed with respect to the topology but is, instead, aligned and parallel with the related sides of the microlens. In Figure 17 a portion of the central part of one end of the microlens has been broken away to show details of structure.

Figure 18 is an elevation view, partly in cross section, taken along the line and in the direction indicated by the arrows 18-18 in Figure 17.

Figure 19 is an isometric view of another embodiment of a dispersive Fresnel type microlens constructed in accordance with the present invention. The microlens shown in Figure 19 has a rectangular topology, like the microlens shown in Figure 17. The dispersive grating is perpendicular to the direction arrow 143. The microlens shown in Figure 19 differs from the microlens shown in Figure 17 in the fact that the microlens shown in Figure 19 is fabricated by a binary fabrication process while the microlens shown in Figure 17 is fabricated by a non-binary fabrication process.

Figure 20 is a side elevation view of a dispersive non-Fresnel microlens and shows, in diagrammatic fashion in the lower part of the Figure, how the bandwidth of light existing in the blur spot in the image plane is transmitted through the dispersive microlens and is dispersed into individual wavelengths or individual wavebands A, B and C at specific locations on the detector plane.

Figure 21 is an isometric view showing specific spectral lines of the distributions (the intensity levels and the area locations) of the dispersed wavelengths or wavebands on the detector plane for a dispersive non-Fresnel microlens like

that shown in Figure 20. Figure 21 shows, by the height of the cones, the relative intensities of the specified dispersed wavelengths; and Figure 21 shows, by the areas occupied on the detector plane, the locations of the dispersed wavelengths. The alignment of the locations of the dispersed wavelengths shown in Figure 21 is a straight line which is canted at an angle with respect to the rectangular sides of the pixel shown in Figure 21. This angle results from a corresponding angle of rotation of the related grating of the related microlens. The total bandwidth of the light transmitted through the dispersive non-Fresnel microlens of Figure 20 is distributed within the outer envelope indicated by the dashed outline in Figure 21; and the wavelength separation is in fact a continuum, rather than just the three separate cones shown for purposes of illustration in Figure 21.

Figure 22 is an isometric view of a dispersive, non-Fresnel, binary fabricated microlens constructed in accordance with another embodiment of the present invention. The microlens shown in Figure 22 has a topology which is generally rectangular shaped, and the dispersion grating is not rotated.

Figure 23 is an isometric view showing the spectrum distributions (the intensity levels and the area locations) of the dispersed wavelengths or wave bands on the pixel in the detector plane for the dispersive, non-Fresnel, binary microlens shown in Fig. 22. The bandwidth of light in the blur spot at the microlens in the image plane is dispersed to the smaller but elongated blur spot on the detector plane, and the wavelengths in the elongated blur spot in the pixel on the detector plane (as shown in Figure 23) are varied in a progressive way from one end of the blur spot to the other end. As noted below with reference to

Figures 35 and 36, the total energies that fall on each detector area (within the total bandwidth) are obtained by a convolution, or integration, of the spectral blur spots and the responsivity function. The alignment of the dispersed wavelengths or wavebands in Figure 23 is a straight line which runs parallel to the sides of the pixel, and this alignment is produced by a zero rotation of the dispersive grating of the non-Fresnel microlens as shown in Figure 22.

Figures 24, 25 and 26 show the respective high distribution (red), medium distribution (green) and low distribution (blue) components existing in the elongated pixel blur spot shown in Figure 23. It should be noted that the terms red, green and blue are used here and throughout the text to refer to the distribution in the waveband discussed and not to specific colors as such.

Figure 24 is an isometric view showing only the distribution (locations) and intensity levels of the longest (in this case red) wavelengths in the elongated pixel plane blur spot shown in Figure 23.

Figure 25 is an isometric view showing only the distribution (locations) and intensity levels of the mid (in this case green) wavelengths of the elongated pixel plane blur spot shown in Figure 23.

Figure 26 is an isometric view showing only the distribution (locations) and intensity levels of the shortest (in this case blue) wavelengths of the elongated pixel plane blur spot shown in Figure 23.

Figure 27 is a side elevation view of a dispersive, Fresnel, non-binary microlens constructed in accordance with another embodiment of the present invention and shows, in diagrammatic fashion in the lower part of the

figure, how the bandwidth of light existing in the blur spot at the microlens in the image plane is transmitted through the dispersive microlens and is dispersed into individual wavelengths or individual wavebands C, B and A at specific locations in a pixel on the underlying detector plane.

Figure 28 is an isometric view showing the spectrum distributions (the intensity levels and the area locations) of the dispersed wavelengths or wavebands on the pixel in the detector plane for the dispersive, Fresnel, non-binary microlens shown in Figure 27. The bandwidth of light in the blur spot at the microlens in the image plane is dispersed to the smaller but elongated blur spot on the detector plane, and the wavelengths in the elongated blur spot in the pixel on the detector plane (as shown in Figure 28) are varied in a progressive way from one end of the blur spot to the other so that more than one wavelength can be detected and/or located within the elongated blur spot on the detector plane. The alignment of the dispersed wavelengths or wavebands in Figure 28 is a straight line which is rotated with respect to the sides of the pixel, and this alignment is produced by a corresponding rotation axis of the dispersive grating of the Fresnel, non-binary microlens shown in Figure 27.

Figure 29, 30 and 31 show the respective red (high distribution), green (medium distribution) and blue (low distribution) components existing in the elongated pixel blur spot shown in Figure 28.

Figure 29 is an isometric view showing only distribution (locations) and intensity levels of the longest (in this case red) wavelengths in the elongated pixel plane blur spot shown in Figure 28.

Figure 30 is an isometric view showing only the distribution (locations) and intensity levels of the mid (in this case green) wavelengths of the elongated pixel wavelengths of the elongated pixel plane blur spot shown in Figure 28.

Figure 31 is an isometric view showing only the distribution (locations) and intensity levels of the shortest (in this case blue) wavelengths of the elongated pixel plane blur spots in Figure 28.

Figure 32A is a side elevation view of two side by side dispersive, Fresnel, rotated dispersive grating, microlenses formed directly on one surface of the substrate. Each microlens is associated with three related detectors located in a correspondingly rotated blur spot in a related pixel on the opposite side of the substrate.

Figure 32B is a bottom plan view, taken generally along the line and in the direction indicated by the arrows 32B--32B in Figure 32A. Figure 32B shows how the three detectors are aligned in the pixel in the detector plane for detecting the dispersed wavelengths or wavebands within the elongated blur spot indicated by the dashed outline in Figure 32B.

Figure 33 is a side elevation view, generally like Figure 32A, but showing an embodiment in which two loop hole detectors are used in each pixel. The non-binary, non-Fresnel, dispersive microlenses shown in Figure 33 are fabricated in silicon and are mated to a frontside-illuminated detectors side as the loophole CdTe array.

Figure 34A is an enlarged elevation view in cross section of one of the detectors of Figure 33.

Figure 34B is an isometric view of the detector shown in Fig. 34A.

Figures 35 and 36 are related views showing how two sets of detectors in a pixel in the detector plane can be specifically sized and positioned to pick up two different sets of signal information from the same overall color dispersed information contained within the elongated blur spot in the pixel in the detector plane. Figures 35 and 36 give a visual representation. The total energies that fall on each detector area are obtained by a convolution, or integration, of the spectral blur spots and the spectral responsivity functions.

Figure 37 is a graph showing the information obtained from the two different detectors positioned within an elongated blur spot in a single pixel by a convolution of the dispersed optical blur spot and detector responsivity function.

Figure 38 is an isometric, fragmentary view showing an array of non-dispersive, non-binary, Fresnel microlenses which can be positioned in a peripheral part of the image plane.

Figure 39 is an isometric view showing the spectral distributions (the intensity level and the area locations) of the wavelengths in the symmetrical spot formed on the detector plane by a non-dispersive microlens like one of the microlenses shown in Figure 38. Figure 39 illustrates how the higher order harmonics (extending orthogonally outwardly from the central cone for a square lens in Figure 39) produce an Airy disk pattern. This orthogonal pattern can produce resulting cross talk noise between adjacent pixels in the detector plane; because the patterns can be aligned, and the

harmonics from one pattern can extend into and can add to the harmonics in an adjacent pixel.

Figure 40 is an isometric, fragmentary view like Figure 39, but showing how an elongated blur spot formed in the pixel plane by a dispersive microlens in the image plane can also produce higher order harmonics in the pixel which can extend orthogonally into and in alignment with harmonics in adjacent pixels to produce cross talk noise.

Figure 41 shows how a diagonally rotated dispersion grating angle can result in a diagonal alignment of higher order harmonics which can still result in cross talk noise between diagonally adjacent pixels in the pixel plane.

Figure 42 shows a topology for square microlenses with a diagonal rotation angle of the dispersion grating which is effective to eliminate orthogonal cross talk noise but which can still result in diagonal cross talk noise between diagonally adjacent pixels.

Figure 43 shows a topology in which rectangular shaped microlenses, each having a diagonal rotation angle of the dispersion grating, can be longitudinally offset or staggered in adjacent rows to eliminate any diagonal cross talk noise between diagonally adjacent pixels in the detector plane.

Figures 44, 45, 46 and 47 show configurations for microlenses.

Figure 44 shows a rectangular configuration.

Figure 45 shows a rhombic, trapezoidal configuration.

Figure 46 shows a hexagonal configuration. This configuration has a number of advantages for maximizing the concentration and distribution of information in a related detector plane.

Figure 47 shows a circular configuration for a microlens.

Figure 48 shows a microlens array in which the individual microlenses are circular microlenses.

Figure 49 shows a microlens array in which the individual microlenses have a rhombic configuration.

Figure 50 shows a microlens array in which the individual microlenses have a hexagonal configuration.

Figure 51 shows a microlens array in which each individual microlens has a rectangular configuration and in which each microlens in each row is offset with respect to the microlenses in adjacent rows.

Figure 52 is an elevation view of a rectangular, Fresnel, binary, dispersive microlens constructed in accordance with an embodiment of the present invention.

Figure 53 is a diagrammatic plan view of the microlens shown in Figure 52 and shows the dispersion grating having a zero rotation angle (as indicated by the direction arrow 143 which is perpendicular to the grating).

Figure 54 is a top plan photograph (generated by a scanning electron microscope -- SEM) of the fabricated dispersive microlens shown in Figures 52 and 53.

Figure 55 is a top plan SEM photograph showing a fabricated array of microlenses made up of individual

microlenses each having the construction shown in Figure 54.

Figure 56 is a diagrammatic plan view, like Figure 53, but showing a rectangular microlens having the dispersion grating rotated at an angle perpendicular to the direction arrow 143 in Figure 56.

Figure 57 is a top plan SEM photograph of the fabricated dispersive microlens shown in Figure 56 and embodying the Fresnel, binary construction shown in Figure 52.

Figure 58 is a top plan view of four pixels in a detector plane, offset in adjacent rows, to correspond to the offset of related rectangular microlenses like the microlens shown in 57, and showing the location of the elongated blur spot in each pixel as produced by the microlens construction shown in Figure 57.

Figure 59 is an isometric view of a dispersive, Fresnel microlens like that shown in Figure 57. Figure 59 shows a dispersive, rectangular-shaped, binary fabricated, Fresnel microlens having the dispersion grating rotated at the angle indicated by the direction arrow in Figure 59.

Figure 60 is an isometric view (similar to Figure 21) showing specific spectral lines of the distributions (the intensity levels and the locations) of dispersed wavelengths on the pixel in the detector plane for the dispersive, Fresnel, binary microlens shown in Figure 59. As noted above with reference to Figure 21, the illustrated spectral blur spots are typical (blue, green, red) and are related to the lambda-low to lambda-high continuum within the total bandwidth (indicated by the dashed outline in Figure 60).

Figure 61 is a schematic plan view showing a hexagonal shaped microlens having a dispersion grating inclined at the angle indicated by the direction arrow in Figure 61.

Figure 62 is a plan SEM photograph of a fabricated low dispersive, binary, Fresnel, hexagonal shaped microlens having the dispersion grating inclined at the angle indicated in Figure 61.

Figure 63 is a top plan SEM photograph of a fabricated test array of hexagonal shape microlenses having the structure of the microlens shown in Figure 62.

Figure 64 is a fragmentary, plan view showing a rhombic shaped microlens having a dispersion grating rotated at the angle perpendicular to the direction arrow in Figure 64.

Figure 65 is a top plan SEM photograph of a fabricated high dispersive, hexagonal shaped, binary fabricated, Fresnel microlens having a dispersion grating rotated at the angle perpendicular to the direction arrow 143 in Figure 64.

Figure 66 is a top plan view of a composite array of pixels located at the detector plane and comprising a high resolution, (multicolor) pixel array of hexagonal shaped pixels in the central part of the composite array and having a lower resolution (wideband) pixel array of pixels in the peripheral part of the array. It should be noted that the use of multicolor and/or wideband may be a particular choice for a particular application. The high resolution region in combination with a low resolution region is often a more fundamental issue.

Figure 67 is an isometric, fragmentary, enlarged view showing a composite array of microlenses in an image plane for association with the composite array of pixels shown in Figure 66. High resolution, dispersive, hexagonal microlenses comprise the central part of the composite microlens array; and non-dispersive, low resolution, wideband microlenses make up the outer peripheral part of the composite microlens array.

Figure 68 is an elevation view showing how three emitters (each emitting a specified wavelength of color -- red, green and blue) are arranged in alignment within an axially rotated, elongated blur spot in a pixel in the pixel plane and are associated with a related, same rotation angle of dispersive grating, microlens in an image plane for combining the three separate wavelengths or wavebands of light emitted by the three emitters into a bandwidth of light at a blur spot existing at the location of the dispersive microlens in the image plane. The color content and intensity in the bandwidth of the light in the blur spot at the microlens are dependent upon the relative intensities of the different wavelengths emitted by the three emitters in the detector plane.

Figure 69 is a bottom plan view taken along the line and in the direction indicated by the arrows 69-69 in Figure 68.

Figure 70 is a diagrammatic view showing how the dispersive lens of the present invention is used in one (color combining) mode for combining a plurality of different, emitted wavelengths (emitted from emitters in an emitter plane) into a bandwidth of the wavelengths (at a blur spot in an image plane) and is used in another (color

detecting) mode for detecting multiple different wavelengths (by detectors at a detector plane) from a bandwidth of wavelengths (existing within an image plane blur spot) so as to enable color information not only to be emitted and combined but also to be dispersed and detected for color transmitting and regenerating methods and apparatus, such as, for example, color television, color recording, color facsimile and color printing processes and apparatus.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention relates to dispersive microlens apparatus and methods which can be used in a detecting mode for dispersing and detecting multiple different wavelengths or wavebands from a bandwidth of the wavelengths existing within an image plane blur spot and which can also be used

in a combining mode (for combining a plurality of different, emitted wavelengths into a bandwidth of the wavelengths at a blur spot in an image plane).

Figures 1 and 2 of the drawings illustrate object imaging environments in which the dispersive microlens apparatus and methods of the present invention are utilized to perform complex object imaging and analysis operations.

Figures 68, 69 and 70 of the drawings illustrate color combining environments in which the dispersive microlens apparatus and methods of the present invention are used for combining a plurality of different, emitted wavelengths into a bandwidth of wavelengths at a blur spot in an image plane.

Figure 70 illustrates how the dispersive microlens apparatus and methods enable color information not only to be dispersed, separated and detected but also to be emitted and combined for color transmitting and regenerating applications, such as, for example, color television, color recording, color facsimile and color printing processes and apparatus.

The use of the dispersive microlens in the first mode (the mode for detecting multiple different wavelengths or wavebands from a bandwidth of the wavelengths) will be described first and will be described with reference to use in a sensor environment of the general kind shown in Figures 1 and 2.

Figure 1 shows a sensor system, indicated generally by the reference numeral 101, which can be used for imaging/detecting an object and which can also provide (by use of the dispersive microlens apparatus and methods of the present invention) real time discrimination of sensed optical information for certain other qualities, such as, for example, color and/or temperature, of the object or objects generating the optical information.

The sensor system 101, as illustrated in Figure 1, includes imager optics 109, focal plane arrays 111 (comprising microlens arrays and detector arrays), and a signal processing unit 113.

Figure 2 is a diagrammatic view showing how each of three adjacent microlens 119 has an individual instantaneous

field of view (IFOV-1, IFOV-2 and IFOV-3) and showing how the energy (or object) in that individual IFOV is transmitted to the detectors (124A and 124B) associated with the particular microlens.

Figure 3 is an enlarged, diagrammatic view which illustrates details of the focal plane arrays 111 shown in Figures 1 and 2.

The focal plane arrays 111 in Figure 3 comprise a microlens array 115 in an image plane and a pixel array 117 in a detector plane.

The use of the microlens array 115 at the image plane in the focal plane arrays 111 allows the concentration of incident irradience to a small fraction of the pixel area in the detector plane.

As illustrated in Figure 3 (and as shown in more detail in the fragmentary enlarged Figure 67 view), the microlens array 115 (in one embodiment of the invention) is a composite array which comprises a central (foveal vision) array of high resolution, dispersive, individual microlenses 119 surrounded by an outer, peripheral array of non-dispersive, low resolution, wideband, individual microlenses 121. In other embodiments, different combinations of high and low resolution regions may be used and different combinations of dispersive and non-dispersive microlens may be used.

The pixel array 117 contains a plurality of pixels with each individual pixel related to a corresponding individual microlens in the microlens array 115.

Thus, in the specific embodiment shown in Figure 3, high resolution (multicolor) pixels 123 are located in the central part of the composite pixel array 117 and lower resolution (wideband) pixels 126 are located in the peripheral part of the composite pixel array 117.

As best illustrated in Figures 2, 3, 6 and 7, an instantaneous field of view (IFOV), and any object or objects within that instantaneous field of view, are imaged into an individual blur spot 125 at the location of an individual microlens 119 at the image plane. The optical information within this blur spot is transmitted through the microlens

119 to a related pixel 123 in the detector plane. (See Figure 2.)

As will be described in greater detail below, one or more detectors 124 (see Figures 2, 4A, 4B, 4C, 7, 8A, 8B, 9 and 10) are positioned within each pixel in the detector plane for receiving a signal or signals from the reduced size pixel blur spot.

Figures 4A, 4B and 4C are enlarged, fragmentary views, partly in cross section, showing how multiple detectors are associated with non-Fresnel dispersive microlenses (Figure 4A) and Fresnel dispersive microlenses (Figure 4B) and showing how a single detector is associated with a wideband Fresnel, non-dispersive microlens (Figure 4C).

It is desirable not to have any dead space in the focal plane arrays 111, for reasons which can best be understood by reference to Figure 5.

Figure 5 shows a detector plane used without an associated micro-optics array. An object 127 within a blur spot 125 which falls substantially fully upon a related detector 124 would have substantially all of the energy and information within that object transmitted to a corresponding component in the signal processing unit 113; so a dead zone between adjacent detectors would not have too much significance with respect to the object 127.

However, if (in the previously used Figure 5, detector-only, focal plane array) an object 129 spans several adjacent detectors 124 and also is disposed above dead zones between the microlenses (as indicated by the double cross-hatched portion 131 of the object image 129 in Figure 5), then that portion of the object image 129 (which does not fall onto any detector 124) would not be transmitted to the signal processing unit 124 and would be lost.

The present invention includes micro-optics above the detector plane array. As will be more clear from the description to follow, this use of the microlenses permits the detectors to be spaced apart from one another without any problems of dead zone losses as described immediately above in reference to the previously used Figure 5 detector array construction.

The preferred construction is to have all of the microlenses in the microlens array immediately adjacent one another so as not to have any optically dead space between any of the microlenses.

Figure 6 shows such construction for square shaped (in plan), Fresnel-type microlenses 121.

Figure 6 and related Figure 7 illustrate how all of the optical information within each individual blur spot 125 is preserved and is transmitted to detectors 124 in pixels 123 in the detector plane, even when a blur spot spans more than one individual microlens in the microlens array 115.

Thus, for example, the object image 129 which falls on four adjacent microlenses 121 (in Figure 6) is fully transmitted to four detectors 124 in the four related pixels 123 (see Figure 7) in the detector plane.

All of the energy is conserved.

It should also be noted that each individual microlenses, in the course of transferring the optical information at an image plane blur spot into a smaller detector plane blur spot in a related pixel in the detector plane, is effective to produce a high contrast ratio, high fill factor and high optical gain of the optical information in the detector plane blur spot with respect to any existing, unwanted noise (produced by large detector elements) which may be present at the detector plane.

The optical gain achieved is the area ratio of the microlens to the detector (see Figure 8A).

The microlens array 115 and pixel array 117 provide high overall optical efficiency, nearly 100% fill factor, extended wavelength response and reduced detector noise levels.

Microlenses constructed in accordance with the present invention may typically range in size from a diameter D of 50 microns to 1000 microns, and the related detectors may be fabricated from bulk material that is thinned to a thickness t that represents an *f*/1 lens.

Because the microlenses transfer the optical information in the image plane blur spots into respective smaller detector plane blur spots in respective detector plane pixels, the small detector plane blur spots (corresponding

generally to the diameter d of the detector 124 shown in Figure 8A) leave relatively large adjacent areas, or real estate, in the detector plane which can be used for other purposes.

As shown in Figure 8A and 8B, micro cooling channels 133 can be positioned in the relatively large adjacent areas and used for cooling nearby structure.

The available real estate may also be utilized for analog signal processing circuits, such as, for example, the analog circuits 126 in Figures 8A and 8B. As will be described in more detail below, the circuits can be conventional detector read-out circuits, detector signal adding circuits or ratio-ing circuits, as the system design requires.

As also indicated by Figure 8A, and as will be described in more detail below, multiple detectors, such as the detectors 124A, 124B and 124C shown in Figure 8B, can be positioned in a number of locations and in a variety of alignments within each individual pixel. Having the space available to do this in a detector plane pixel is a benefit which is of particular utility in connection with a dispersive microlens like the dispersive, high resolution microlens 119 shown in Figure 8B, as will be described in more detail below.

Figure 9 is a fragmentary plan view which shows how two detectors 124A and 124B can be positioned (in this case orthogonally) in each unit pixel 123.

Figure 10 is a fragmentary top plan view showing how three detectors 124A, 124B and 124C may be positioned within each unit pixel 123.

It should be noted that the blur spot 125 results from a combination of refraction and diffraction. The blur resulting from refraction (geometric optics) results from the different focus of different wavelengths. The blur caused by diffraction (wave optics) is inherent to a certain degree in all refractive (geometric optics) lenses. This blur spot phenomenon which results primarily from refraction (geometric optics) and, to a much lesser extent, diffraction (wave optics) of lenses is described at pages 727 and 728 of

Physics by Hausmann and Slack, 3rd edition, 1948, and published by D. Van Nostrand Company, Inc., New York.

In accordance with the present invention, a microlens (1) is constructed to transmit a selected bandwidth of light existing in the incident blur spot at the microlens plane 115 to a smaller pixel blur spot in a pixel plane 117 spaced at a selected distance from the microlens and (2) includes dispersion means for producing both a controlled dispersion of the bandwidth of light (as the light is transmitted to the smaller blur spot) and also an elongated shape of the smaller pixel blur spot (in which the elongated shape wavelengths or wavebands are varied in a progressive way from one end of the elongated blur spot to the other so that more than one wavelength can be detected and/or located within the elongated blur spot).

The dispersion means comprise a configured surface formed integrally on the microlens.

Figures 11, 12 and 13 are related views showing how a dispersion producing surface configuration (Figure 11) can be visualized as being combined with a plano convex surface configuration microlens (Figure 12) to form a single, combined surface, dispersive non-Fresnel microlens (Figure 13) in accordance with one embodiment of the present invention.

As illustrated in Figure 11 the dispersion producing means 135 may be visualized as a series of identically sized, identically spaced, individual prism surfaces each having an inclined surface 136 and a vertical surface 138. The prism surfaces are aligned in a grating arrangement (an arrangement in which corresponding surfaces

on corresponding prisms extend parallel to one another). The prism surfaces are effective to produce dispersion substantially entirely by geometric refraction (and not to any significant extent by the wave optics diffraction of a diffraction grating).

The grating arrangement shown in Figure 11 is a grating in the general sense of the term. That is, the arrangement of the prismatic surfaces, when viewed from above, can have

the appearance of parallel elements, like a grating of latticed bars set in a window, door, etc. The use of the term grating with reference to the construction shown in Figure 11 is not a reference to a grating as an optical diffraction grating. The grating shown in Figure 11 does not produce slits equally spaced which can cause dispersion by spreading of a wave into its component frequencies. The grating arrangement shown in Figure 11 instead essentially causes dispersion of the light by causing different wavelengths of the light to be transmitted through the material of the microlens at different velocities. There is, of course, always some diffraction which is caused by the material of the lens itself. In this regard, see the above discussion of the formation of the blur spot 125 and the reference to pages 727 and 728 of Physics by Hausmann and Slack.

Figure 12 shows a plano convex microlens 137 having a convex surface 140.

When the dispersion surface means 135 shown in Figure 11 are combined with a plano convex surface microlens 137 shown in Figure 12 a dispersive microlens 119 shown in Figure 13 is obtained. The curved surfaces 142 of the dispersive microlens 119 have curvatures which are a combination of the curvature 140 of Figure 12 and the inclination of the prismatic surfaces 136 shown in Figure 11.

The surfaces 138 shown in Figure 13 correspond to the surfaces 138 shown in Figure 11 for producing the prism effects.

Figures 14, 15 and 16 are related views showing how a dispersion producing surface configuration 135 (Figure 14) is associated with a Fresnel-type plano convex microlens 139 (Figure 15) to form a dispersive Fresnel microlens 119 (Figure 16) in accordance with another embodiment of the present invention.

The dashed lines shown in Figure 16 are included just to represent the amount of material which is eliminated thus resulting in a thinner wafer when the lens is fabricated in a Fresnel structure rather than in a non-Fresnel structure.

Figure 17 is an isometric view of a dispersive, Fresnel microlens 119 constructed in accordance with one embodiment of the present invention.

The dispersive microlens 119 shown in Figure 17 is basically like the lens shown in Figure 16 but is shown (in Figure 17) mounted on a substrate 141.

The substrate 141 may be a separate material if required for a particular optomechanical application, or the substrate 141 may be common for the lenses on one side and the detectors on the other side (back illuminated detectors).

The microlens 119 shown in Figure 17 has a rectangular topology (is in the shape of a rectangle as viewed in plan view), and the grating is not rotated with respect to the topology but is instead, aligned and parallel with the related sides of the microlens. In Figure 17 a portion of the central part of one end of the microlens has been broken away to show details of structure.

Figure 18 is an elevation view, partly in cross section, and is taken along the line and in the direction indicated by the arrows 18-18 in Figure 17.

The dispersive, Fresnel microlens shown in Figure 17 is fabricated by non-binary techniques.

Figure 19 shows a dispersive, Fresnel microlens having a rectangular, square topology and a non-rotated grating angle (all similar to the microlens shown in Figure 17), but the microlens 119 shown in Figure 19 is fabricated by a binary fabrication process.

The angle of the dispersive grating is perpendicular to the direction arrow 143 in Figure 19.

Figure 19 shows, in the dashed outline beneath the direction grating arrow 143, the cross section configuration of the Fresnel-type dispersive microlens in that part of the microlens.

As illustrated in Figure 19, the vertical wall surfaces 138 which form part of the dispersion grating are curved surfaces (as viewed in plan) rather than straight lines.

Because the dispersive microlens 119 is constructed by binary fabrication, the surfaces 142 are not smoothly curved (like the smoothly curved surfaces 142 shown in Figure 17)

but are instead formed as a series of discrete levels 142A, 142B, 142C, 142D, 142E and 142F. The number, n, of discrete levels produced is a function ($n=2^M$) of the number, M, of photolithographic and anisotropic etching steps (Number of Masks) involved in the fabrication. Note that 2^M is the definition of binary as a number. The number of levels determines the smoothness to which the surface can be approximated and, consequently, its efficiency.

As noted above, the dispersive microlens of the present invention transmits a selected bandwidth of light (existing in the incident blur spot 125 at the microlens) to a much smaller pixel blur spot in a plane space at a selected distance from the microlens. This much smaller pixel blur spot is indicated in Figure 20 by the reference numeral 145. In Figure 20 the blur spot 145 is shown, for easier viewing, larger than and out of scale to the actual ratio of diameters D (at the image plane) to d (at the detector plane).

The dispersive means on the microlens produce both a controlled dispersion of the bandwidth of the light (as the light is transmitted to a smaller pixel blur spot) and also an elongated shape of the smaller pixel blur spot. The wavelengths or wavebands in the elongated pixel blur spot are varied in a progressive way from one end of the elongated blur spot to the other so that more than one wavelength can be detected and/or located within the elongated blur spot.

Figures 20 and 21 illustrate how the bandwidth of light existing in the blur spot 125 (see Figure 6) at the microlens 119 in the image plane is transmitted (see the illustrative light rays indicated by the dashed lines in Figure 20) through the dispersive microlens and is dispersed into individual wavelengths or wavebands 145A, 145B and 145C within the elongated detector plane blur spot 145 at specific locations on the detector plane.

Figure 21 is an isometric view showing selected wavelengths from the spectrum distributions (the intensity levels and the area locations) of the dispersed wavelengths or wavebands 145A, 145B and 145C on the detector plane pixel 123 for a dispersive, non-Fresnel microlens like that shown in Figure 20. Figure 21 shows, by the height of the cones

145A (blue), 145B (green) and 145C (red), the relative intensities of the dispersed wavelengths or wavebands.

As noted above in the description, the use of the terms blue, green and red is a use to indicate the low, medium and high wavelengths from the spectral band existing in the blur spot. The use of the terms is not intended to refer to specific, visible colors as such.

Figure 21 shows, by the areas occupied (by the basis of the cones 145A, 145B and 145C) on the detector plane, the locations of the dispersed wavelengths or wavebands. The alignment of the locations of the dispersed wavelengths or wavebands 145A (blue), 145B (green), and 145C (red) shown in Figure 21 is a straight line which is canted at an angle with respect to the rectangular sides of the pixel 123 shown in Figure 21. This angle results from a corresponding angle of rotation of the related grating of the related microlens 119 shown in Figure 20.

Figure 22 is an isometric view of a dispersive, non-Fresnel binary fabricated microlens constructed in accordance with another embodiment of the present invention. The microlens 119 in figure 22 has a topology which is generally square shaped, and the axis of the dispersion grating is aligned with the sides of the microlens so that there is no rotation to this axis. The dashed lines in Figure 22 show the cross sectional configuration of the microlens at the locations of the dashed lines.

Figure 23 is an isometric view showing the spectrum distributions (the intensity levels and the area locations) of the dispersed wavelengths or wavebands on the pixel 123 in the detector plane for the dispersive, non-

Fresnel, binary microlens 119 shown in Figure 22. The bandwidth of light in the blur spot 125 at the location of the microlens 119 in the image plane is dispersed to the smaller but elongated blur spot 145 on the detector plane. The wavelengths in the elongated blur spot 145 in the pixel 123 on the detector plane (as shown in Figure 23) are varied in a progressive way from one end of the pixel plane blur spot to the other so that more than one wavelength can be detected and/or located within the elongated blur spot 145 on the detector plane. The elongated blur spot is dispersed into the respective components 145A (blue), 145B (green), and 145C (red) components as shown in Figure 23. The alignment of the dispersed wavelengths or wavebands of the pixel plane blur spot 145 in Figure 23 is a straight line which runs parallel to the sides of the pixel 123, and this alignment is produced by a zero angle rotation of the dispersive grating on the non-Fresnel microlens 119 shown in Figure 22.

Figures 24, 25 and 26 show the respective red, green and blue components existing in the elongated pixel plane blur spot shown in Figure 23.

Figure 24 is an isometric view showing only the distribution (location) and intensity levels of the longest (in this case red) wavelengths in the elongated pixel plane blur spot shown in Figure 23.

Figure 25 is an isometric view showing only the distribution (location) and intensity levels of the mid (in this case green) wavelengths in the elongated pixel plane blur spot shown in Figure 23.

Figure 26 is an isometric view showing only the distribution (locations) and intensity levels of the shortest (in this case blue) wavelengths of the elongated pixel plane blur spot shown in Figure 23.

Figure 27 is a side elevation view of a dispersive, Fresnel, non-binary, rotated grating axis, microlens 119 constructed in accordance with another embodiment of the present invention.

Figure 28 is an isometric view (generally similar to the isometric view shown in Figure 23) showing the spectrum distributions (the intensity levels and the area locations) of the dispersed wavelengths or wavebands 145A (blue), 145B (green), and 145C (red) which make up the elongated pixel plane blur spot 145 produced by the microlens 119 shown in Figure 27. The alignment of the dispersed wavelengths or wavebands in Figure 28 is a straight line which is rotated with respect to the sides of the pixel 123, and this alignment is produced by a corresponding rotation axis of the dispersive grating of the microlens 119 shown in Figure 27.

Figures 29, 30 and 31 show the respective red, green and blue components existing in the elongated pixel plane blur spot 145 shown in Figure 28.

There are a number of ways which the dispersive microlens 119 and associated detectors 124 can be structured in accordance with the present invention.

Figures 32A and 32B show one way, and Figures 33, 34A and 34B show another way.

In the construction shown in Figures 32A and 32B, dispersive, Fresnel, skewed dispersive grating, microlenses 119 are formed directly on one surface of a commercially available cadmium tellurium (CdTe) substrate 147.

Figure 33 shows how a dispersive, non-Fresnel, microlenses 119 fabricated in silicon (Si) is mated to a frontside-illuminated, commercially available, loophole array of two CdTe detectors 124A and 124B in each pixel plane blur spot 145.

As illustrated in Figure 33, one detector 124A can be used to detect one bandwidth of colors in the elongated pixel plane blur spot 145 and another detector 124B can be used to detect another, different bandwidth of colors within the elongated pixel plane blur spot 145.

This positioning and selection of multiple detectors to detect multiple signals from the single, elongated pixel plane blur spot 145 will be described in more detail below with reference to Figures 35 and 36.

Because the dispersive microlens of the present invention disperses the component wavelengths or wavebands of light within the elongated pixel plane blur spot 145 in a progressive way and at exact locations in the pixel plane blur spot, a plurality of detectors can be positioned at particular locations within the elongated blur spot to detect specific signals which are dependent upon the locations of the detectors in the pixel plane blur spot. This feature of the present invention is best illustrated in Figures 35 and 36.

Figures 35 and 36 are related views showing how two sets of detectors in a pixel 123 in the detector plane can be specifically sized and positioned to pick up two different

sets of signal information from the same overall color dispersed information contained within the elongated blur spot 145 in the pixel 123 in the detector plane. The particular selection chosen is system dependent.

The uses of the two sets of detectors illustrated in Figures 35 and 36 permit the pick-up of two different sets of signal information from the long, medium and short wavelengths within any given bandwidth. In the particular example illustrated in Figures 35 and 36 the illustrated band is long wavelength infrared (LWIR) in the 8-12 micron bandwidth.

This 8-12 LWIR is an example. Similar results may be generated in other wavelength bands, i.e., visible (Vis) near infrared (NWIR), short infrared (SWIR), mid infrared (MWIR) region.

Figure 35 shows how one detector 124A is sized and positioned to pick up a signal which is representative of the energy contained within both the 145C (red, 12 micron) wavelength and the 145B (green, 10 micron) wavelength while the other detector 124B is sized and positioned to pick up a signal which is representative of the energy primarily within the 145A (blue, 8 micron) wavelength of the elongated detector plane blur spot 145.

In Figure 35 the dispersive microlens which produces the elongated blur spot 145 is a 100 micrometer square, Fresnel microlens having a rotated grating which is rotated to an angle of 14 degrees (perpendicular to the line indicated by the direction arrow 143). Grating rotation/canting angle is selected from a design requirement to minimize optical cross-talk between neighboring pixels. The microlens was fabricated by a binary fabrication process utilizing two photolitho-graphic and anisotropic etching steps. The resulting blur spot 145 shown in Figure 35 is basically like that illustrated in Figure 28 of the drawings.

Figure 36 shows how a different set of signals can be obtained (from the same pixel plane blur spot as shown in Figure 35) by using a set of detectors which are positioned at locations different from the set of detectors shown in Figure 35.

In Figure 36 the detector 124A is sized and positioned to pick up a signal which represents all of the energy contained within the 145C portion (the red, 12 micron) wavelength and part of the energy contained within the longer wavelength end of the 145B portion (the red-green, 11 micron) wavelengths. The other detector 124B is positioned to pick up a signal which is representative of all of the information contained within the portion 145C (the blue, 8 micron) wavelength and a part of the 145B portion (the green, 9 to 10 micron) wavelengths. Thus, the detector 124B picks up a signal which represents the energy contained within the 10 to 8 micron waveband and the detector 124A picks up the energy contained in the 12 to 11 waveband in the Figure 36 positioning of the two detectors.

Other topologies, detector layouts, size selection, fabrication techniques and Fresnel/non-Fresnel selections can be used for other, specific applications.

Figure 37 is a graph which illustrates how two different detectors positioned within a single elongated blur spot in a single pixel (see Figure 33) provide multiple signals which can be used to obtain highly effective information with regard to objects imaged within the blur spot at the dispersive microlens.

The detectors in each pixel can be summed in the acquisition mode to obtain an increased signal.

In the discrimination mode the color contrast is evaluated to determine the object temperature.

The ratio of the energies are also used as a temperature discriminator.

The present invention recognizes the possible problem of cross talk noise between adjacent pixels in the detector plane and provides a number of constructions and arrangements for minimizing or eliminating such cross talk noise.

How this problem of possible cross talk noise can develop will now be discussed with reference to Figures 39, 40, 41, 42 and 43.

Figure 39 shows the pixel plane blur spot 125 formed within a pixel 126 by a single, non-dispersive, wideband

microlens (such as, for example, a single microlens 121 shown in Figure 38).

Figure 39 shows how the blur spot 125 has higher order harmonics 125-1, 125-2, 125-3, etc. (extending orthogonally outwardly from the central cone in Figure 39). This produces an Airy disk pattern when the microlens is a simple, wideband, non-dispersive lens like a microlens 121 shown in Figure 38. This orthogonal pattern can produce resulting cross talk noise between adjacent pixels in the detector plane because (depending on how the microlenses and pixels are aligned in the respective arrays) the noise patterns can be aligned and the harmonics from one pattern in one pixel can extend into and can add to the harmonics in an adjacent pixel.

Figure 40 shows how an elongated blur spot 145 formed in a pixel 123 in the pixel plane by a dispersive microlens in the image plane can also produce higher order harmonics which can extend orthogonally into and in alignment with harmonics in adjacent pixels to produce cross talk noise. The higher order harmonics are illustrated but are not numbered in Figure 40.

Figure 41 shows how a diagonally rotated dispersion grating angle (a grating perpendicular to the arrow 143) can result in a diagonal alignment of higher order harmonics which can still result in cross talk noise between diagonally adjacent pixels 123 in the pixel plane, even though the transverse higher order harmonics (indicated by the direction arrows 149 in Figure 41) are laterally offset from one another between adjacent pixels 123.

Figure 42 shows a topology for rectangular microlenses with a diagonal rotation angle (perpendicular to the direction arrow 143) of the dispersion grating which is effective to eliminate orthogonal cross talk noise (in the direction indicated by the arrows 149 in Figures 41 and 42) but which can still result in diagonal cross talk noise (in the direction indicated by the direction arrow 143) between diagonally adjacent pixels.

Figure 43 shows a topology in which rectangularly shaped microlenses, each having a diagonal rotation angle (perpendicular

to the direction arrow 143) of the dispersion grating, can be longitudinally offset or staggered in adjacent rows to eliminate any diagonal cross talk noise between diagonally adjacent pixels in the detector plane.

Figures 44 through 51 illustrate topologies and arrangements of arrays of microlenses which may be used in the present invention.

Two basic features are thus available, in accordance with the present invention, for optimizing a construction to eliminate or to modulate signal to noise. The two features are topology (pixel shape) and grating orientation. By combining these two features in a specific way for a specific application the signal to noise can be optimized.

Figures 44, 45, 46 and 47 show respective square, rhombic, hexagonal and circular configurations for microlenses. Any and all of these configurations may incorporate dispersive means so that the microlenses are dispersive microlenses 119 rather than wideband, non-dispersive microlenses. Any and all of these configurations can also be used for wideband, non-dispersive microlenses.

The various configurations of the individual microlenses shown in Figures 44-47 can be arranged in the various arrays shown in Figures 48-51.

In addition, as illustrated in Figure 67, composite arrays (which contain combinations of microlens shapes and features) can be utilized to obtain specific, desired results.

Figures 52-55 illustrate how a square, Fresnel, binary fabricated, dispersive microlens 119 having a zero skew angle grating (perpendicular to the arrow 143 in Figure 53) is assembled in a high resolution microlens array (see Figure 55) with individual microlenses offset in adjacent rows (see Figure 55). As noted above Figures 54 and 55 are photographs of a fabricated microlens and a fabricated microlens array. The photographs were generated by a scanning electron microscope -- SEM.

Figures 56-58 are related views showing how a dispersive, Fresnel-type, binary fabricated, microlens 119 like that shown in Figure 52, but having a skewed grating

angle (perpendicular to the arrow 143) as illustrated in Figure 56, and arranged in longitudinally offset relationship in adjacent rows, produces offset blur spots 145 in the related pixels 123 in the pixel plane so as to minimize or to totally eliminate cross talk noise between both laterally and diagonally adjacent pixels.

Figure 59 is an isometric view of a dispersive, Fresnel microlens like the microlens shown in Figure 57. Figure 59 shows a dispersive, square shaped, binary fabricated, rotated angle grating, Fresnel microlens having the dispersion grating rotated at the angle perpendicular to the direction arrow 143 in Figure 59.

Figure 60 is an isometric view showing the spectrum distribution (the intensity levels and the locations) of the dispersed wavelengths or wavebands 145A, 145B and 145C in the pixel blur spot on the pixel 123 as produced by the microlens 119 shown in Figure 59. Figure 60 shows, in isometric view, the pixel blur spot locations and alignments (which are also shown in Figure 58).

Figures 61, 62 and 63 show how low spectral resolution, dispersive hexagonal shaped, Fresnel-type, binary fabricated, microlenses (having the dispersion grating inclined at an angle perpendicular to the direction arrow 143 in Figure 61) are combined in a low spectral resolution microlens array as shown in Figure 63.

The microlens array shown in Figure 63 is also shown in the upper left hand part of the fragmentary Figure 67 showing.

Figure 64 is a fragmentary, diagrammatic plan view showing a rhombic shaped dispersive microlens having a

dispersion grating rotated at an angle perpendicular to the direction arrow 143.

Figure 65 is a top plan view of a high dispersive, hexagonal shaped, binary fabricated, Fresnel microlens having a dispersion grating rotated at approximately the same angle as the angle in Figure 64.

In accordance with the present invention, composite arrays of microlenses (and related composite arrays of

pixels) can be constructed and utilized to accomplish a variety of specific functions.

Figures 66 and 67 show how composite arrays are constructed to achieve a foveal function quite similar to the foveal vision of the human eye.

Optics and mechanical and electronic components can be readily associated with these composite arrays to enhance imaging and also to provide additional imaging functions and analysis.

The outer peripheral arrays of low resolution (wideband) non-dispersive microlenses 121 (Figure 67) and associated pixels 126 (Figure 66) thus provide peripheral vision which can be utilized effectively for detecting motion; and the high resolution, multicolor, central arrays of dispersive microlenses 119 and associated pixels 123 provide a color sensitive vision which enable even more sensitive and complex imaging to be accomplished.

A composite pixel array like that shown in Figure 66 also provides room, in the areas of the low resolution wideband pixels, for leading out the high density of signal lines which are associated with the inner, high resolution, multicolor pixel array.

The use of the dispersive microlens of the present invention as thus far described has been directed primarily to color detecting uses in environments in which the dispersive microlens have been used in a color detecting mode for detecting multiple different wavelengths or wavebands (by detectors located in a detector plane) from a bandwidth of wavelengths existing within an image plane blur spot at the microlens.

The dispersive microlens of the present invention can be used in another, color combining mode for combining a plurality of different, emitted wavelengths (emitted from emitters in an emitter plane) into a bandwidth of wavelengths (at a blur spot existing at the microlens in an image plane) so as to enable color information not only to be dispersed and detected but also to be emitted and combined for color transmitting and regenerating methods and apparatus, such as,

for example, color television, color recording, color facsimile, and color printing processes and apparatus.

This use of the dispersive microlens of the present invention in a color combining mode will now be described in more detail with reference to Figures 68, 69 and 70.

As shown in Figures 68 and 69, three emitters 151A, 151B and 151C (each emitting a specified wavelength of color -- red, green and blue) are arranged in alignment within an axially rotated, elongated blur spot 145 (see Figure 69) in a pixel 123 in the pixel plane and are associated with a related, same rotation angle of dispersive grating, microlens 119 in an image plane. The three separate emitters 151A, 151B and 151C emit respective blue, green and red wavelengths or wavebands of light, and these emitted wavelengths or wavebands are combined into a blur spot (indicated diagrammatically by the dashed outline 149 in Figure 69) existing at the location of the dispersive microlens 119 in the image plane.

The color content and the intensity in the bandwidth of light in the blur spot 145 are dependent upon the relative intensities of the different wavelengths emitted by the three emitters 151A, 151B and 151C. The energizations of these emitters are modulated to produce the exact color and intensity desired at the specific location of the blur spot 145. By combining an array of the dispersive microlenses and associated array of the pixels containing the multiple emitters, a color screen (composed of an array of dispersive microlenses) can be used as a color display for color television, color printing, color facsimile, etc.

This is better illustrated in Figure 70.

The color system 152 in Figure 70 illustrates a system which may be used for transmitting color facsimile and/or color television from one station to another by utilizing apparatus and methods which incorporate the dispersive microlens of the present invention.

As illustrated in Figure 70 a color combining and generating station 153 is connected, by means of a conduit 155, to a color receiving and/or detecting station 157, where the color information may be used directly or may be detected and further processed.

For simplifying illustration, only a single dispersive microlens has been illustrated at each of the generating and receiving stations 153 and 157, but it will be appreciated that a plurality of dispersive microlenses are used in an array (in combination with a related array of emitter plane pixels/detector plane pixels, and associated components).

As illustrated in the top part of Figure 70, the color generating station comprises a dispersive microlens 119 which is positioned above emitters 151A, 151B and 151C in the manner described above with reference to Figures 68 and 69.

The energization and modulation of each emitter is controlled by respective control lines 159A, 159B and 159C.

The waveband of color, as combined in the microlens 119, is displayed on a pixel 161A on an array 163A of such pixels.

The combined color information contained in the pixel 161A is transmitted by a connector 165A to a transmitter 167. The transmitter may transmit the information by fiber optics or may convert the information to electrical form for sending to the receiver station 157.

A component 169 may be used to serve a repeater function, or a switching function or a conversion function, depending upon the specific application.

At the receiver station 157, the operations performed on the operation received on the line 155 are substantially the reverse of the operations performed at the generating station 153.

The color information (as initially generated by the individual emitter plane pixels 123) is distributed back to corresponding, individual detector plane pixels 123.

Thus, the portion of the color information (as combined in the dispersive microlens 119 at the color combining station 153) is transmitted by the connector 165B and the screen pixel 161B to the related dispersive microlens 119 in the receiver station 157, where the bandwidth of information in that blur spot is dispersed to the separate detectors 124A, 124B and 124C.

The information in these particular wavelengths or wavebands can then be supplied (by respective connectors 126A, 126B and 126C) to a processor for further image processing or other use if desired.

It should also be noted that the color information developed and received on the screens 163A and 163B, or the information developed on the microlenses 119 in the color combining and generating station 153, can, for some purposes, be used directly without further processing.

This information, for example, can be used directly if it is desired only to view the image and color developed on the screen.

The organized pattern of color information as detected by the detectors 123 at the color receiving and/or detecting station 157 (as generated by an input other than an input from the station 153) may be sent from the station 157 to the color combining and generating station 153 by means of the transmitter 171B, the line or bus 173, the component 175, and the transmitter 171A, all as illustrated in Figure 70.

While I have illustrated and described the preferred embodiments of my invention, it is to be understood that these are capable of variation and modification, and I therefore do not wish to be limited to the precise details set forth, but desire to avail myself of such changes and alterations as fall within the purview of the following claims.

78585-3

CLAIMS:

1. A unitary, dispersive microlens apparatus for use in dispersing a bandwidth of light into multiple selected wavelengths or wavebands of light at specified locations in an elongated blur spot so that detectors in the specified locations can detect the multiple wavelengths or wavebands, said microlens apparatus having height dimensions in the order of a few micrometers, said microlens comprising,

a microlens constructed to transmit and to concentrate a selected bandwidth of light existing in a blur spot at the microlens to a smaller blur spot in a detector plane spaced at a selected distance from the microlens, and

dispersion means for producing both a dispersion of the bandwidth of light as the light is transmitted and concentrated to the smaller blur spot and also an elongated shape of the smaller blur spot in which the wavelengths or wavebands are varied from one end of the elongated blur spot to the other so that more than one wavelength can be detected by detectors at specified locations within the elongated blur spot in the detector plane, said dispersive means comprising a grating formed integrally on the microlens and wherein the unitary construction of the grating integrally on the microlens enables one unitary, dispersive microlens apparatus to perform multiple, designed, refraction and dispersion functions while eliminating noise and reflection losses which could otherwise occur across an interface between a separated, non-unitary microlens and grating.

2. The invention defined in claim 1 wherein the

dispersion means comprise a blazed grating formed integrally on the microlens.

3. A unitary, dispersive bidirectional microlens apparatus which can be used in a first mode, in which first mode light is transmitted through the microlens apparatus in a first direction, for detecting multiple different wavelengths from a bandwidth of the wavelengths existing within the microlens apparatus at an image plane blur spot and which can be used in a second mode, in which second mode light is transmitted through the microlens apparatus in a second direction opposite to said first direction, for combining a plurality of different, emitted wavelengths into a bandwidth of the wavelengths within the microlens apparatus, said dispersive microlens apparatus comprising,

a microlens constructed to be positioned in an image plane at an image plane blur spot and to transmit and to concentrate a selected bandwidth of light from the image plane blur spot into a smaller detector/emitter plane blur spot in a detector/emitter plane which is spaced from the image plane, and

dispersion means for producing, in relation to the bandwidth of light in the image plane blur spot, a dispersion of the bandwidth of light and an elongated detector/emitter plane blur spot in which the wavelengths are varied and dispersed to specified locations from one end to the other of the smaller, elongated blur spot so that, in said first mode, more than one wavelength or band of wavelengths can be detected by detectors at the specified locations within the elongated blur spot when light is transmitted from the image plane to the detector plane and so that, in said second mode, a plurality of specified

wavelengths of light can be emitted from a plurality of specified locations in the elongated blur spot and can be combined into a bandwidth of light in the image plane blur spot when light is transmitted from the emitter plane to the image plane, said dispersion means comprising a grating formed integrally on the microlens and wherein the unitary construction of the grating integrally on the microlens enables one unitary, dispersive microlens apparatus to perform multiple, designed, refraction and dispersion functions while eliminating noise and reflection losses which could otherwise occur across an interface between a separated, non-unitary microlens and grating.

4. The invention defined in claim 3 wherein the dispersion means comprise a blazed grating formed integrally on the microlens.

5. Apparatus for transmitting and concentrating optical information contained in optical blur spots in an image plane to small fractions of the areas of related pixels in a detector plane which is spaced from the image plane, said apparatus comprising,

microlens means comprising a plurality of individual microlenses, positioned at a plurality of image plane blur spot locations, for transmitting and concentrating the optical information in an image plane blur spot into a smaller detector plane blur spot in a related pixel in the detector plane, so that the area of the detector plane blur spot is decoupled from the area of the pixel, and for producing a contrast ratio, fill factor and optical gain of said optical information in the detector plane blur spot with respect to any existing, unwanted noise present at the detector plane,

at least certain ones of said individual microlenses including a grating formed integrally on the individual microlens for dispersing the optical information in at least certain ones of the image plane blur spots to create an elongation of a related detector plane blur spot and a dispersed distribution of the optical information to specific locations within that elongated blur spot which permits multiple, different signals to be detected by detectors at the specific locations within that elongated blur spot and wherein the unitary construction of the grating integrally on the microlens enables one unitary, dispersive microlens to perform multiple, designed, refraction and dispersion functions while eliminating noise and reflection losses which could otherwise occur across an interface between a separated, non-unitary microlens and grating.

6. The invention defined in claim 5 wherein the microlens means include an array of individual, dispersive microlenses and wherein the dispersion means comprise a blazed grating formed integrally and in a regular pattern on each individual, dispersive microlens.

7. The invention defined in claim 6 wherein the microlens means comprise circular shaped microlenses.

8. The invention defined in claim 6 wherein the microlens means comprise square shaped microlenses.

9. The invention defined in claim 6 wherein the microlens means comprise hexagonally shaped microlenses.

10. The invention defined in claim 6 wherein the microlens means comprise rhombic shaped microlenses.

11. The invention defined in claim 6 wherein the microlens means comprise non-Fresnel microlenses.

12. The invention defined in claim 6 wherein the microlens means comprise Fresnel microlenses.

13. The invention defined in claim 6 wherein the microlens means comprise microlenses which are non-Fresnel, non-binary microlens.

14. The invention defined in claim 6 wherein the microlens means comprise microlenses which are non-Fresnel binary microlenses.

15. The invention defined in claim 6 wherein the microlens means comprise microlenses which are non-Fresnel type lenses and which are analog microlenses.

16. The invention defined in claim 6 wherein the microlens means comprise microlenses which are Fresnel lenses and which are non-binary microlenses.

17. The invention defined in claim 6 wherein the microlens means comprise microlenses which are Fresnel lenses and which are binary microlenses.

18. The invention defined in claim 6 wherein the individual dispersive microlenses are arranged in rows in the array.

19. The invention defined in claim 5 including detector means for detecting multiple, different signals from the optical information in each elongated blur spot to thereby permit real time discrimination of the optical information for certain qualities of an object or objects generating or reflecting the optical information.

20. The invention defined in claim 19 wherein the detector means include three detectors in each elongated blur spot for detecting high, medium and low color information.

21. The invention defined in claim 20 including electronic means for supplying the detected color information to a processor which uses the detected color information for color displays.

22. The invention defined in claim 19 wherein the detector means include multiple, individual detectors in each elongated blur spot for detecting multiple signals which can be summed in an acquisition mode to obtain an increased signal and which can be used in a discrimination mode to evaluate color contrast to determine object temperature and also to discriminate for temperature on the basis of the ratios of energies of the detected signals.

23. The invention defined in claim 22 wherein the multiple, individual detectors provide signals which enable the use of a few spectral bands to suppress background and to enhance signal detectability.

24. The invention defined in claim 22 wherein two detectors looking at the same scene can be used to detect lack of registration between two objects.

25. The invention defined in claim 22 wherein the multiple, separate detectors can be selectively sized and positioned in the elongated blur spot to pick up different, selected sets of information dependent on the sizes and positions of the detectors in the elongated blur spot.

26. The invention defined in claim 19 including analog circuit means for processing signals produced by the detector means.

27. The invention defined in claim 26 wherein the analog circuit means are used for combining the signals for enhanced signal-to-noise or for ratioing the signals.

28. The invention defined in claimed 27 wherein the analog circuit means for each detector means are placed next to the detector means on the otherwise unused portion of the area existing outside respective detector/emitter plane blur spots.

29. Apparatus for transmitting and concentrating optical information contained in optical blur spots in an image plane to small fractions of the areas of related pixels in a detector plane which is spaced from the image plane, said apparatus comprising,

microlens means, positioned at a plurality of image plane blur spot locations, for transmitting and concentrating the optical information in an image plane blur spot into a smaller detector plane blur spot in a related pixel in the detector plane, so that the area of the detector plane blur spot is decoupled from the area of the pixel, and for producing a contrast ratio, fill factor and optical gain of said optical information in the detector plane blur spot with respect to any existing, unwanted noise present at the detector plane,

certain ones of said microlens means including dispersion means formed integrally on said microlens means for dispersing the optical information in at least certain ones of the image plane blur spots to create an elongation

of a related detector plane blur spot and a distribution of the optical information within that elongated blur spot which permits multiple, different signals to be detected from within that elongated blur spot, and

wherein the microlens means include wideband, non-dispersive microlenses in outer, peripheral portions of the image plane and the certain ones of the microlens means and integral dispersion means include high resolution, dispersive microlenses in the central portion of the image plane.

30. The invention defined in claim 29 wherein there is no dead, optically inactive zone between the microlenses in the microlens array and wherein the dispersive microlenses in the central portion of the image plane have a hexagonal configuration.

31. Apparatus for transmitting and concentrating optical information contained in optical blur spots in an image plane to small fractions of the areas of related pixels in a detector plane which is spaced from the image plane, said apparatus comprising,

microlens means, positioned at a plurality of image plane blur spot locations, for transmitting and concentrating the optical information in an image plane blur spot into a smaller detector plane blur spot in a related pixel in the detector plane, so that the area of the detector plane blur spot is decoupled from the area of the pixel, and for producing a contrast ratio, fill factor and optical gain of said optical information in the detector plane blur spot with respect to any existing, unwanted noise present at the detector plane,

said microlens means including dispersion means formed integrally on said microlens means for dispersing the optical information in at least certain ones of the image plane blur spots to create an elongation of a related detector plane blur spot and a distribution of the optical information within that elongated blur spot which permits multiple, different signals to be detected from within that elongated blur spot,

said microlens means including an array of individual, dispersive microlenses and wherein the dispersion means comprise a blazed grating formed integrally and in a regular pattern on each individual, dispersive microlens, and wherein the individual dispersive microlenses are arranged in rows in the array, and wherein the grating pattern of each individual, dispersive microlens in a particular row is rotated at an angle with respect to the axis of that row to reduce optical cross talk noise between adjacent pixels in the detector plane.

32. The invention defined in claim 31 wherein the individual, dispersive microlenses in adjacent rows are longitudinally offset from one another to reduce optical cross talk noise between adjacent pixels in the detector plane.

33. Apparatus for transmitting and concentrating optical information contained in optical blur spots in an image plane to small fractions of the areas of related pixels in a detector plane which is spaced from the image plane, said apparatus comprising,

microlens means, positioned at a plurality of image plane blur spot locations, for transmitting and

concentrating the optical information in an image plane blur spot into a smaller detector plane blur spot in a related pixel in the detector plane, so that the area of the detector plane blur spot is decoupled from the area of the pixel, and for producing a contrast ratio, fill factor and optical gain of said optical information in the detector plane blur spot with respect to any existing, unwanted noise present at the detector plane,

said microlens means including dispersion means formed integrally on said microlens means for dispersing the optical information in at least certain ones of the image plane blur spots to create an elongation of a related detector plane blur spot and a distribution of the optical information within that elongated blur spot which permits multiple, different signals to be detected from within that elongated blur spot,

said microlens means including an array of individual, dispersive microlenses and wherein the dispersion means comprise a blazed grating formed integrally and in a regular pattern on each individual, dispersive microlens, and wherein the individual dispersive microlenses are arranged in rows in the array, and wherein the individual, dispersive microlenses in adjacent rows are longitudinally offset from one another to reduce optical cross talk noise between adjacent pixels in the detector plane.

34. Wavelength combining apparatus for combining a plurality of different emitted wavelengths of light, emitted from a plurality of emitters within an emitter plane blur spot, into a bandwidth of light within a unitary, dispersive

microlens apparatus, said wavelength combining apparatus comprising,

emitter means in an emitter plane blur spot for emitting a plurality of separate wavelengths or wavebands of light to be combined into a bandwidth of light within a unitary, dispersive microlens apparatus,

unitary, dispersive microlens apparatus positioned at a distance from the emitter plane which is effective to permit the unitary, dispersive microlens apparatus to receive the light from the emitter means and to form the light into the bandwidth of light at the location of the microlens apparatus,

said microlens apparatus including a microlens and a grating formed integrally on said microlens for combining all of the separate emitted wavelengths or wavebands into a single bandwidth of light so that the multicolor emitted wavelengths appear as a single composite color at the surface of the unitary, dispersive microlens apparatus, and wherein the unitary construction of the grating integrally on the microlens enables one unitary, dispersive microlens apparatus to perform multiple, designed, refraction and dispersion functions while eliminating noise and reflection losses which could otherwise occur across an interface between a separated, non-unitary microlens and grating.

35. The invention defined in claim 34 wherein said emitter plane blur spot is an elongated blur spot so related to the dispersion means that the wavelengths of emitted light can be varied from one end of the elongated blur spot to the other end.

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36. The invention defined in claim 35 wherein the emitter means include a plurality of emitters within the elongated blur spot with each emitter generating a selected wavelength or band of wavelengths which is unique to that emitter and which is within said bandwidth and with each emitter positioned in the elongated blur spot at a location correlated to the wavelength emitted by that emitter.

37. The invention defined in claim 36 including energizing means for energizing the emitters to beam light at the selected wavelengths from the emitters to the dispersive microlens apparatus.

38. The invention defined in claim 37 wherein the energizing means include modulating means for modulating the output of the emitters and for thereby controlling the wavelengths present in said bandwidth at the image plane blur spot and also the relative energy levels of the different wavelengths which are present in said bandwidth at the image plane blur spot.

39. Apparatus for combining a plurality of different emitted wavelengths of light, emitted from a plurality of emitters within an emitter plane blur spot, into a bandwidth of light at an image plane blur spot, said apparatus comprising,

emitter means in an emitter plane blur spot for emitting a plurality of separate wavelengths or wavebands of light to be combined into a bandwidth of light at an image plane blur spot,

microlens means positioned at an image plane at a distance from the emitter plane which is effective to permit the microlens means to receive the light from the emitter

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means and to form the light into an image plane blur spot at the location of the microlens means,

said microlens means including dispersion means formed integrally on said microlens means for combining all of the separate, emitted wavelengths or wavebands into a single bandwidth of light in the image plane blur spot so that the multicolor emitted wavelengths appear as a single composite color at the surface of the microlens means, and

wherein said emitter plane blur spot is an elongated blur spot so related to the dispersion means that the wavelengths of emitted light can be varied from one end of the elongated blur spot to the other end, and

wherein the emitter means include a plurality of emitters within the elongated blur spot with each emitter generating a selected wavelength or band of wavelengths which is unique to that emitter and which is within said certain bandwidth and with each emitter positioned in the elongated blur spot at a location correlated to the wavelength emitted by that emitter, and

including energizing means for energizing the emitters to beam light at the selected wavelengths from the emitters to the dispersive microlens means, and

wherein the energizing means include modulating means for modulating the output of the emitters and for thereby controlling the wavelengths present in said bandwidth at the image plane blur spot and also the relative energy levels of the different wavelengths which are present in said bandwidth at the image plane blur spot, and

wherein the emitters include three emitters for emitting red, green and blue color information.

40. The invention defined in claim 39 including processing means for using the color information as combined in the image plane blur spot for color transmitting and regenerating apparatus.

41. Apparatus for processing color information using at least two separate arrays of dispersion microlenses, said apparatus comprising,

(a) color generating and combining means for generating an organized pattern of color information made up from a plurality of individual, image plane blur spots, said color generating and combining means comprising,

an emitter plane having a plurality of individual, emitter plane blur spots,

emitter means in each emitter plane blur spot for emitting a plurality of separate wavelengths or wavebands of light to be combined into a bandwidth of light at a related image plane blur spot,

first microlens means comprising a first array of individual microlenses positioned at an image plane at a distance from the emitter plane which is effective to permit each individual microlens to receive the light from the emitter means in a related emitter plane blur spot and to form the light into an image plane blur spot at the location of the individual microlens,

said first microlens means including dispersion means formed integrally on each individual microlens for

combining all of the separate, emitted wavelengths or wavebands, emitted from a related emitter plane blur spot, into a single bandwidth of light in the image plane blur spot so that the multicolor, emitted wavelengths appear as a single composite color at the surface of the individual microlens,

(b) color dispersing and detecting means for detecting component wavelengths or wavebands of color contained within individual bandwidths of color in individual, image plane blur spots, which image plane blur spots collectively make up an organized pattern of color information,

said color dispersing and detecting means comprising,

an image plane having a plurality of individual, image plane blur spots,

a detector plane having a plurality of individual pixels with each pixel having a small but elongated pixel blur spot area,

second microlens means comprising a second array of individual microlenses with each individual microlens positioned at a related, individual, image plane blur spot,

said second microlens means including dispersion means formed integrally on each individual microlens for dispersing the bandwidth of color in the related image plane blur spot to a related pixel blur spot area and for producing an elongated pixel blur spot in which the wavelengths are varied from one end to the other, and

detector means in each pixel blur spot for detecting multiple, different colors from the elongated pixel blur spot, and

(c) transmitting means for transmitting the organized pattern of color information bidirectionally between the color generating and combining means and the color dispersing and detecting means.

42. A method of transmitting and concentrating optical information contained in optical blur spots in an image plane to small fractions of the areas of related pixels in a detector plane which is spaced from the image plane, said method comprising,

positioning a microlens at an image plane blur spot for transmitting and concentrating the optical information in the image plane blur spot into a smaller detector plane blur spot in a related pixel in the detector plane, so that the area of the detector plane blur spot is decoupled from the area of the pixel, and for producing a contrast ratio, fill factor and optical gain of said optical information in the detector plane blur spot with respect to any existing, unwanted noise present at the detector plane,

dispersing the optical information in the image plane blur spot through a related microlens having a dispersion producing diffraction grating formed integrally on the microlens which is effective to create an elongation of a related detector plane blur spot and a dispersed distribution of the optical information to specific locations within that elongated, detector plane blur spot and which distribution of the optical information permits multiple, different signals to be detected by detectors at

the specific locations within that elongated, detector plane blur spot, and

detecting the multiple, different signals at the specific locations from the optical information in the elongated, detector plane blur spot to thereby permit real time discrimination of the optical information for certain qualities of an object or objects generating the optical information, and wherein the unitary construction of the grating integrally on the microlens enables one unitary, dispersive microlens to perform multiple, designed, refraction and dispersion functions while eliminating noise and reflection losses which could otherwise occur across an interface between a separated, non-unitary microlens and grating.

43. A method of combining a plurality of different emitted wavelengths of light, emitted from a plurality of emitters within an emitter plane blur spot, into a bandwidth of light at an image plane blur spot, said method comprising,

emitting from a plurality of specific locations in an elongated emitter plane blur spot a plurality of separate wavelengths or wavebands of light to be combined into a bandwidth of light within a unitary dispersive microlens apparatus,

positioning a unitary dispersive microlens apparatus comprising a microlens and a grating formed integrally on the microlens at an image plane at a distance from the emitter plane which is effective to permit the unitary microlens apparatus to receive the light emitted from the emitter plane blur spot and to form the light into

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an image plane blur spot at the location of the unitary microlens apparatus,

combining all of the separate, emitted wavelengths or wavebands into a single bandwidth of light in the image plane blur spot by the grating formed integral on the microlens and so related to locations of the emitted wavelengths or wavebands in the elongated emitter plane blur spot that the multicolor emitted wavelengths appear as a single composite color at the surface of the unitary dispersive microlens apparatus.

SMART & BIGGAR

OTTAWA, CANADA

PATENT AGENT

FIG_1

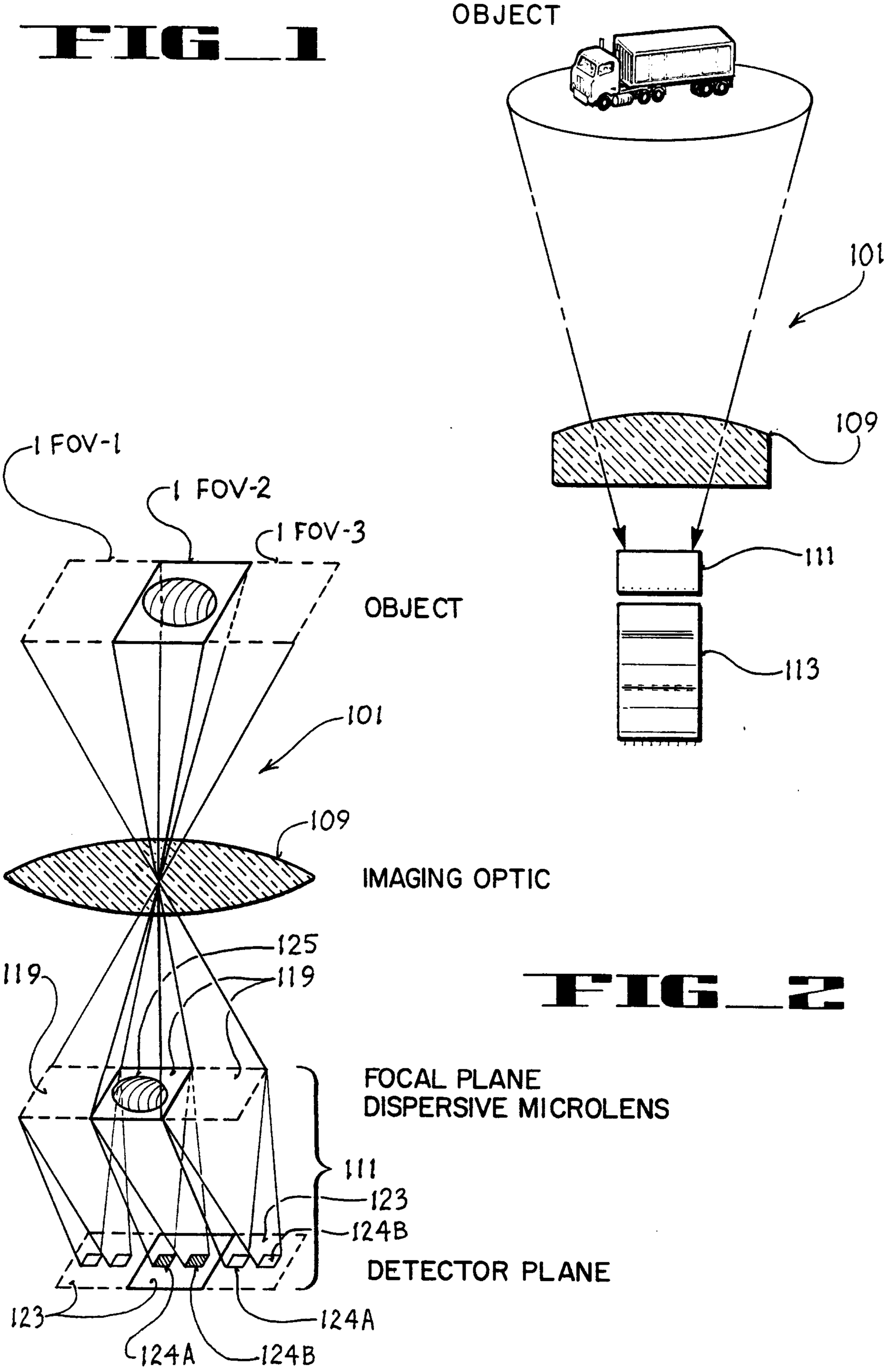

1 FOV-1
1 FOV-2
1 FOV-3
OBJECT
101
109
IMAGING OPTIC
125
119
119
FOCAL PLANE
DISPERSIVE MICROLENS
111
123
124B
DETECTOR PLANE
123
124A
124A
124B
OBJECT
101
109
111
113

FIG_2

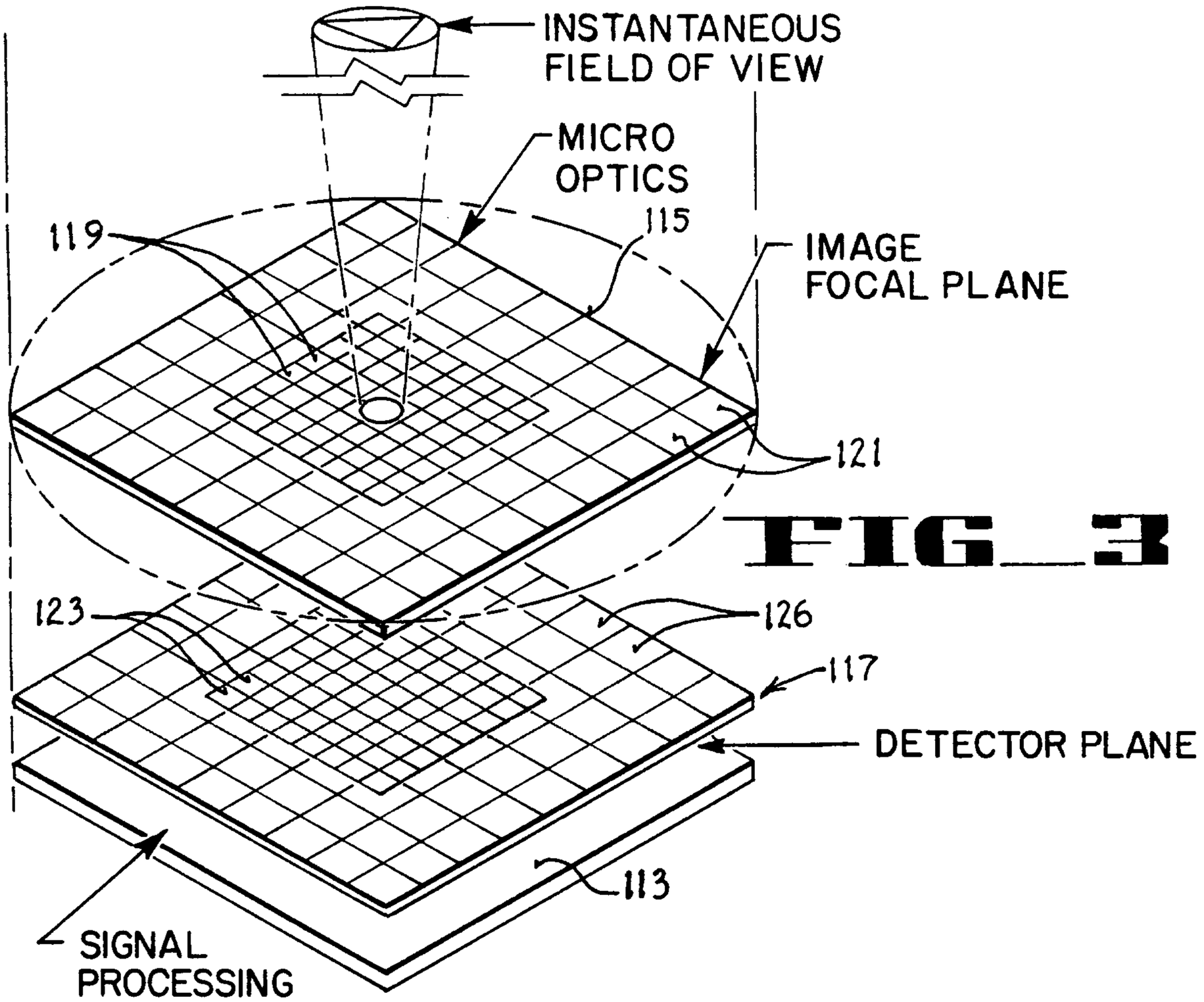


FIG_3

FIG_4A

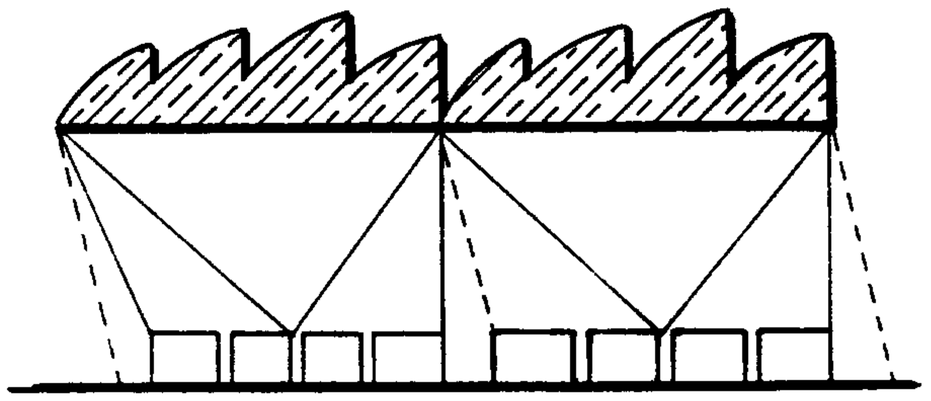


FIG_4B

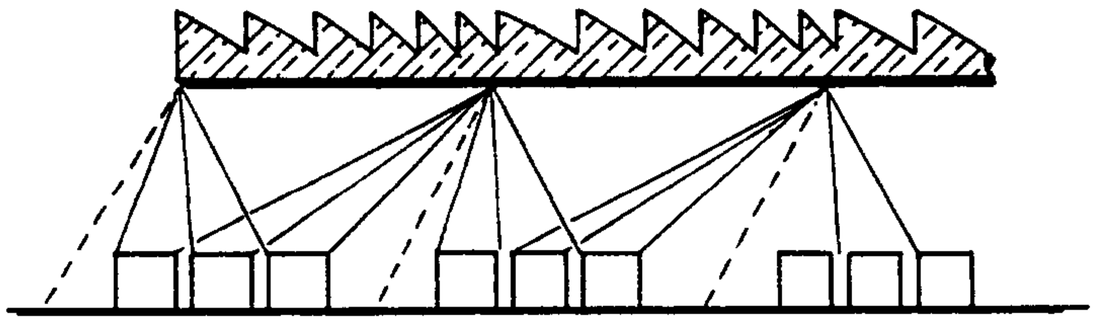


FIG_4C

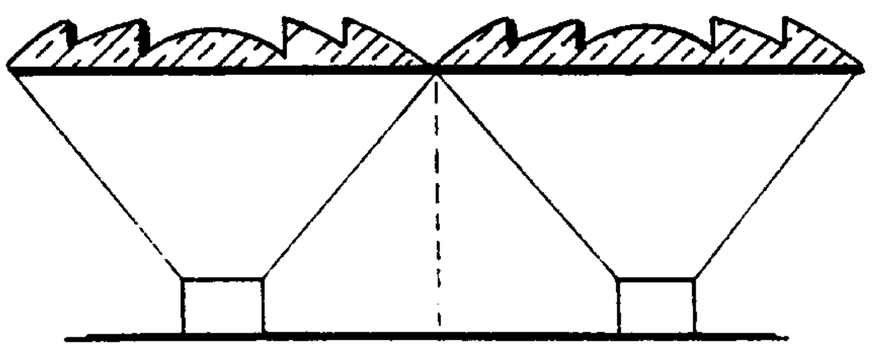


FIG_5

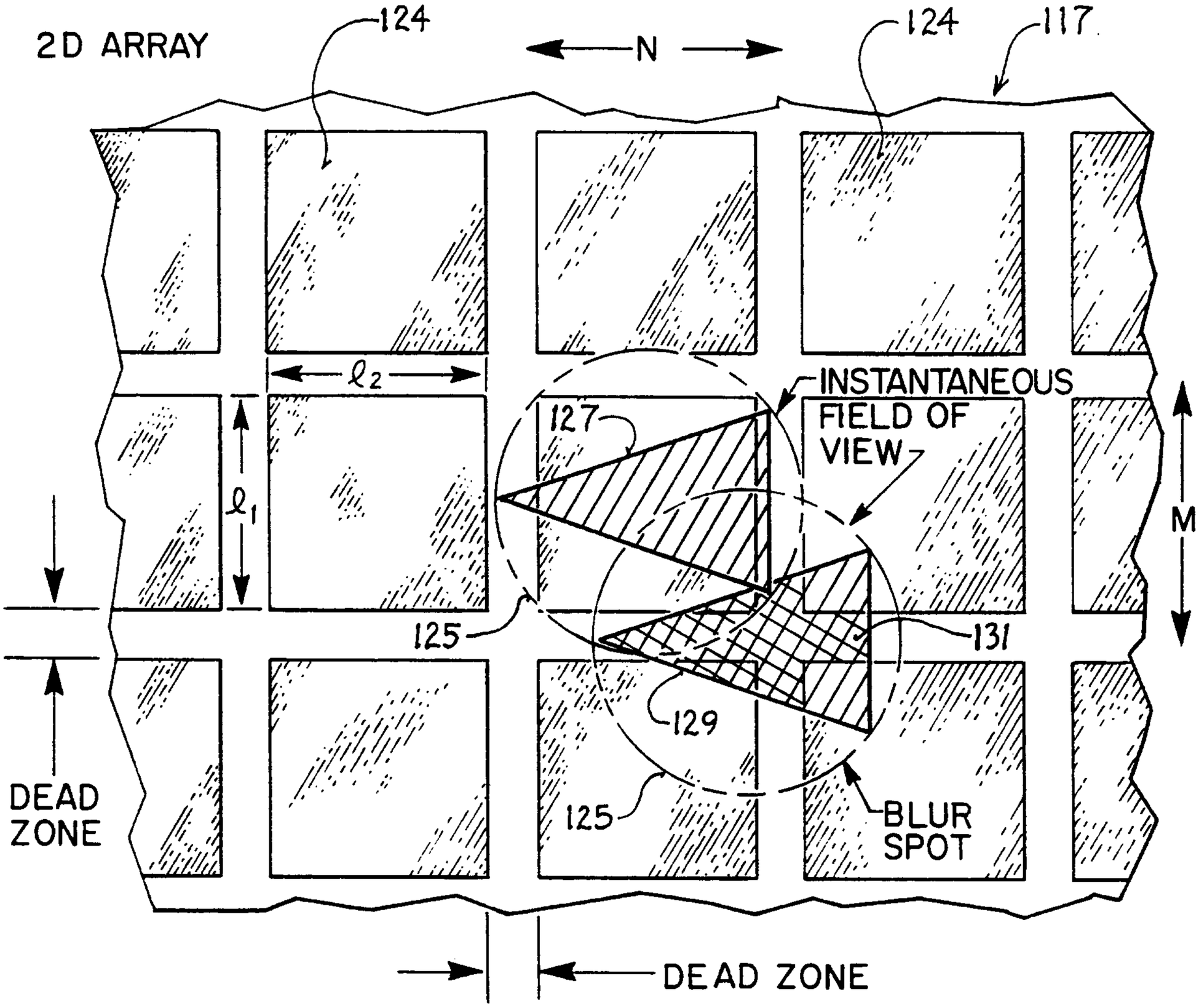
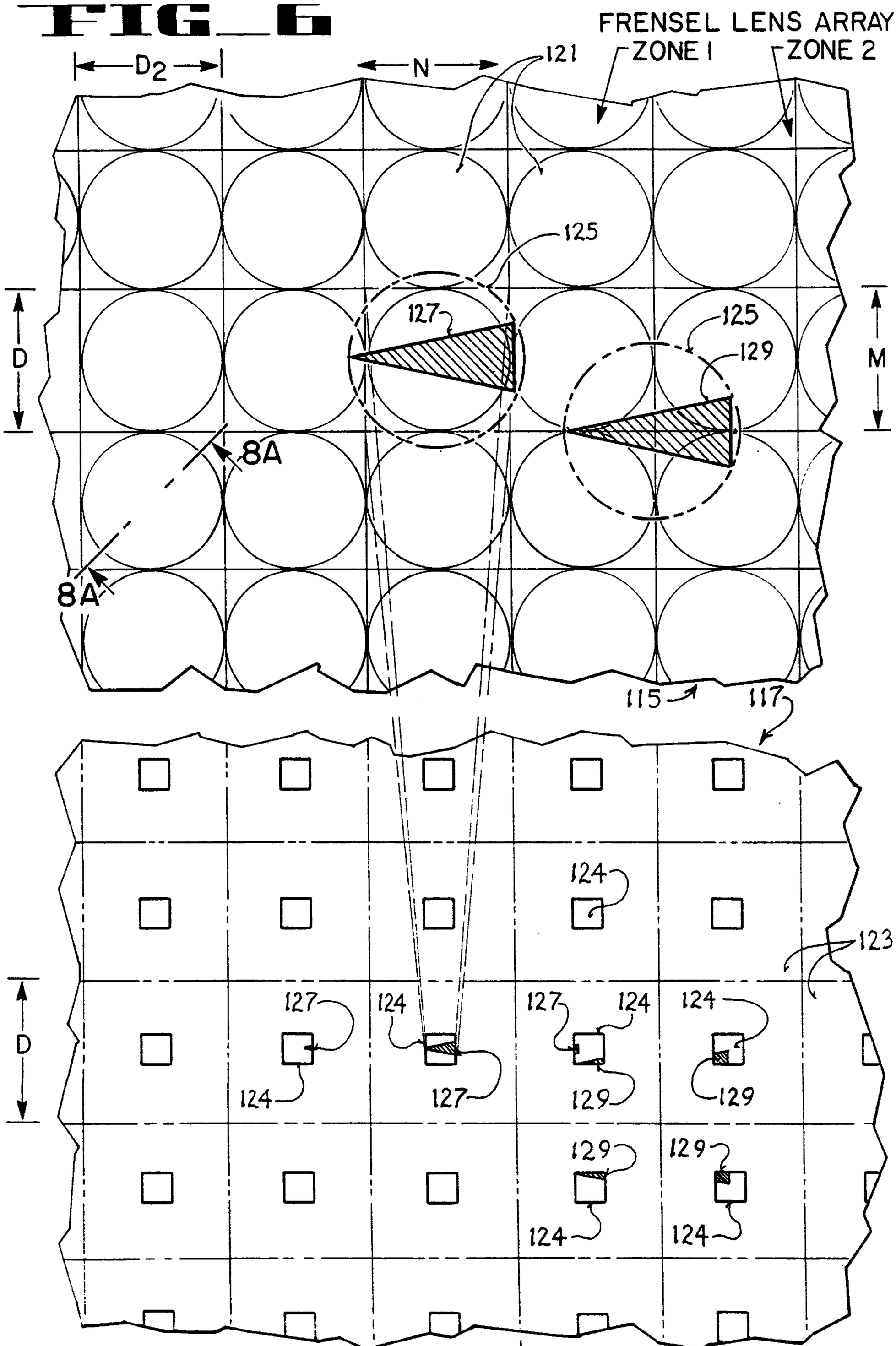

2D ARRAY
N
124
124
117
ℓ_2
ℓ_1
INSTANTANEOUS FIELD OF VIEW
127
125
131
129
125
M
DEAD ZONE
BLUR SPOT
DEAD ZONE

FIG_6


FRENSEL LENS ARRAY
ZONE 1
ZONE 2
121
D_2
N
125
127
125
129
D
M
8A
8A
115
117
124
123
127
124
127
124
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129
129
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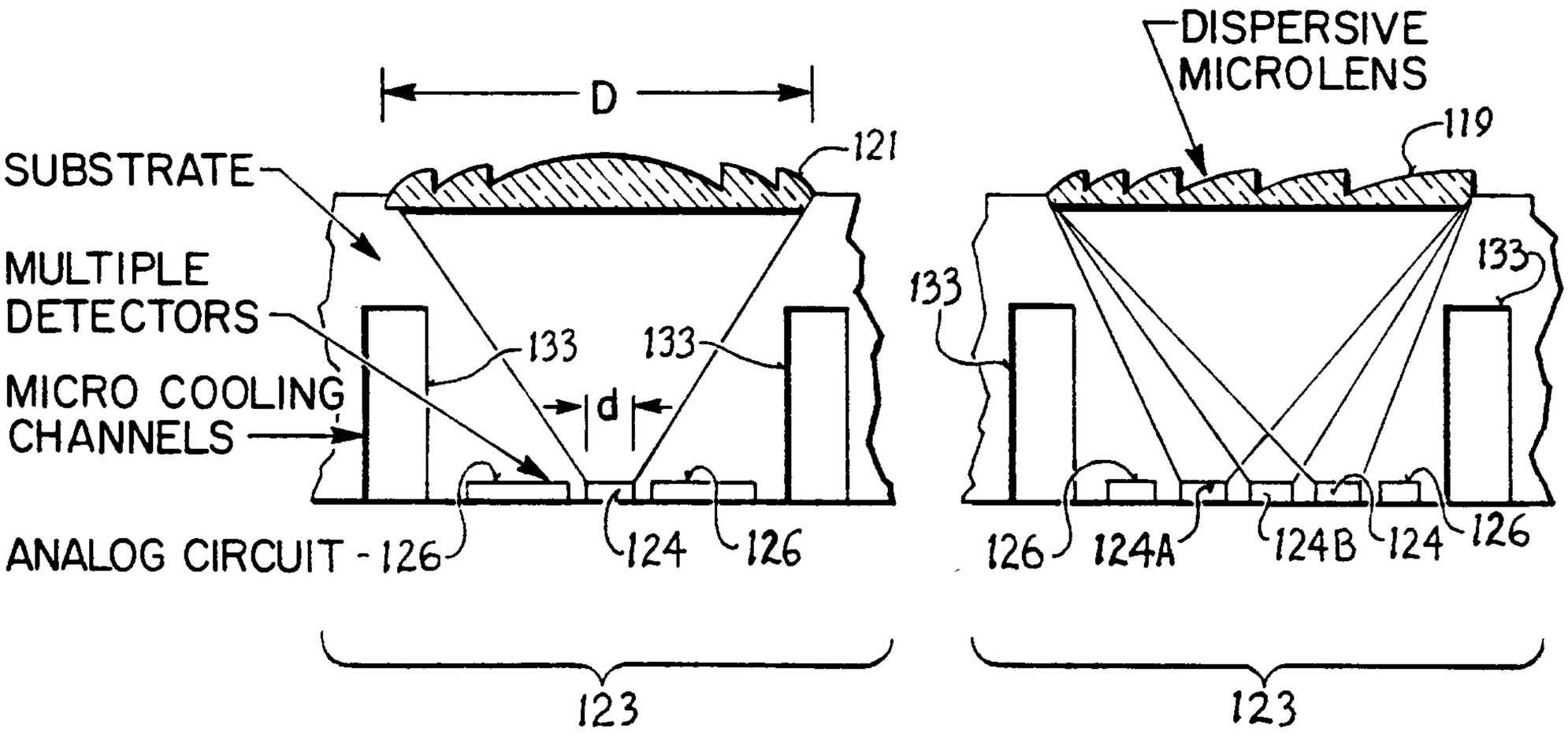
124
124
D
PIXEL
DETECTOR PLANE

FIG_7

FIG_8A

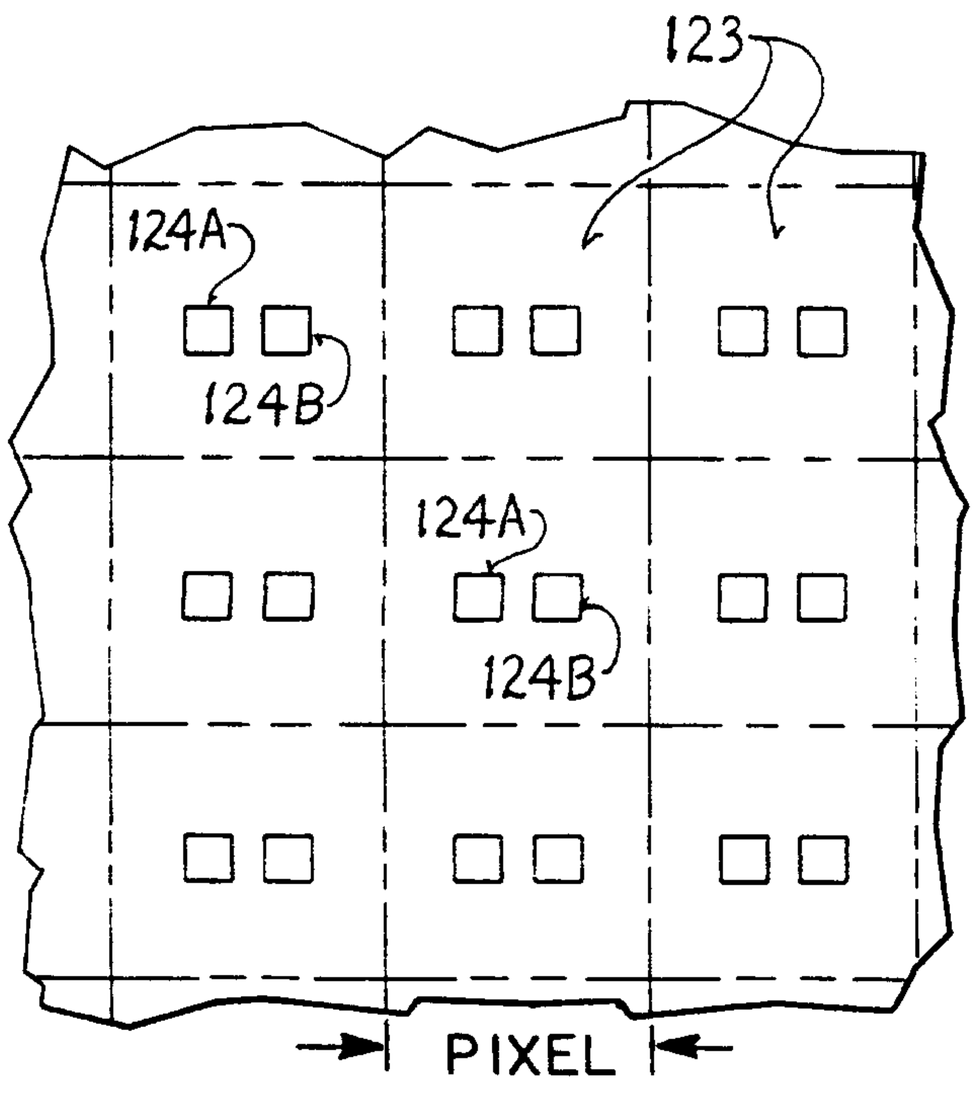
FIG_8B



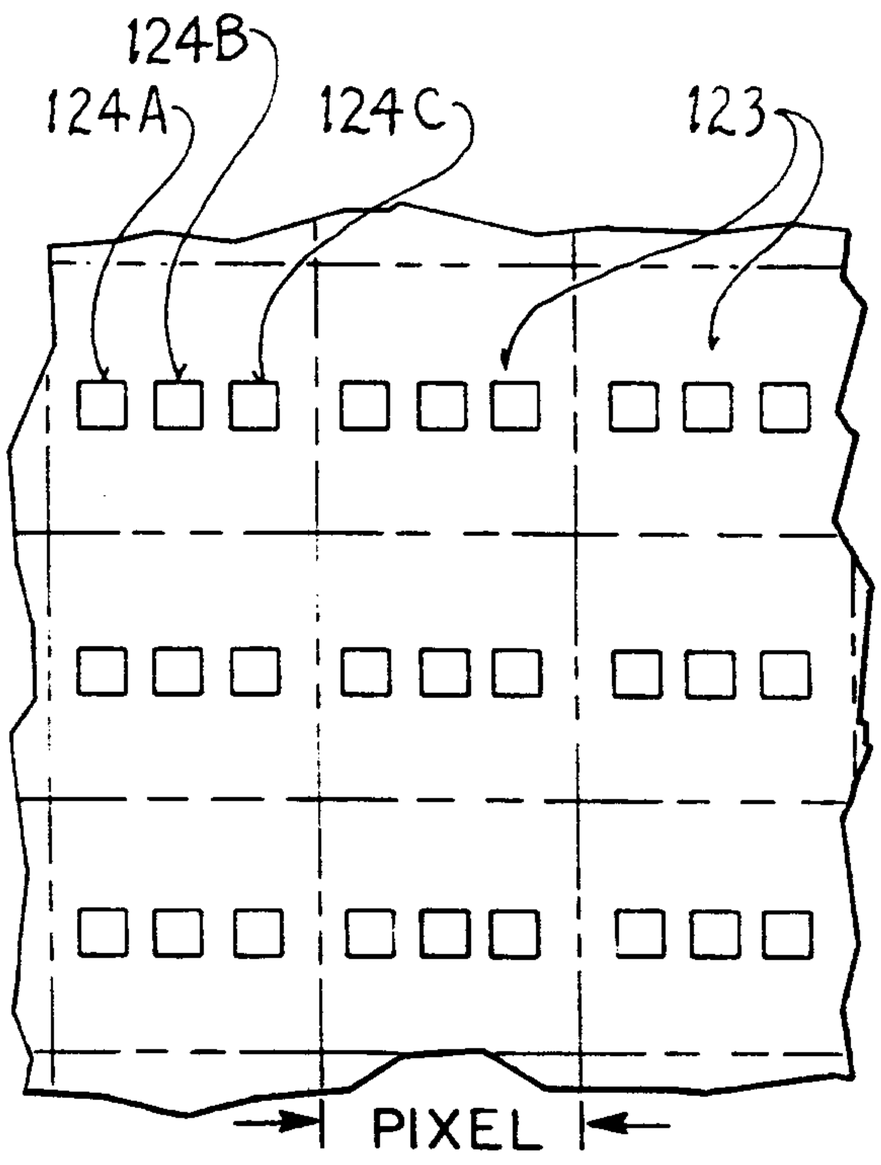
MICROLENS UTILIZATION ON FOCAL PLANES

FIG_9

FIG_10



MULTIPLE DETECTORS (2)



MULTIPLE DETECTORS (3)

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IPEA/US 20 JAN 1994

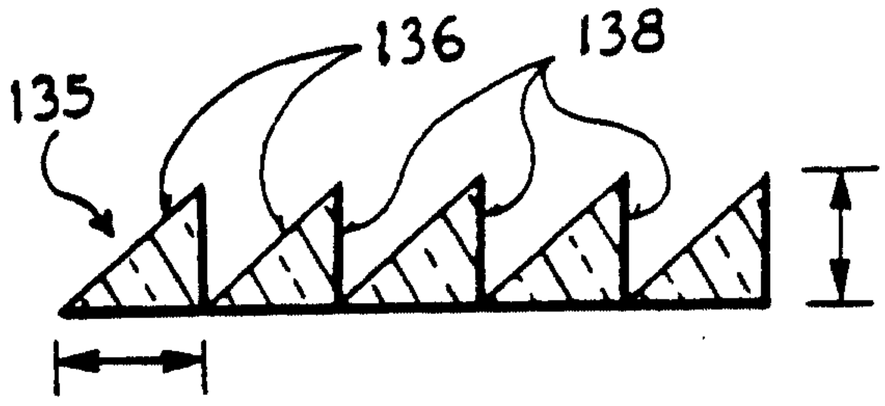


FIG_11

FIG_14

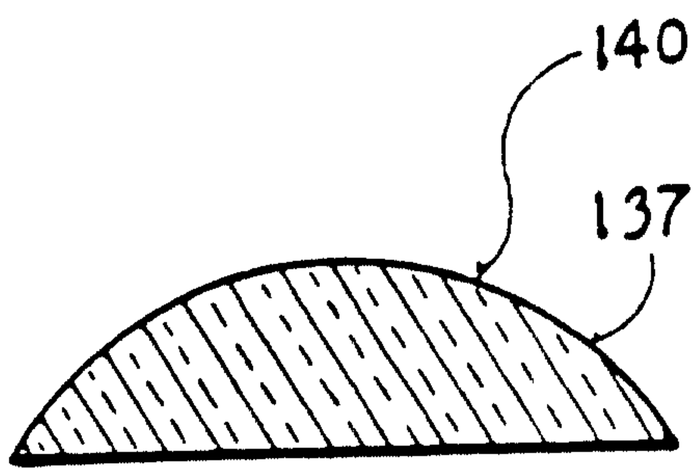
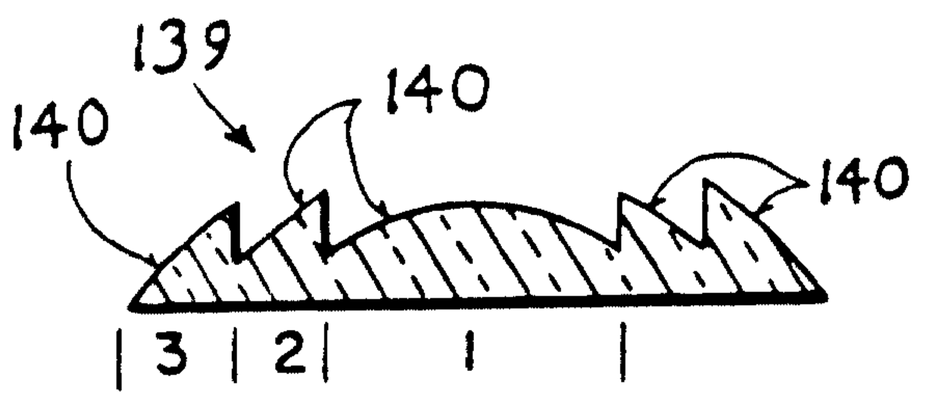


FIG_12



ZONE

FIG_15

DISPERSIVE

NON-FRESNEL

FIG_13

FRESNEL DISPERSIVE

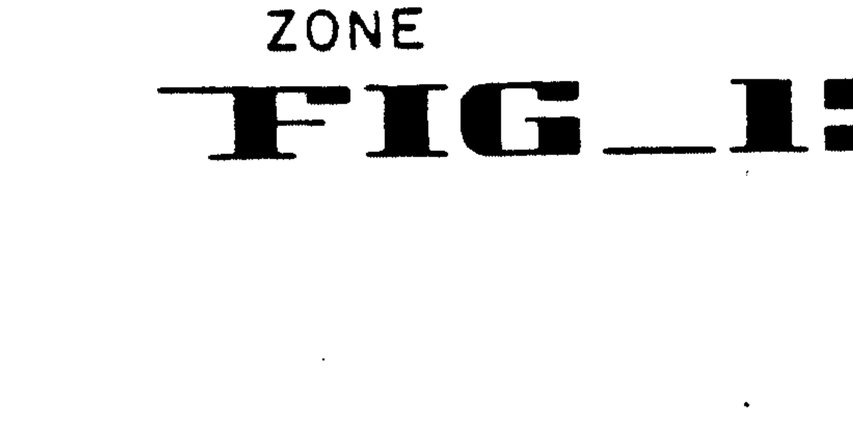


FIG_16

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IPEA/US 20 JAN 1994

FIG_17

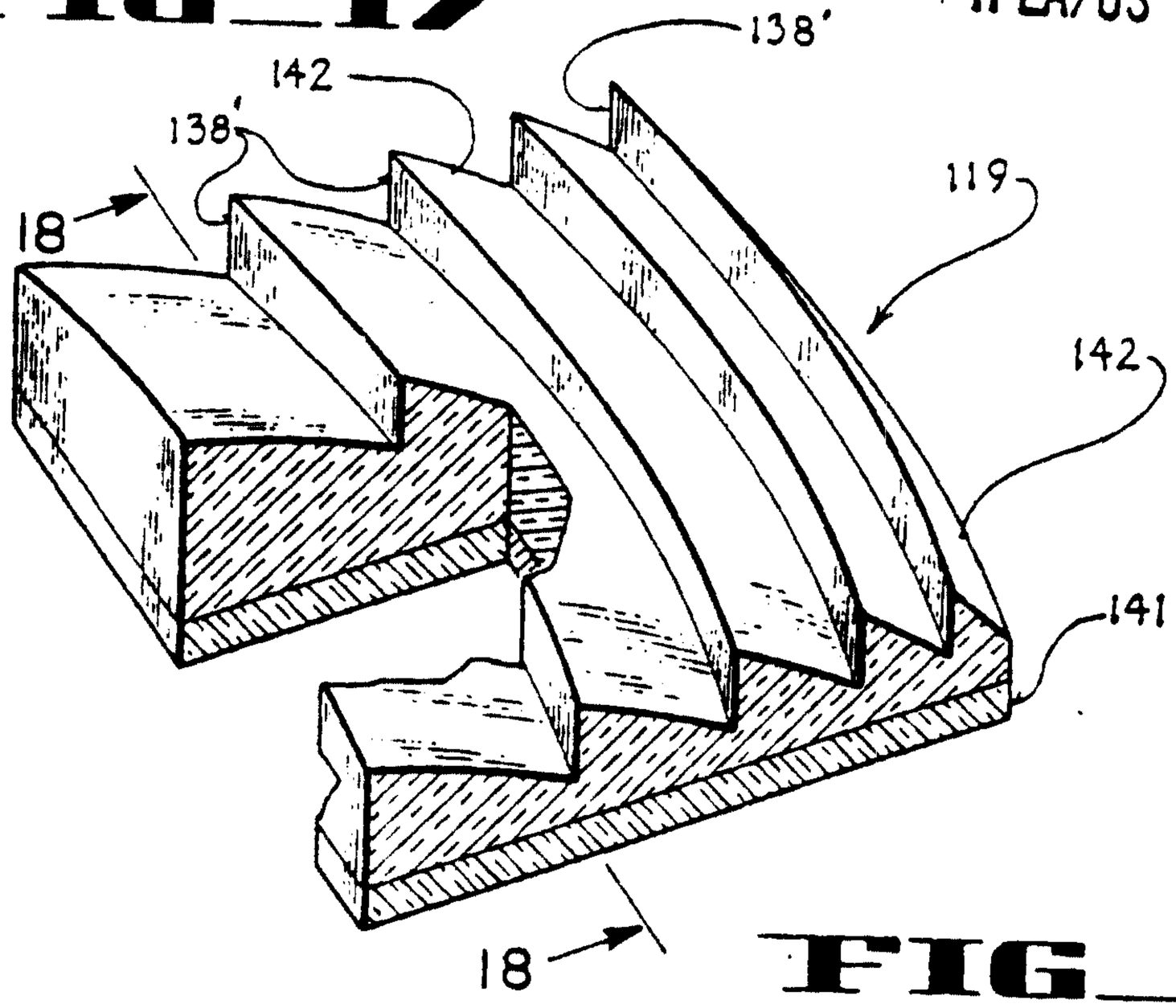

FIG_18

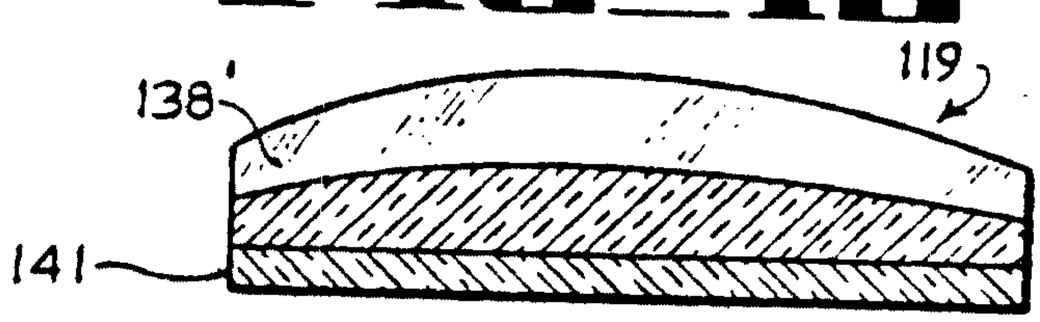

FIG_19

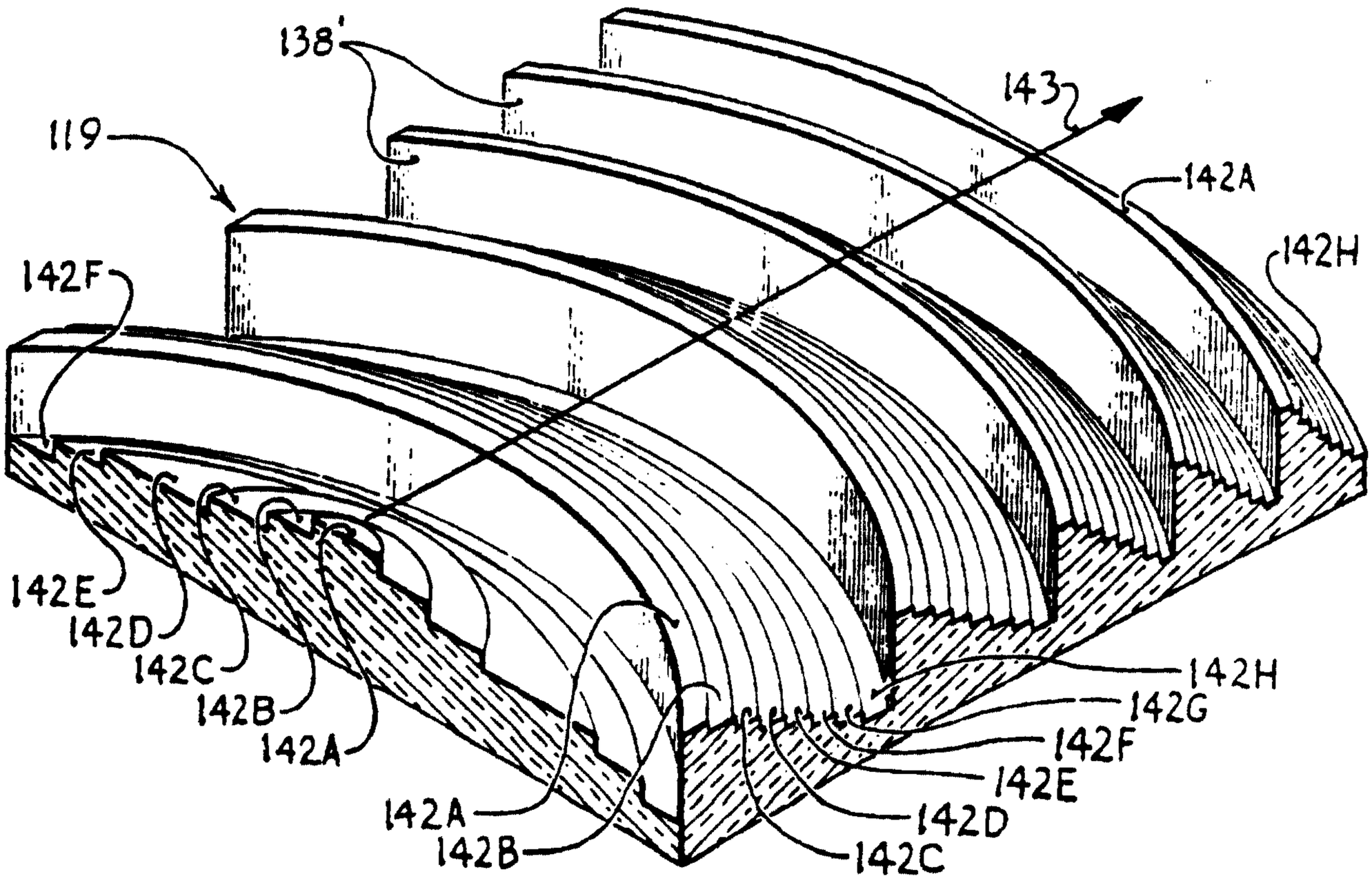

FIG_20

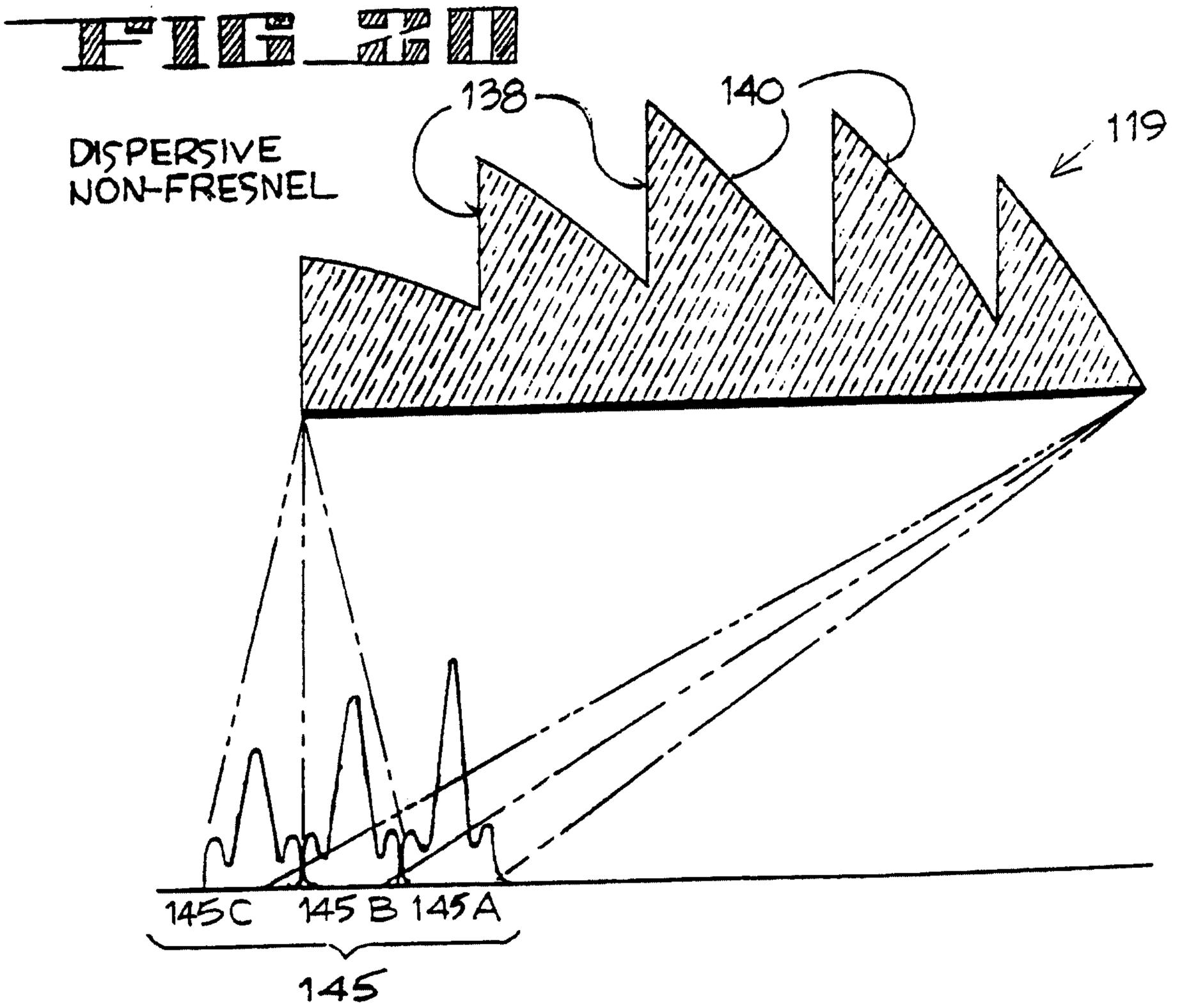
DISPERSIVE
NON-FRESNEL
138
140
119
145C
145B
145A
145

FIG_21

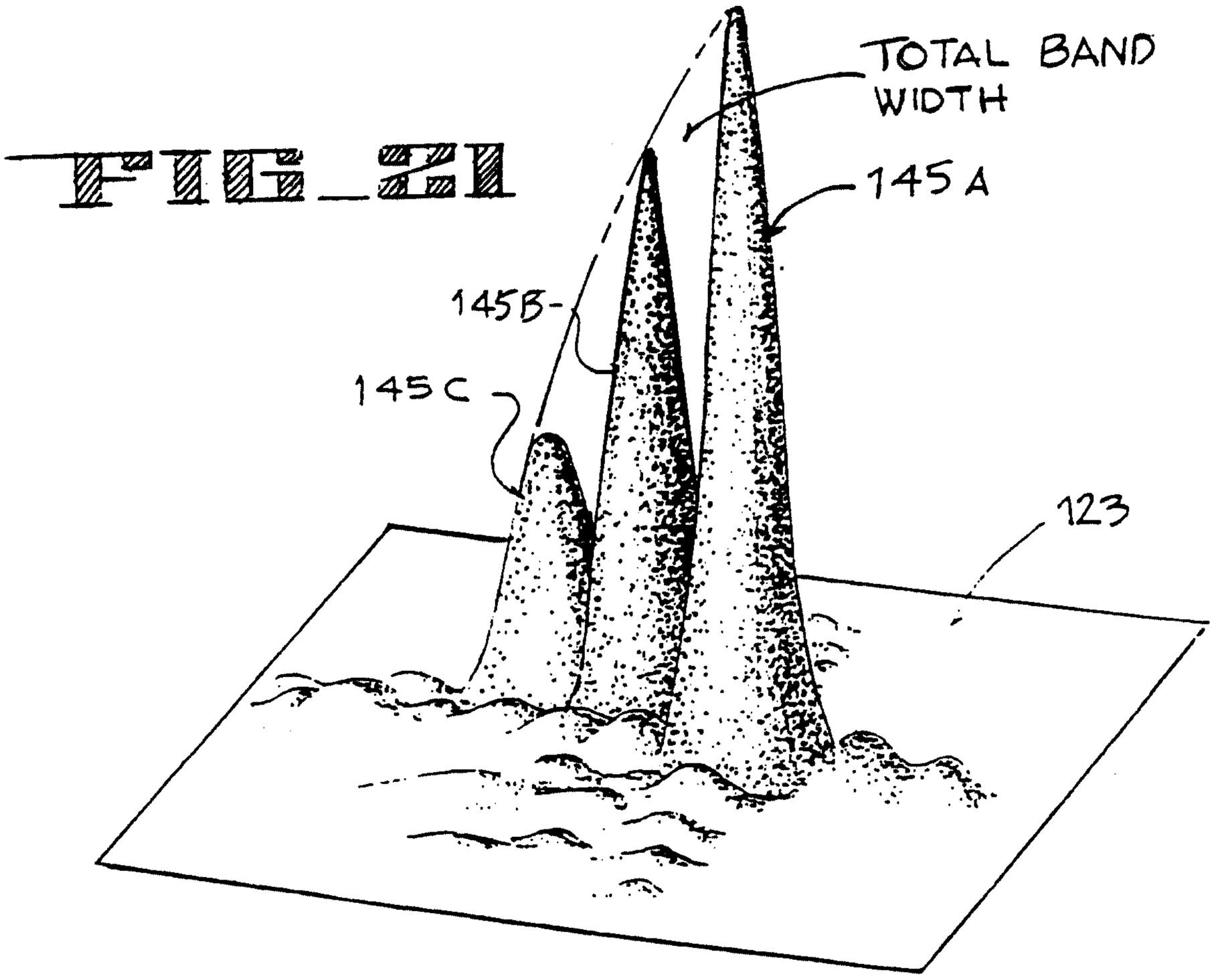
TOTAL BAND
WIDTH
145A
145B
145C
123

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FIG 2

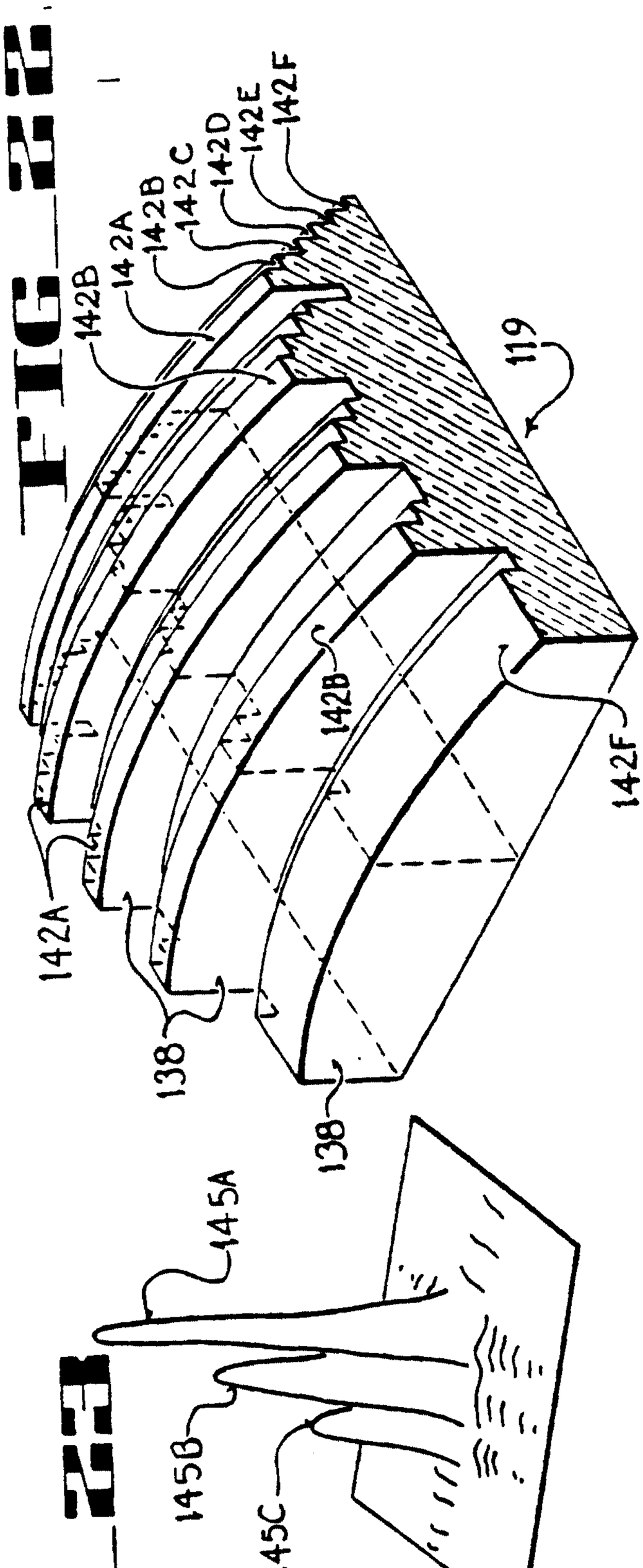


FIG 2a

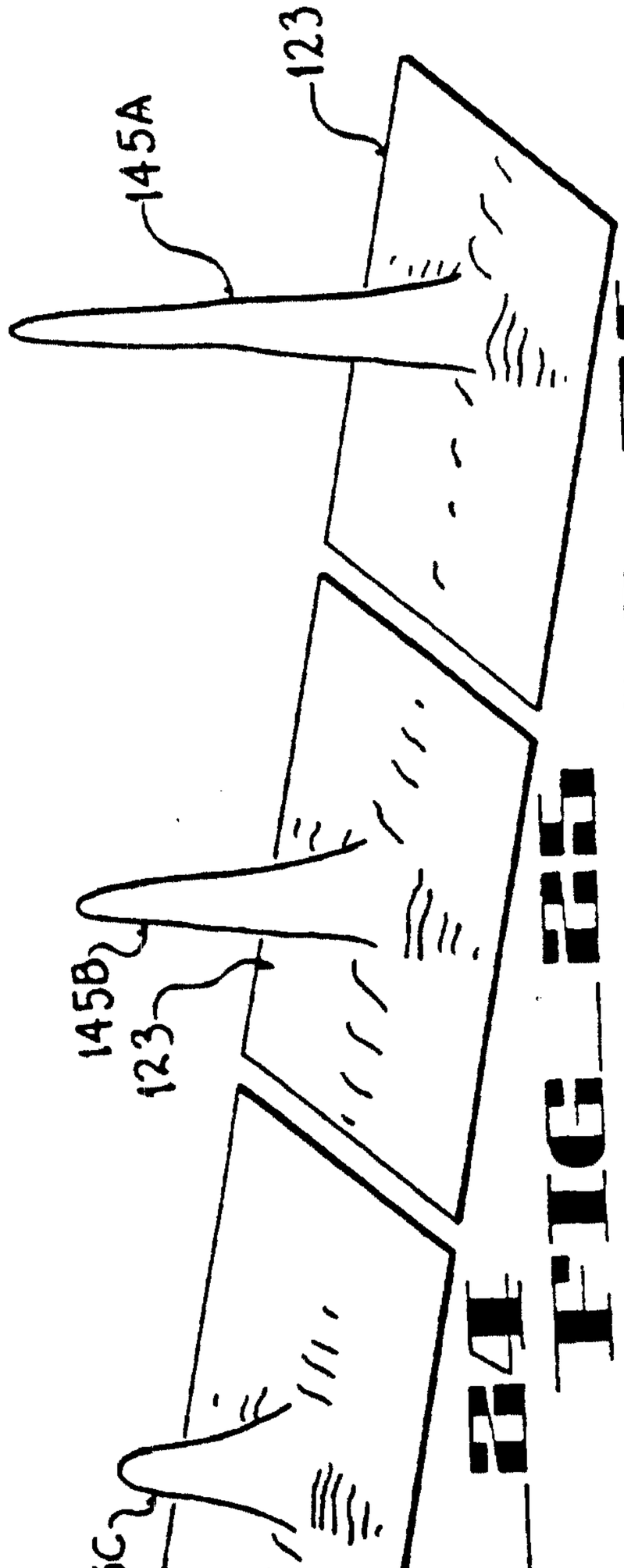


FIG 2b

FIG 2c

FIG 2d

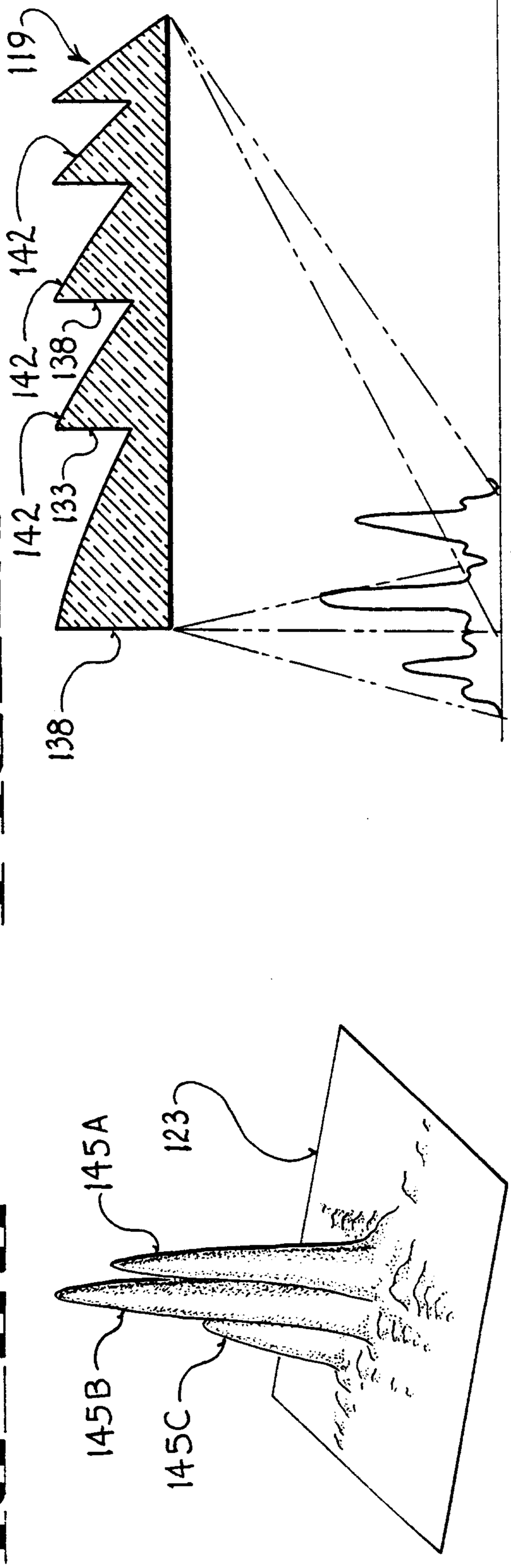


FIG_27

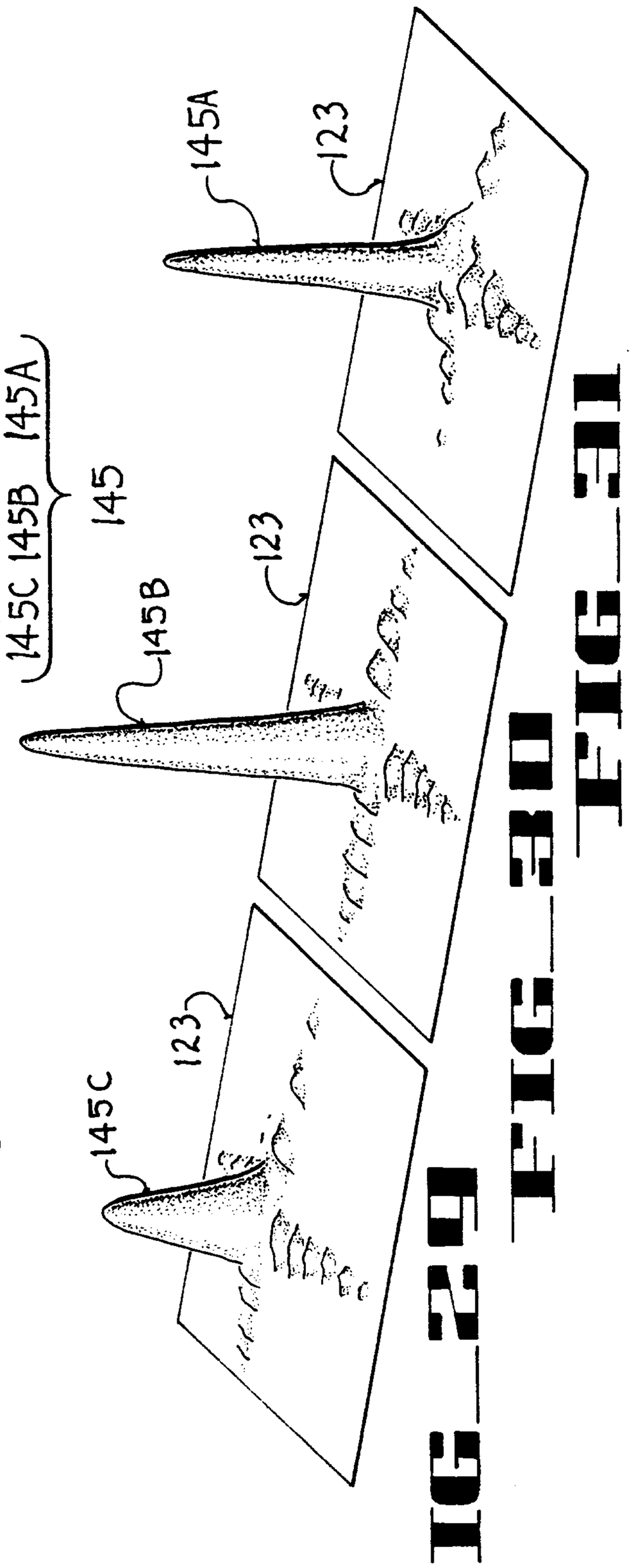
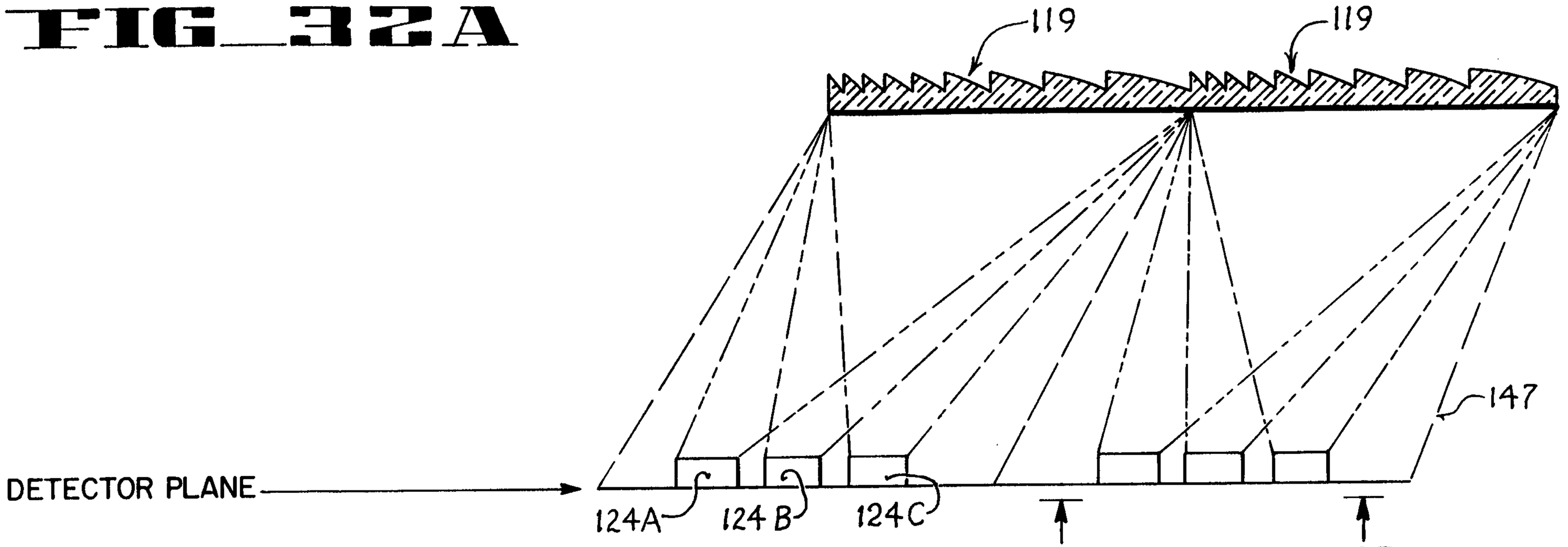


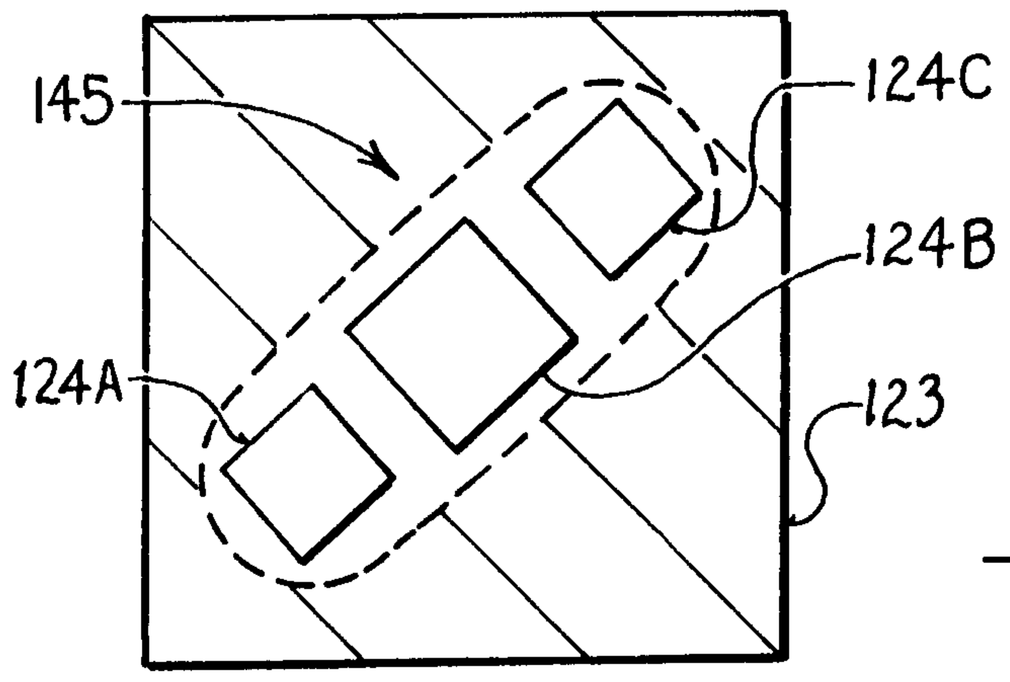
FIG_30

FIG_28

FIG_29

FIG_32A



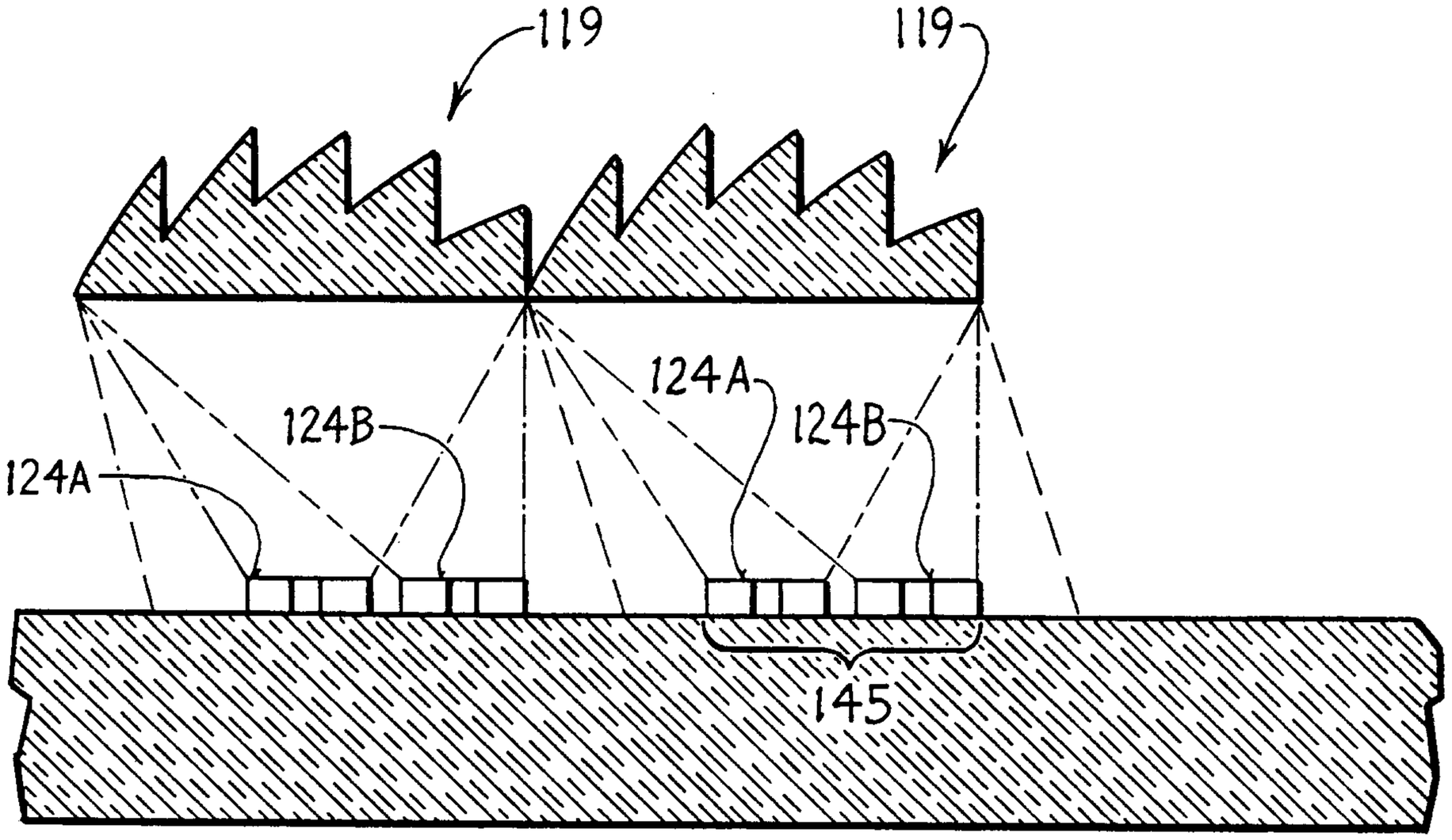


DISPERSIVE FRESNEL MICROLENS

FIG_32B

WO 94/00781
PCT/US93/06012
11/25
2139108

FIG_33



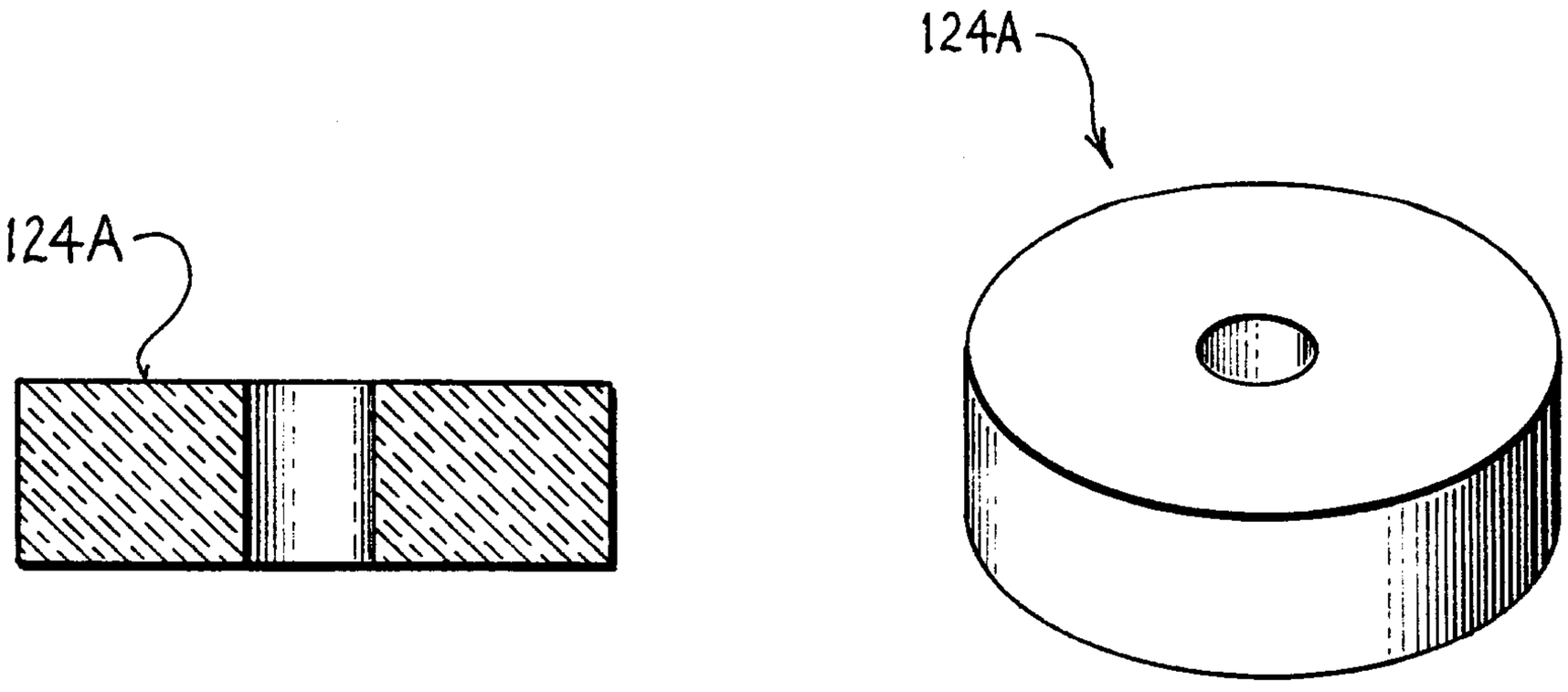


FIG_34A FIG_34B

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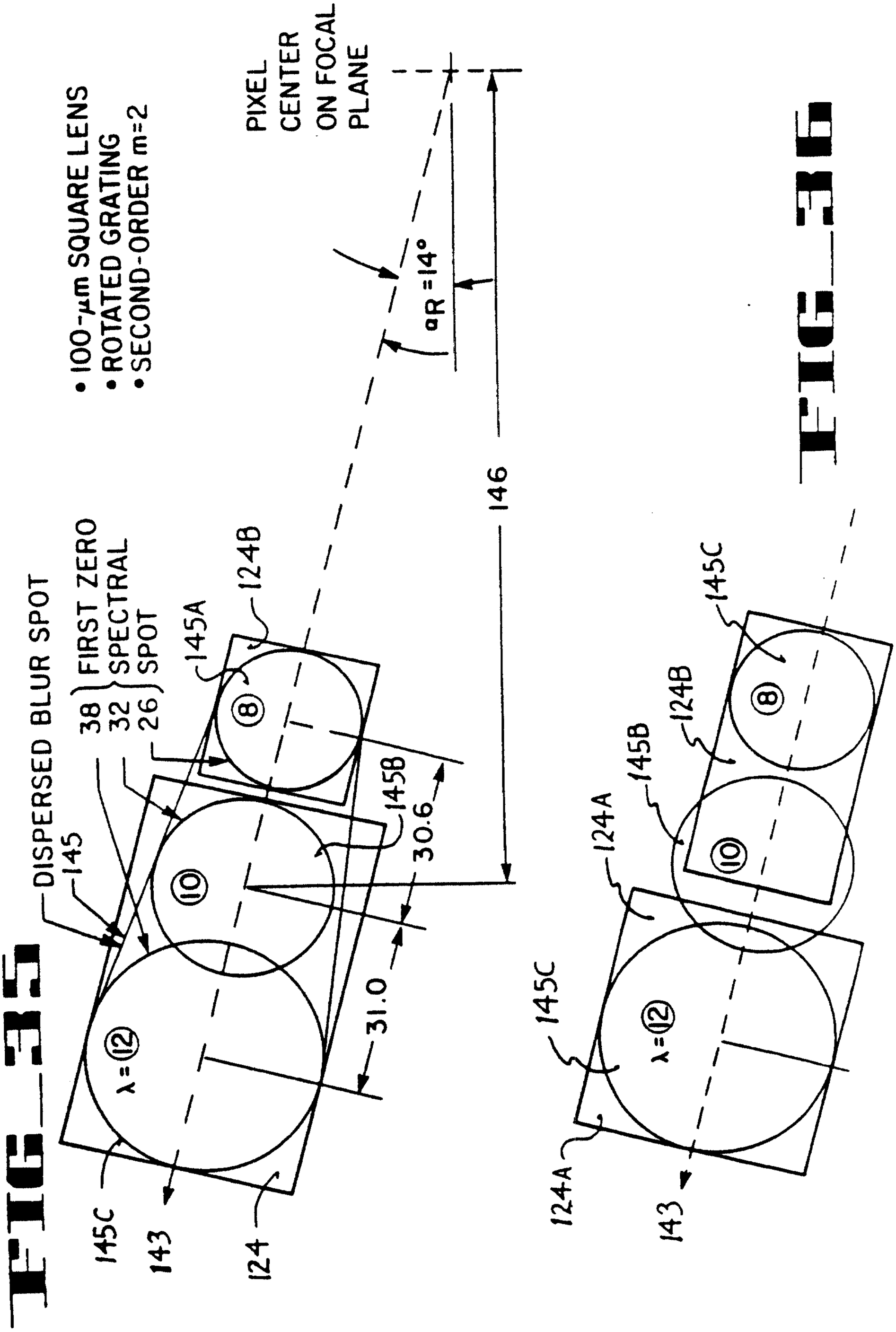


FIG_37

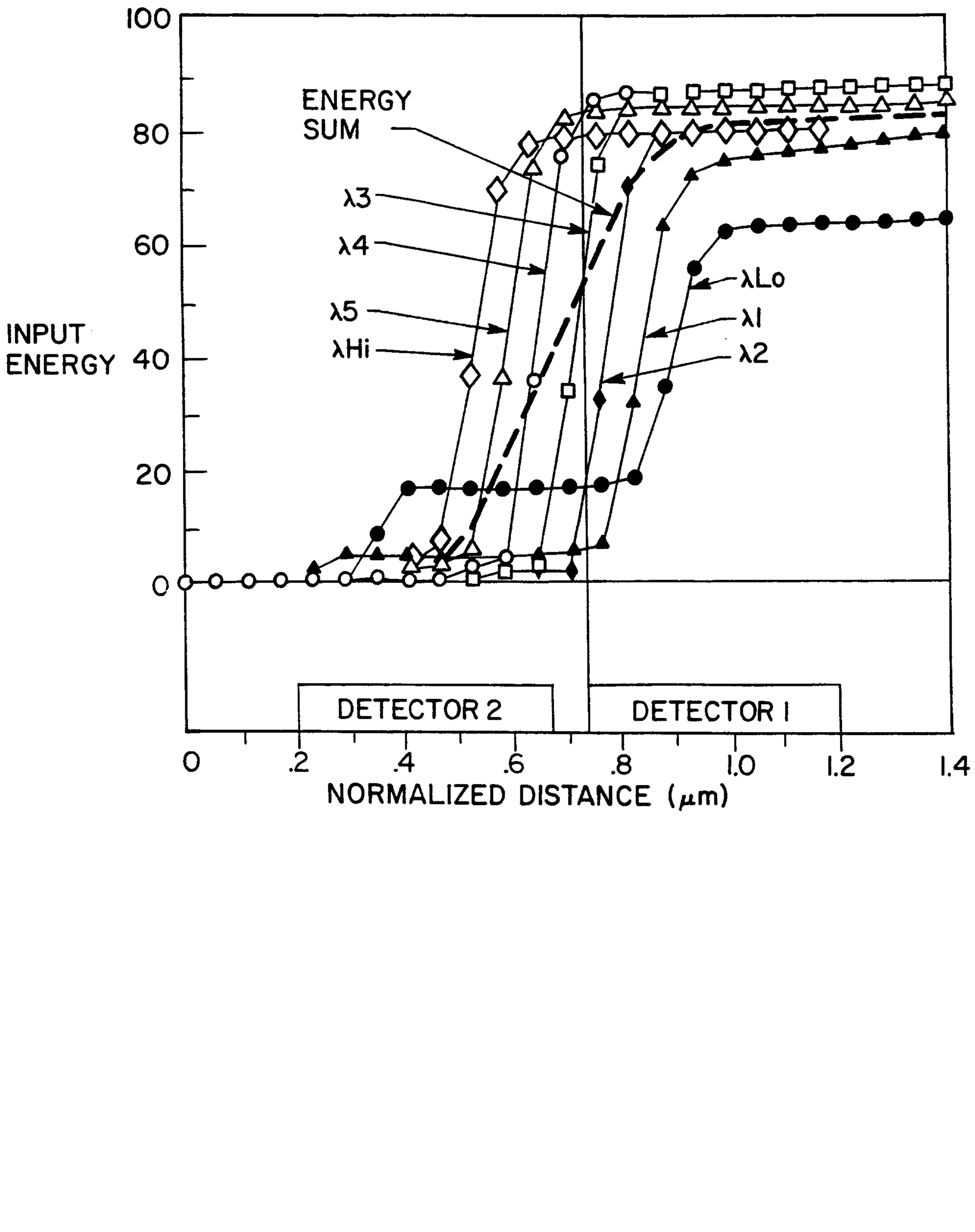
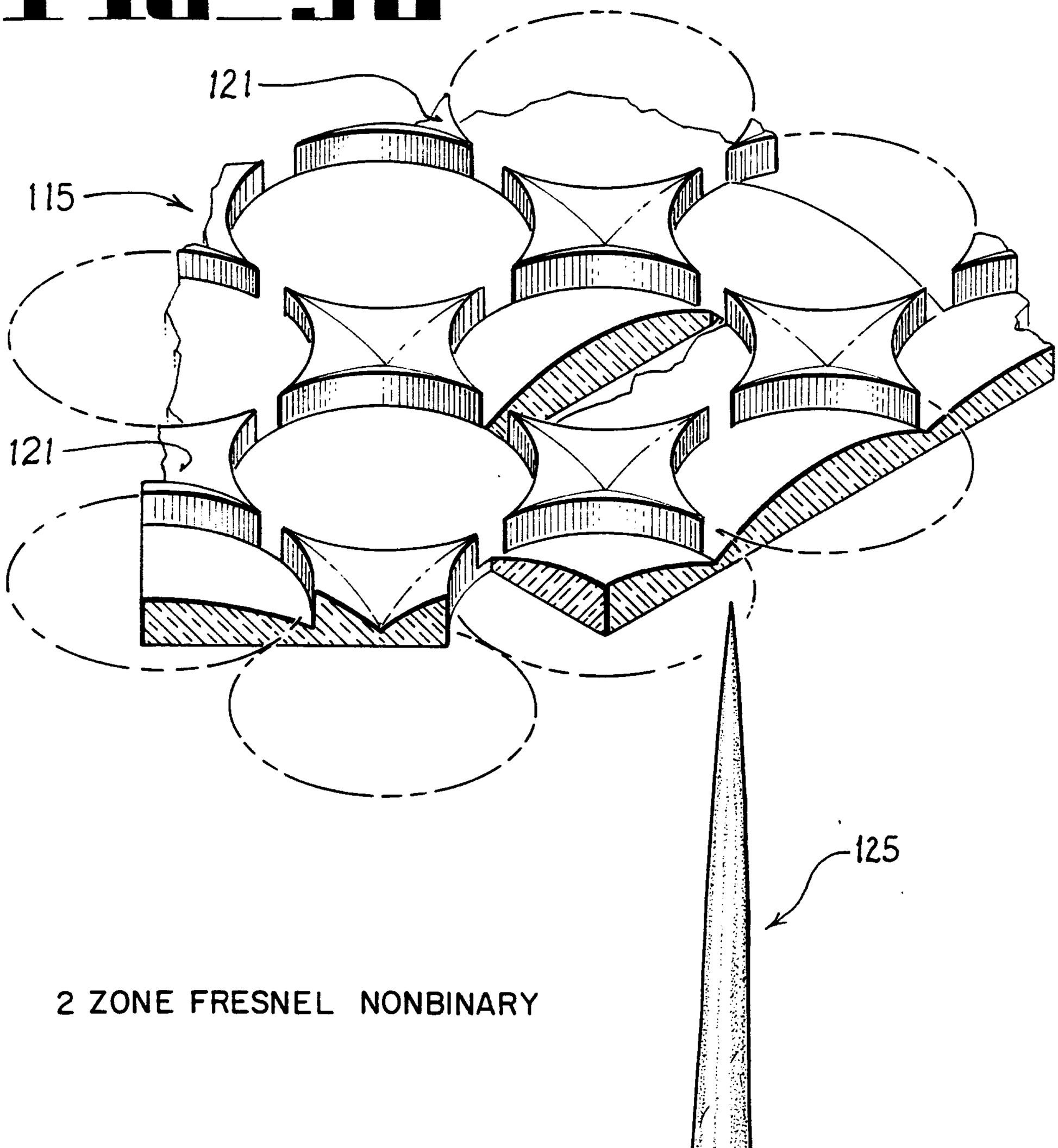

100
80
60
40
20
0
INPUT ENERGY
ENERGY SUM
λ3
λ4
λ5
λHi
λLo
λ1
λ2
DETECTOR 2
DETECTOR 1
0
.2
.4
.6
.8
1.0
1.2
1.4
NORMALIZED DISTANCE (μm)

FIG_38



2 ZONE FRESNEL NONBINARY

FIG_39

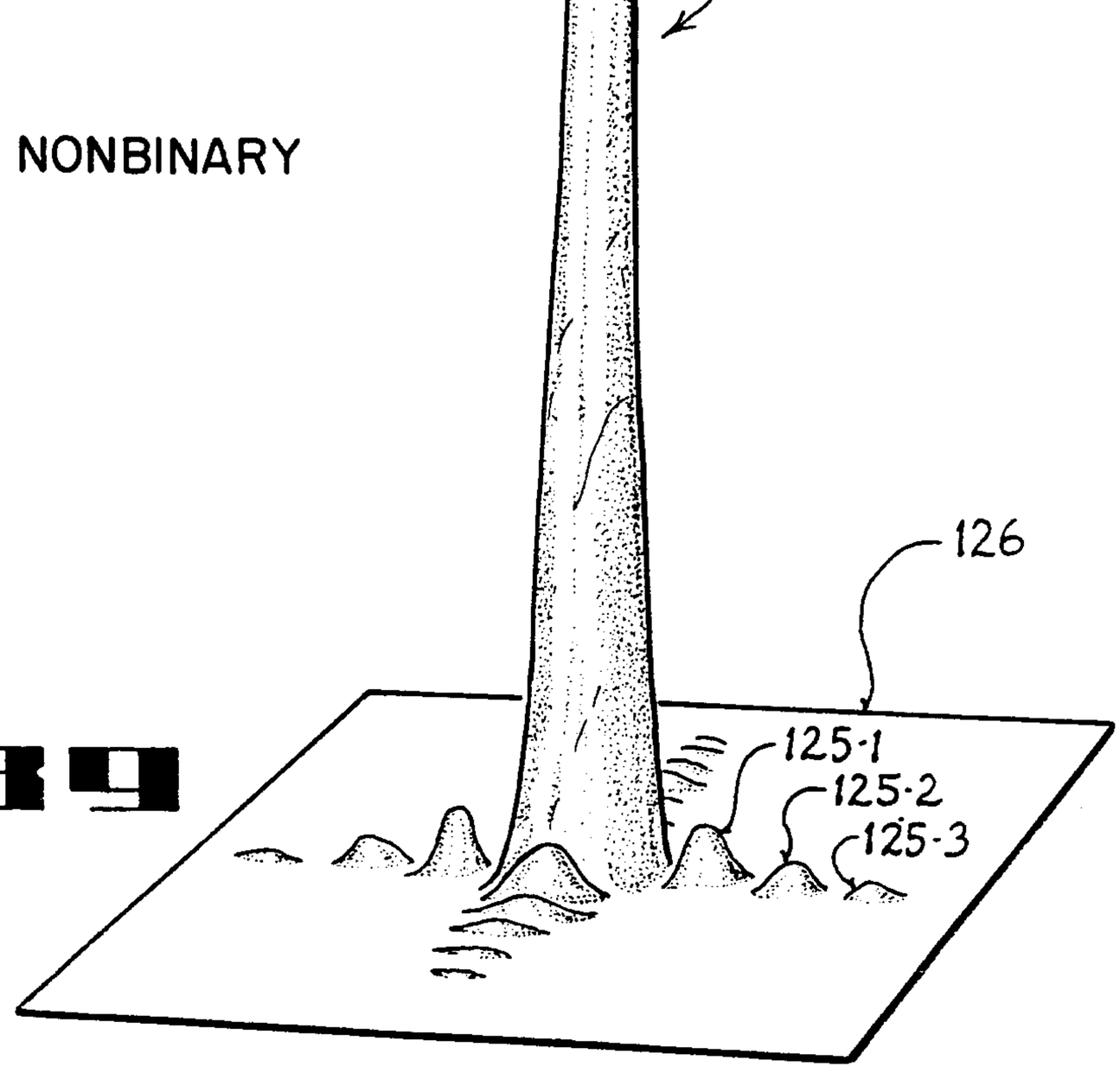


FIG_40

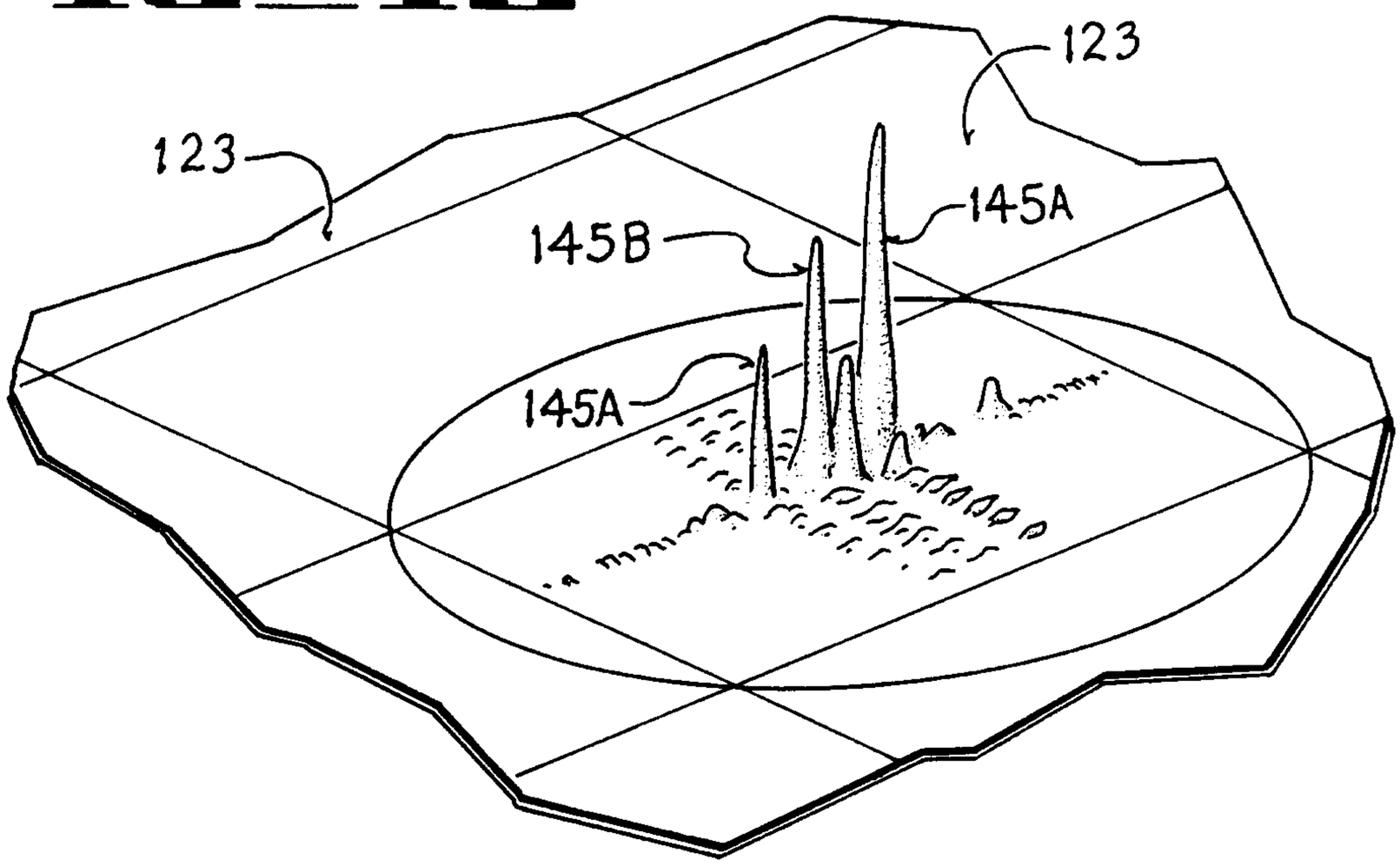


FIG_41

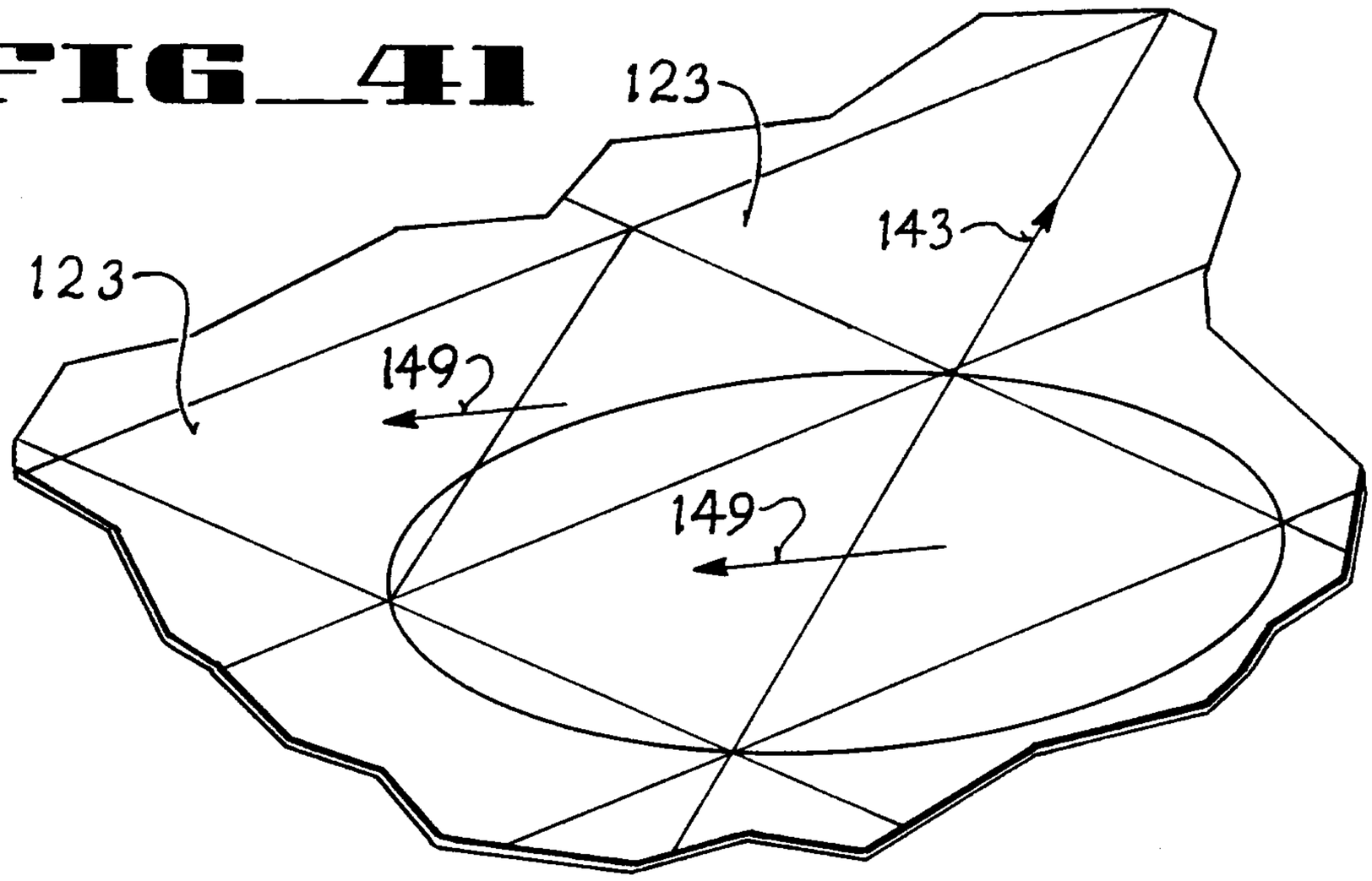


FIG_42

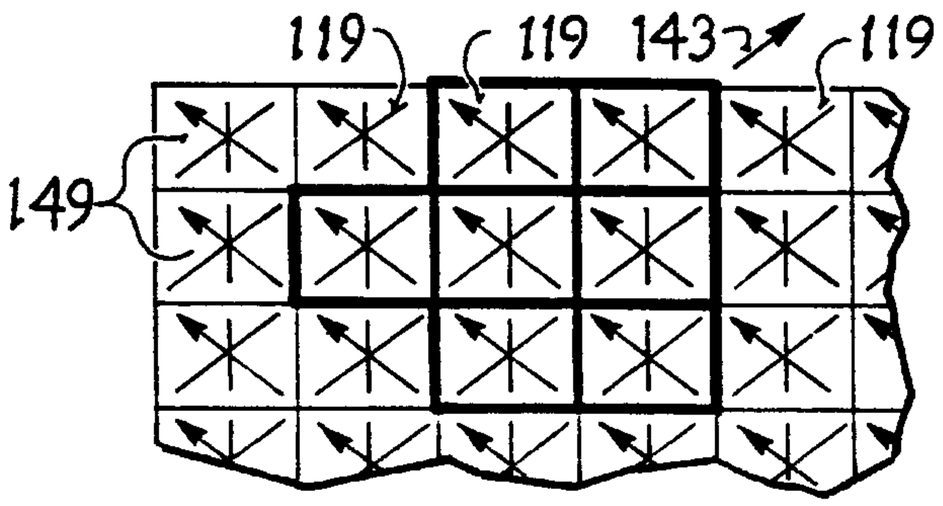


FIG_43

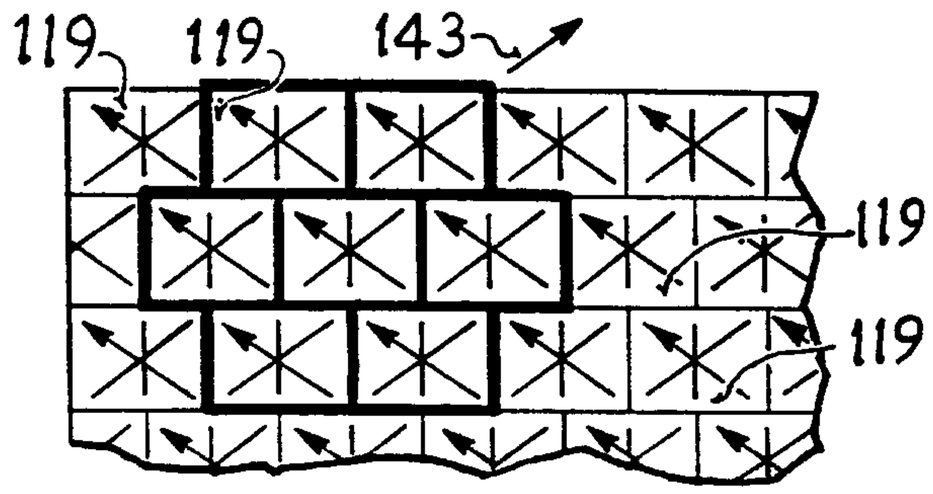


FIG_44

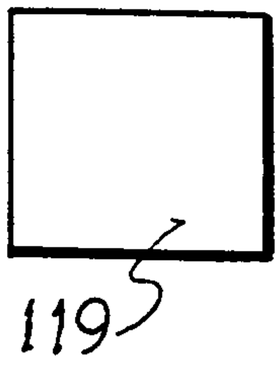
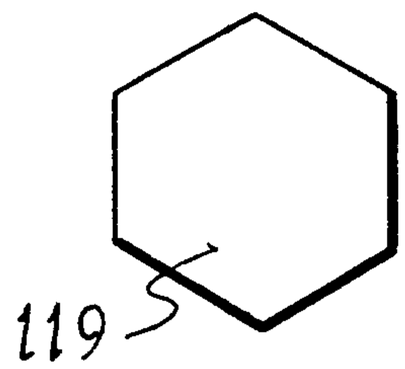


FIG_46



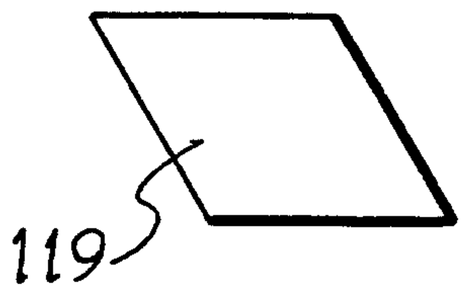


FIG_45

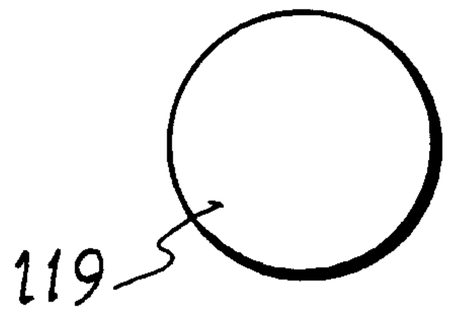
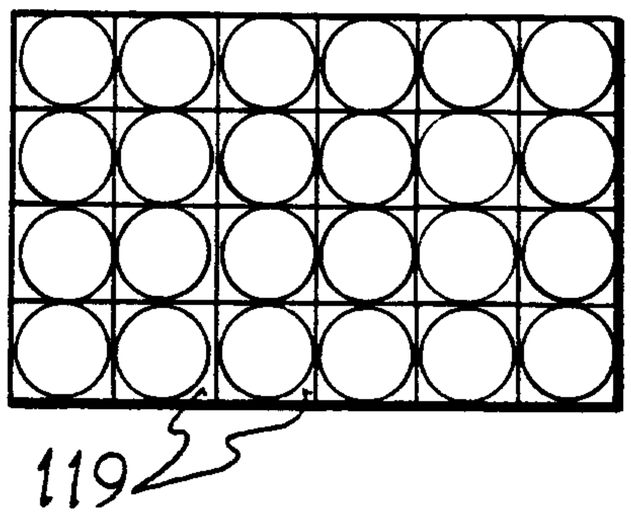
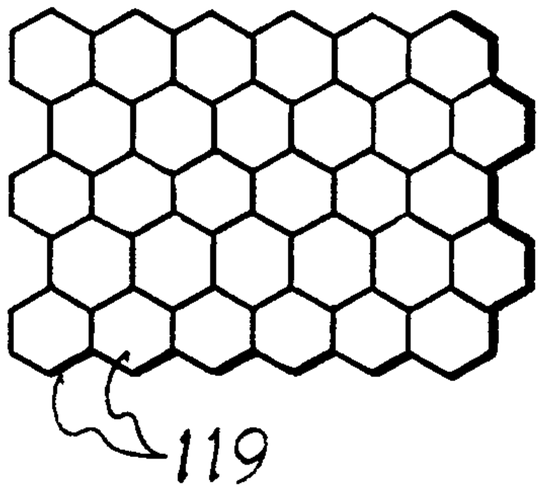


FIG_47

FIG_48

FIG_50





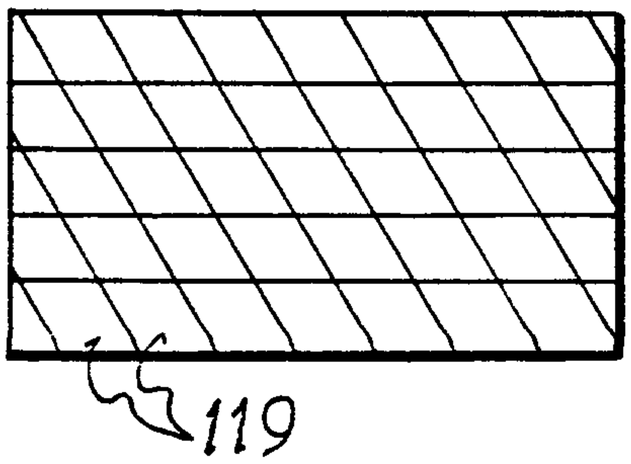


FIG_49

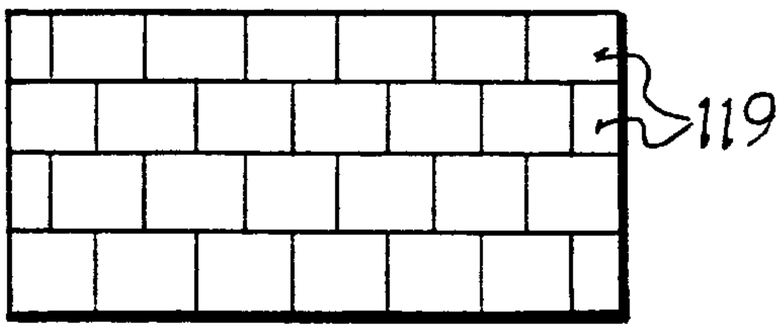


FIG_51

FIG_53

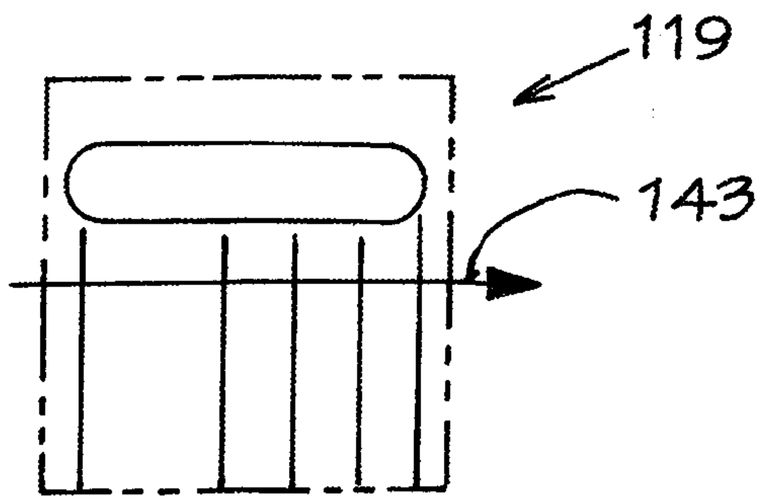


FIG_52

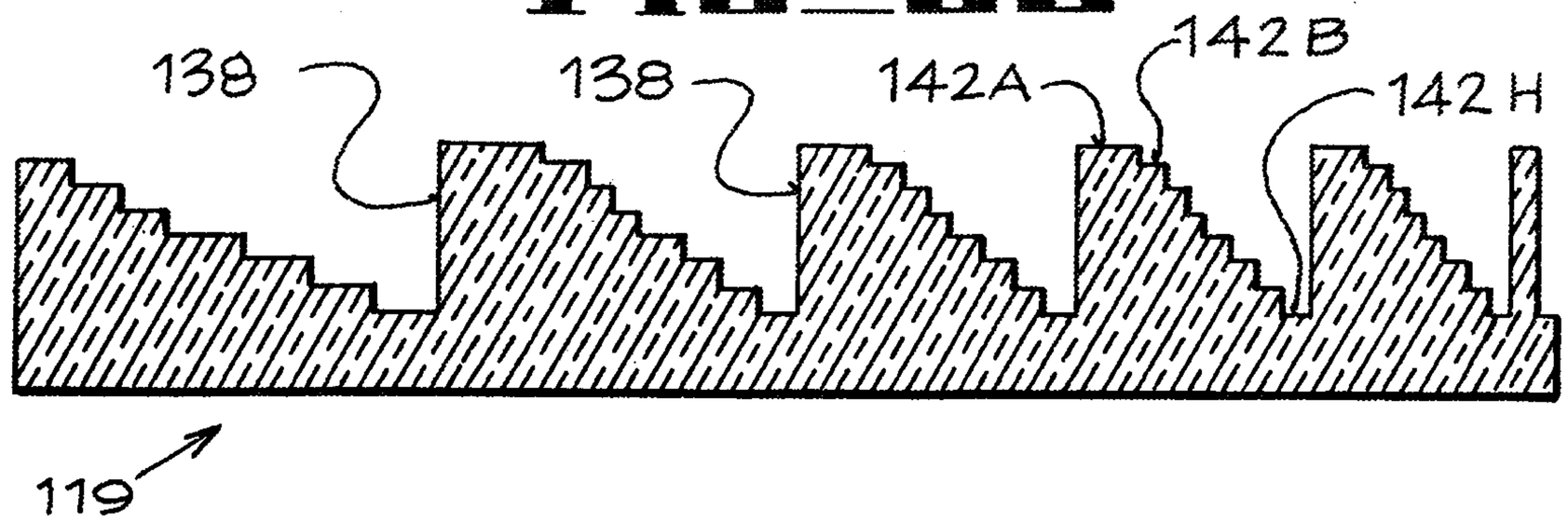


FIG_54

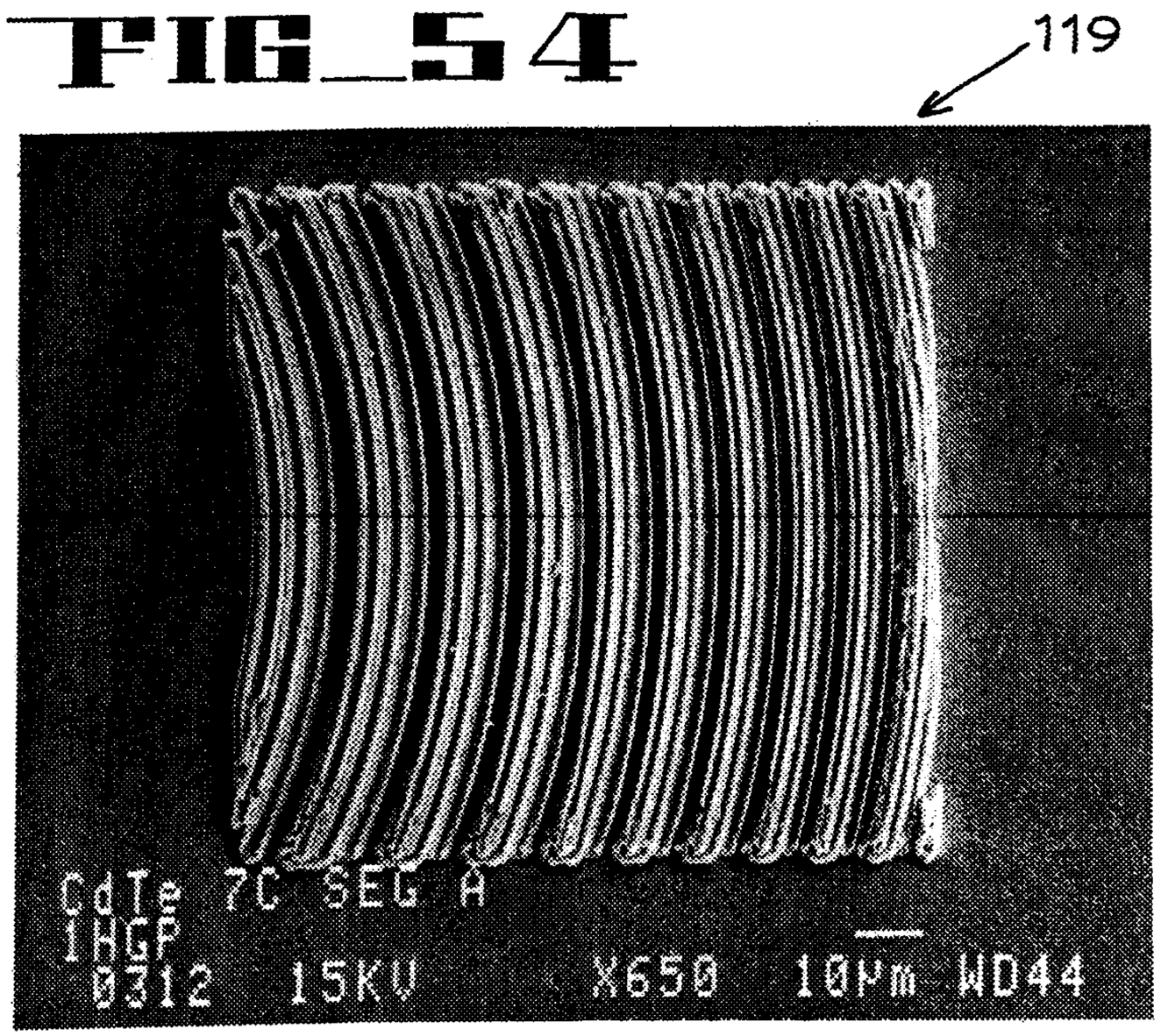


FIG_55

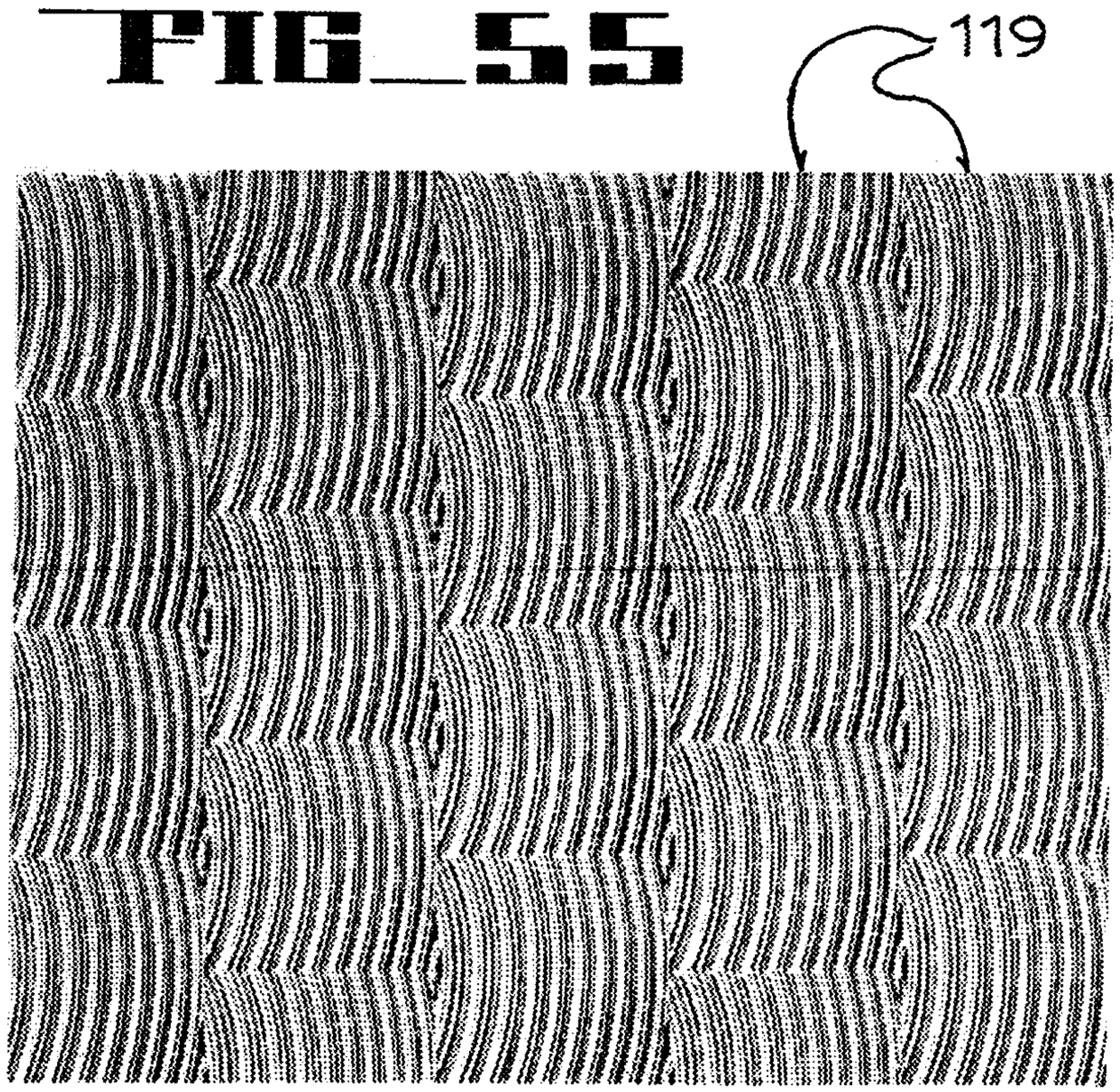


FIG_56

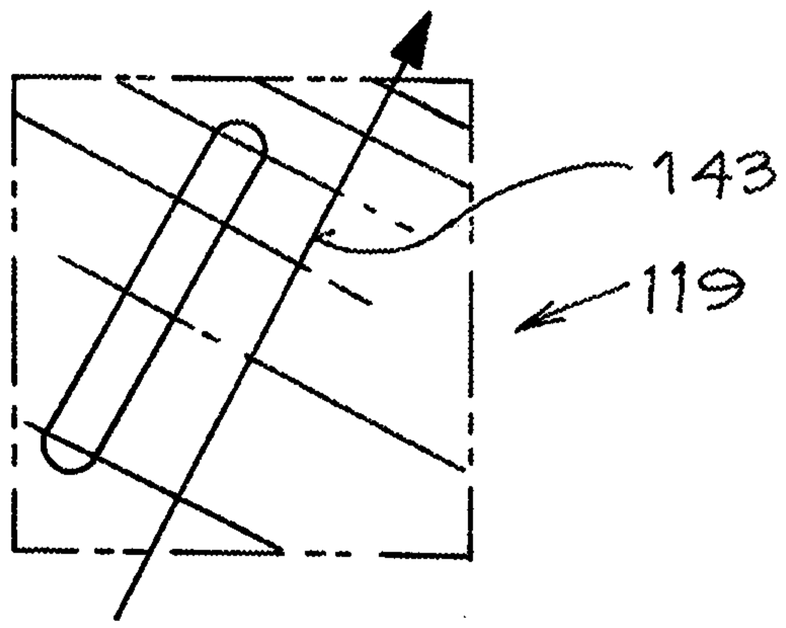


FIG_57

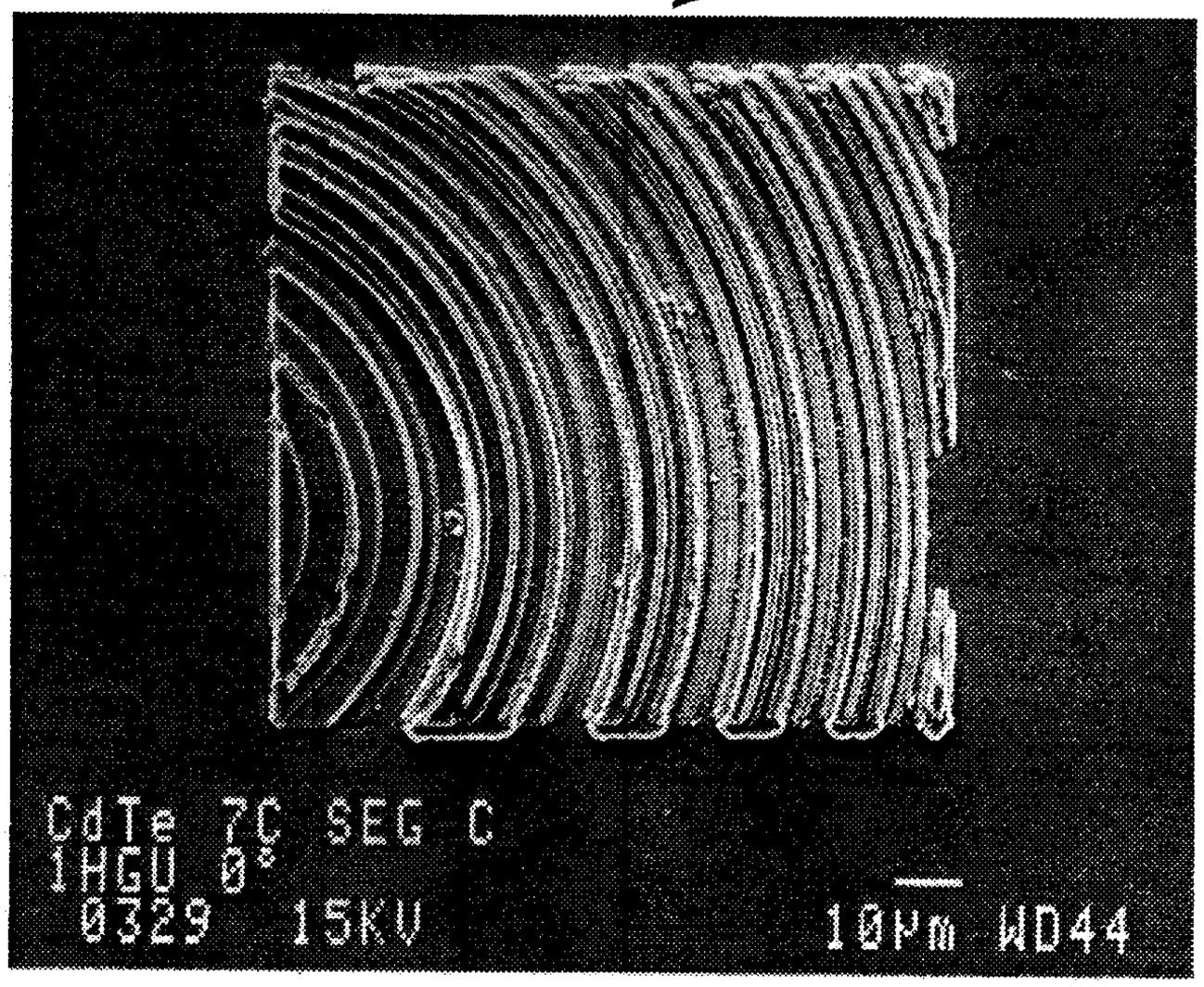


FIG_58

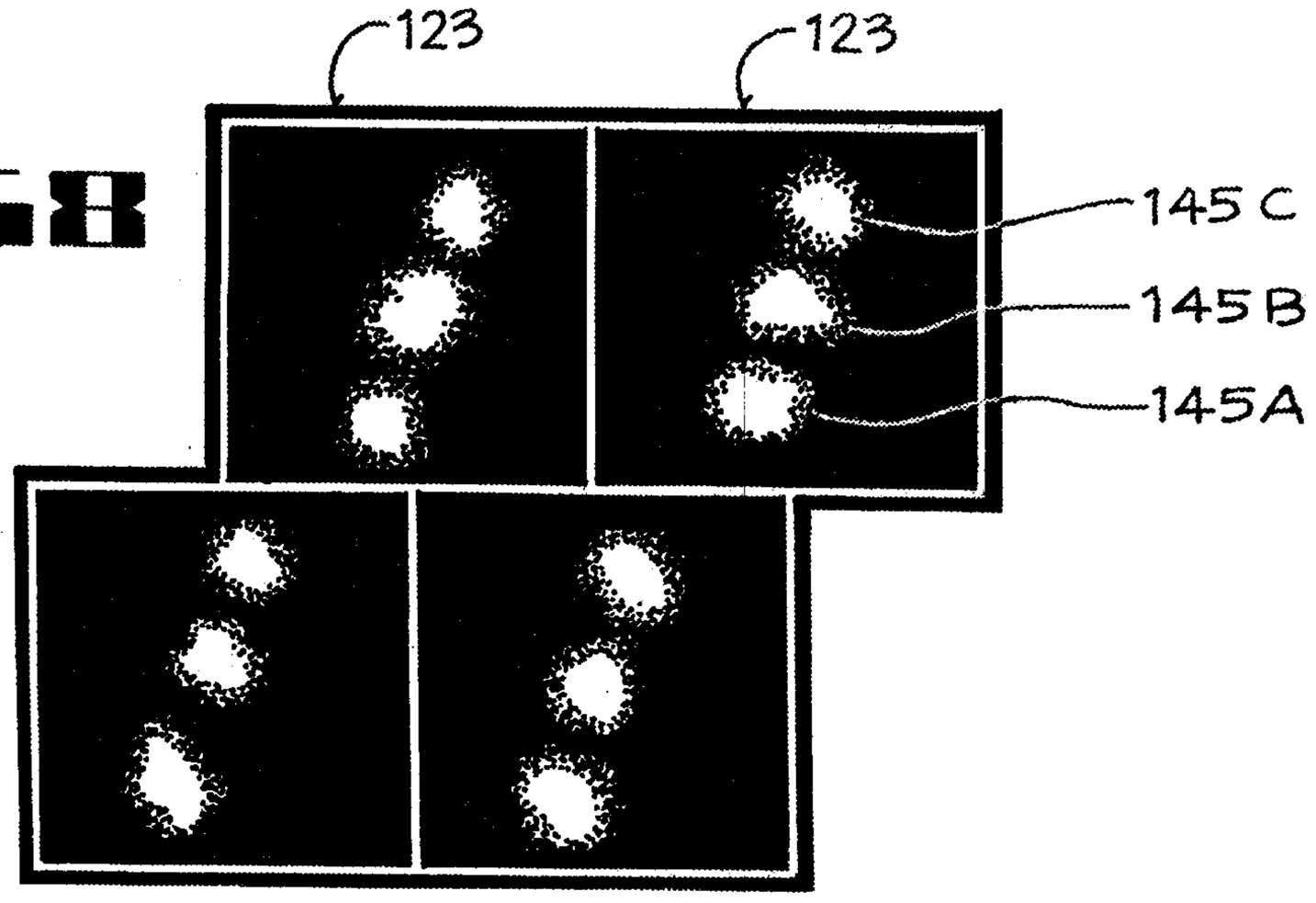


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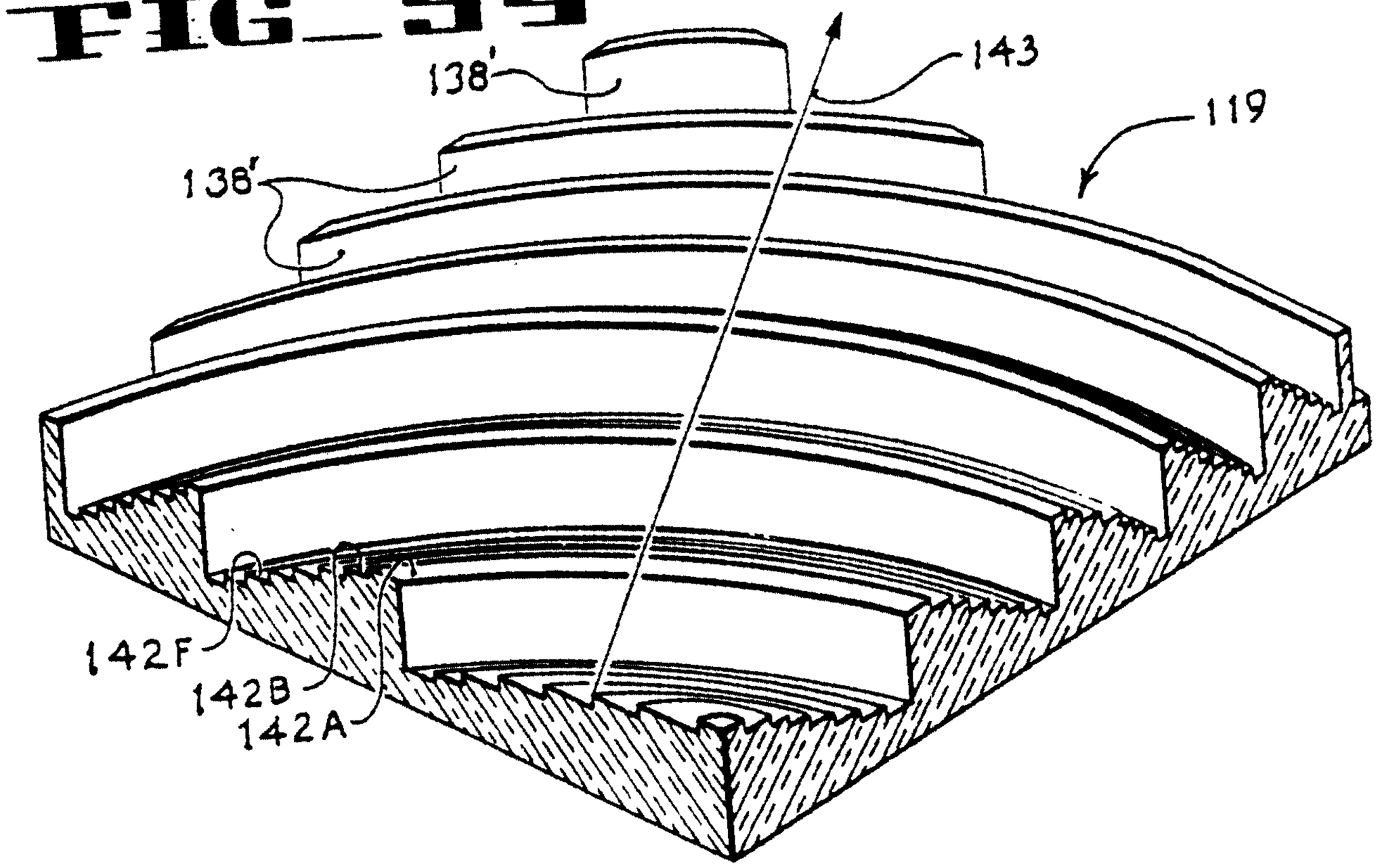
FIG_59



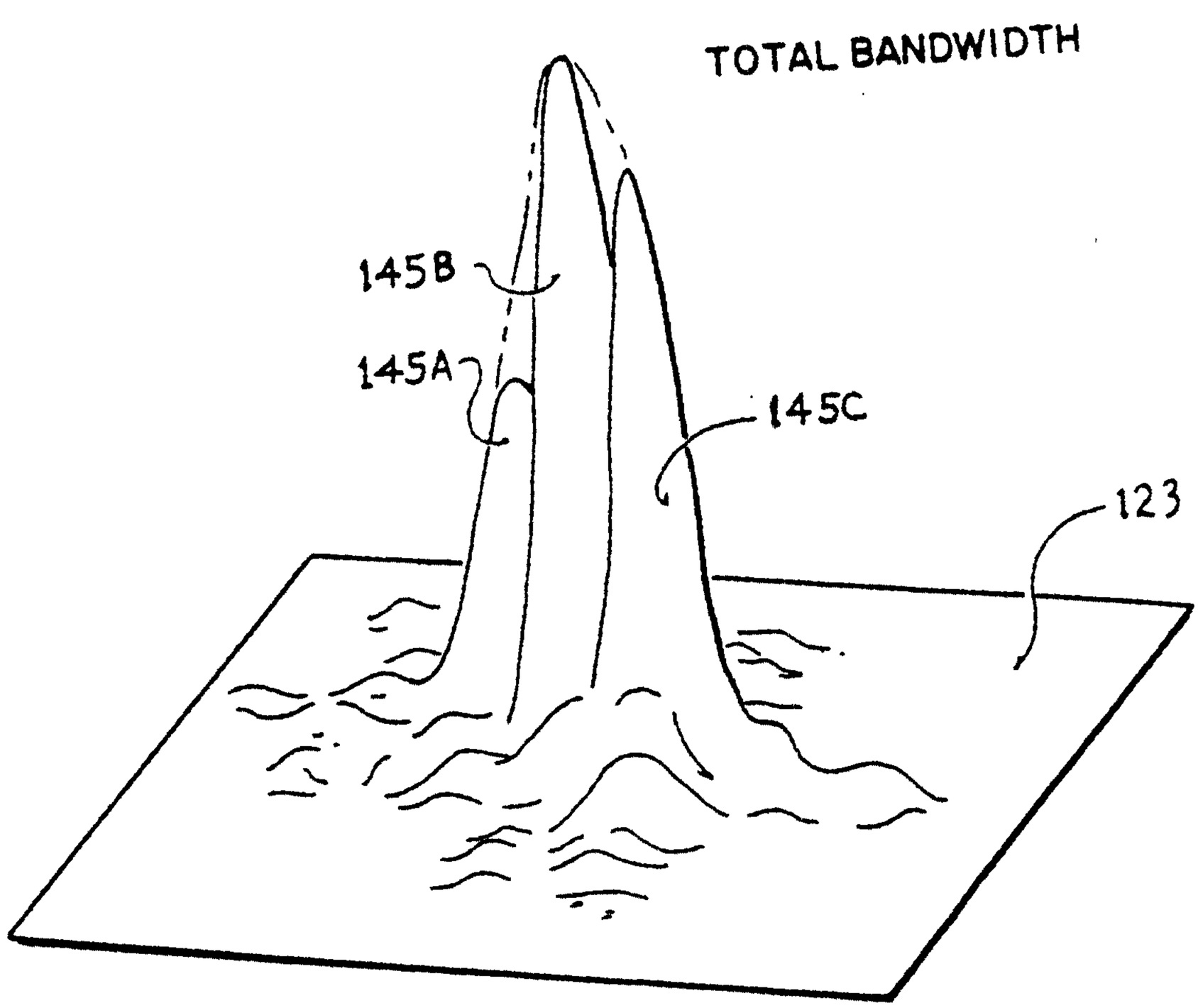


FIG_60

FIG_61

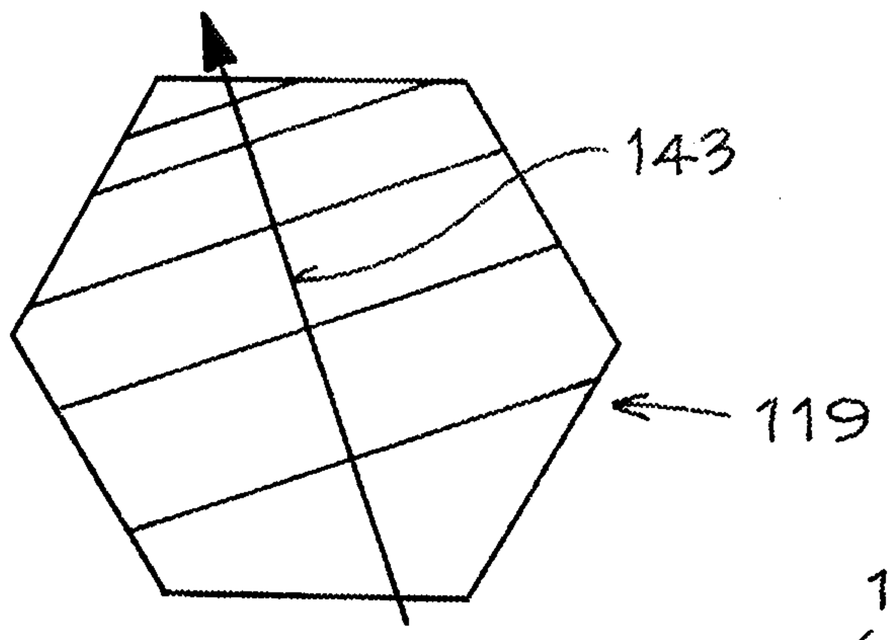


FIG_62

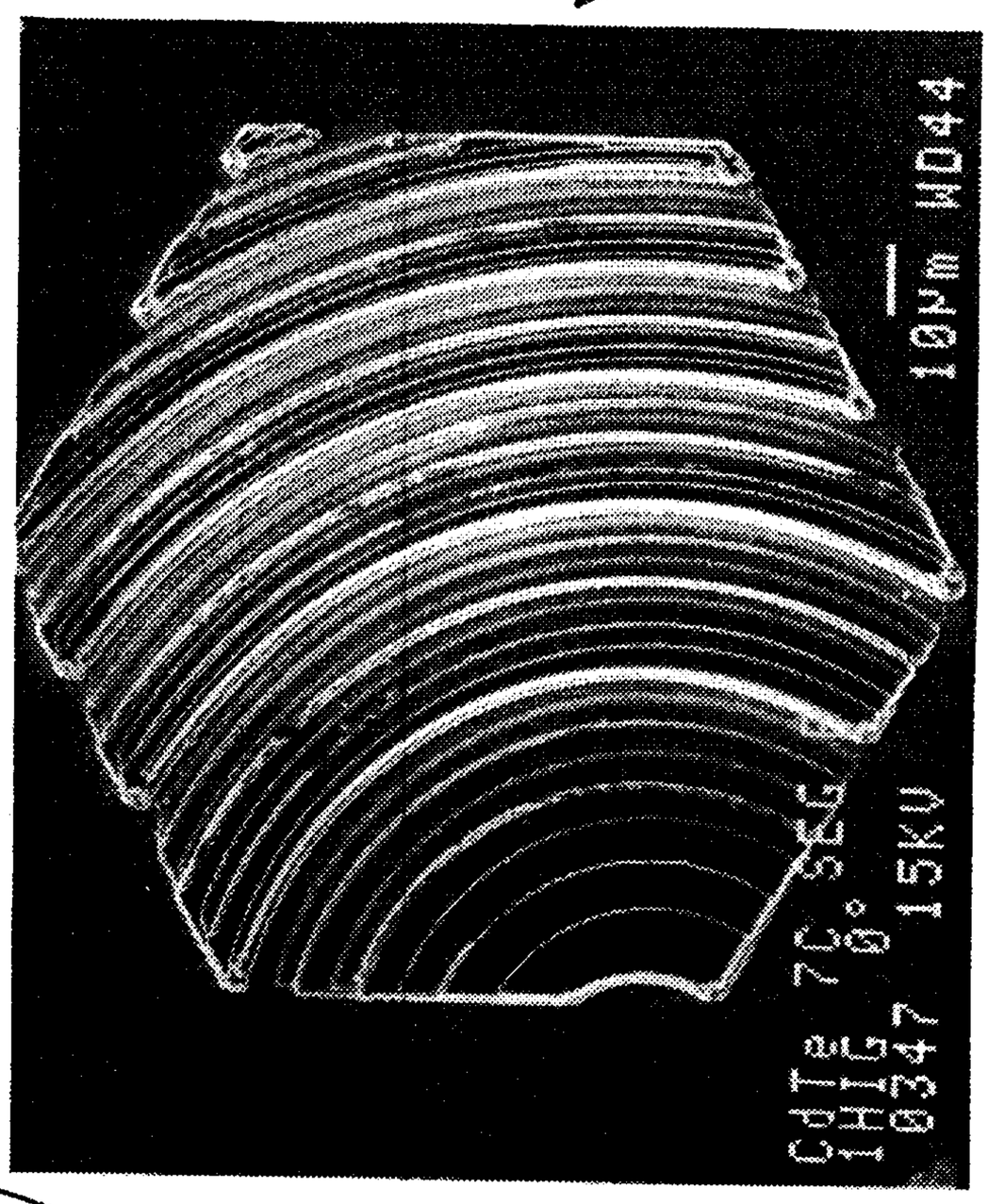


FIG_63

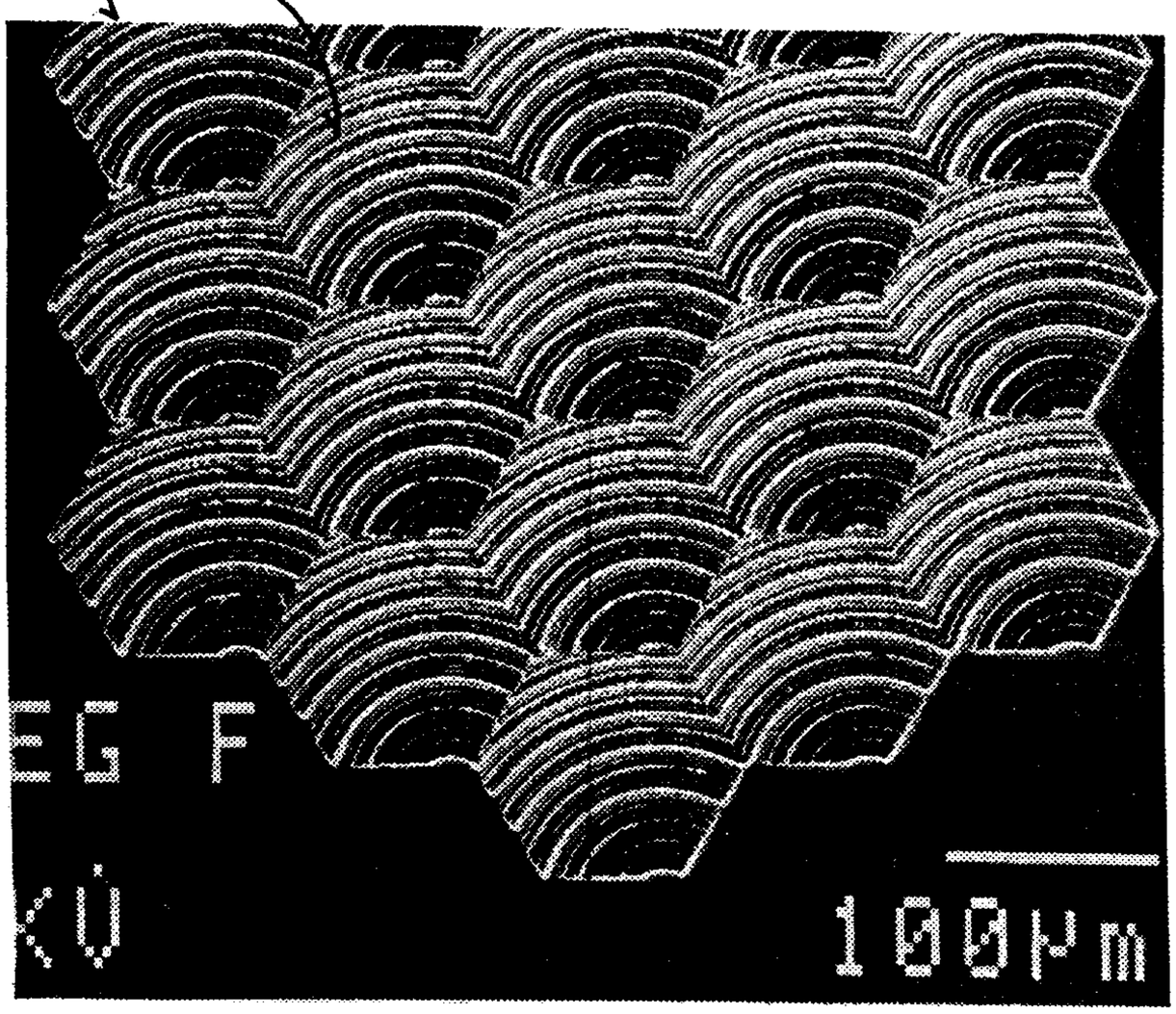


FIG_64

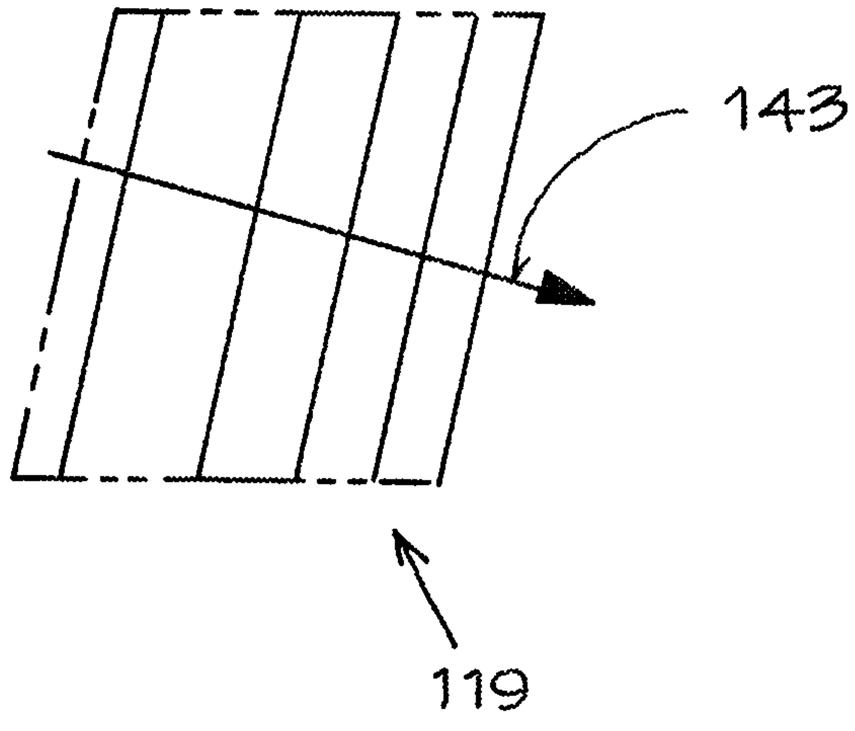


FIG_65

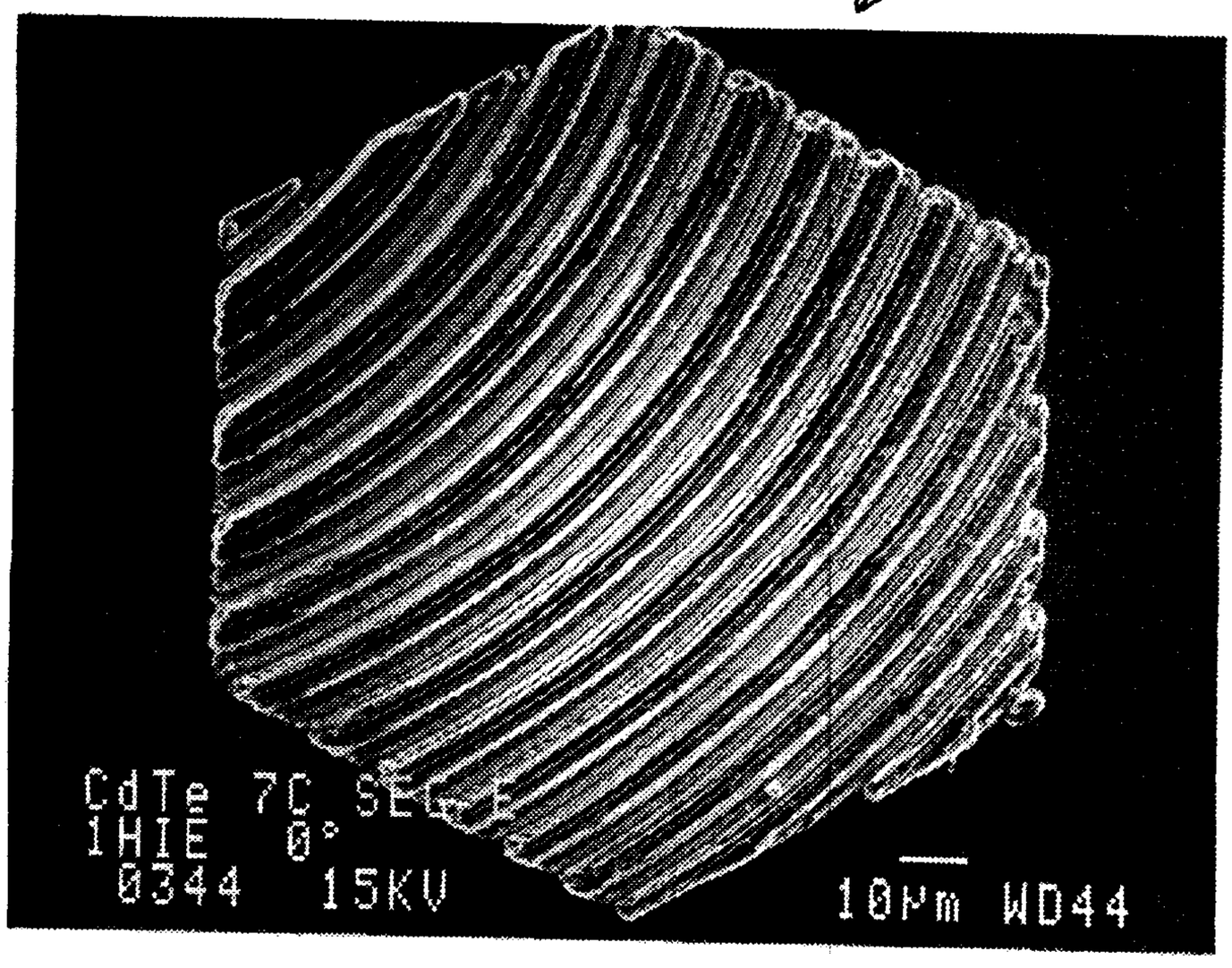
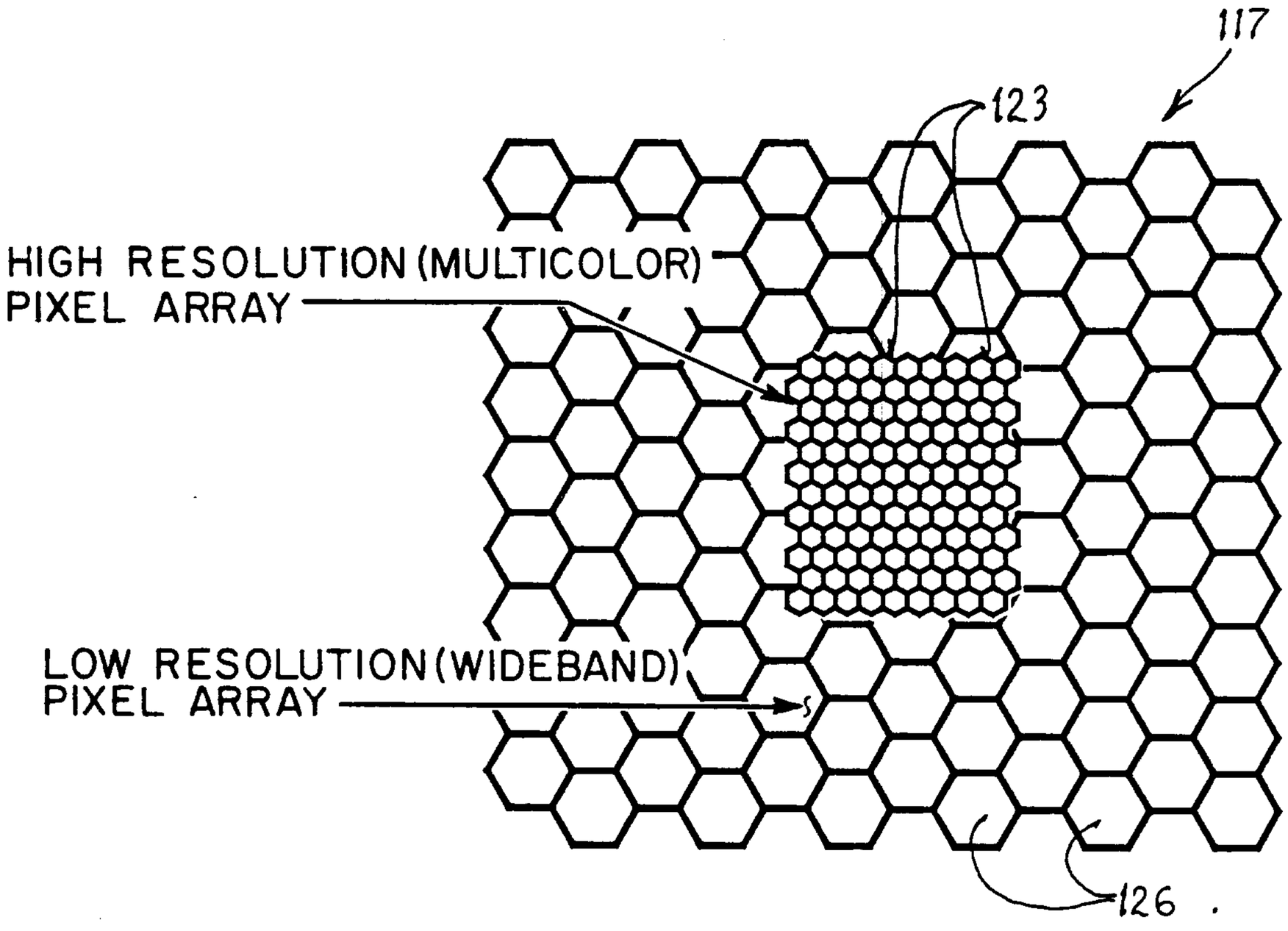


FIG_66


117
123
HIGH RESOLUTION (MULTICOLOR) PIXEL ARRAY
LOW RESOLUTION (WIDEBAND) PIXEL ARRAY
126

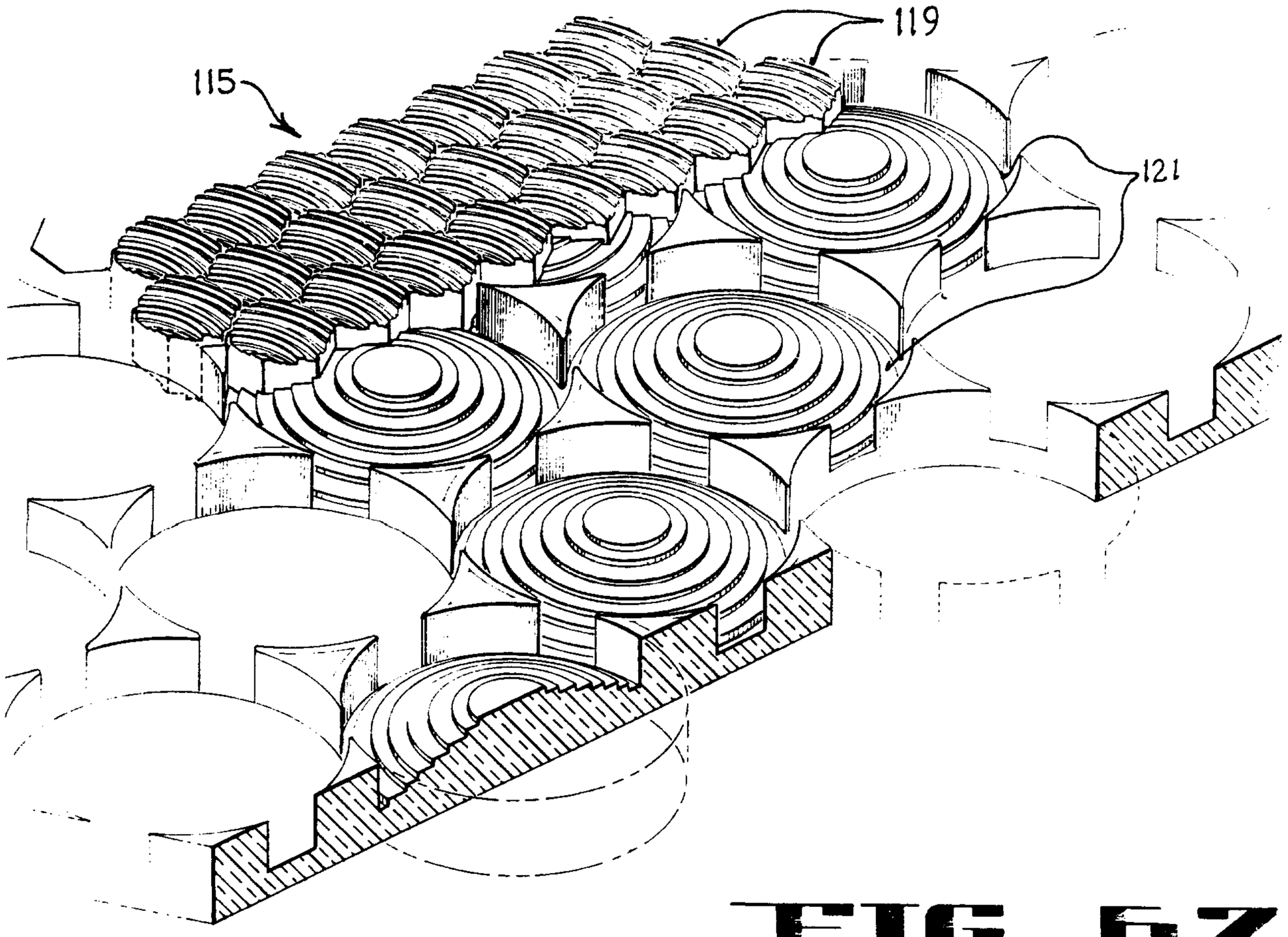

119
115
121

FIG_67

FIG_68

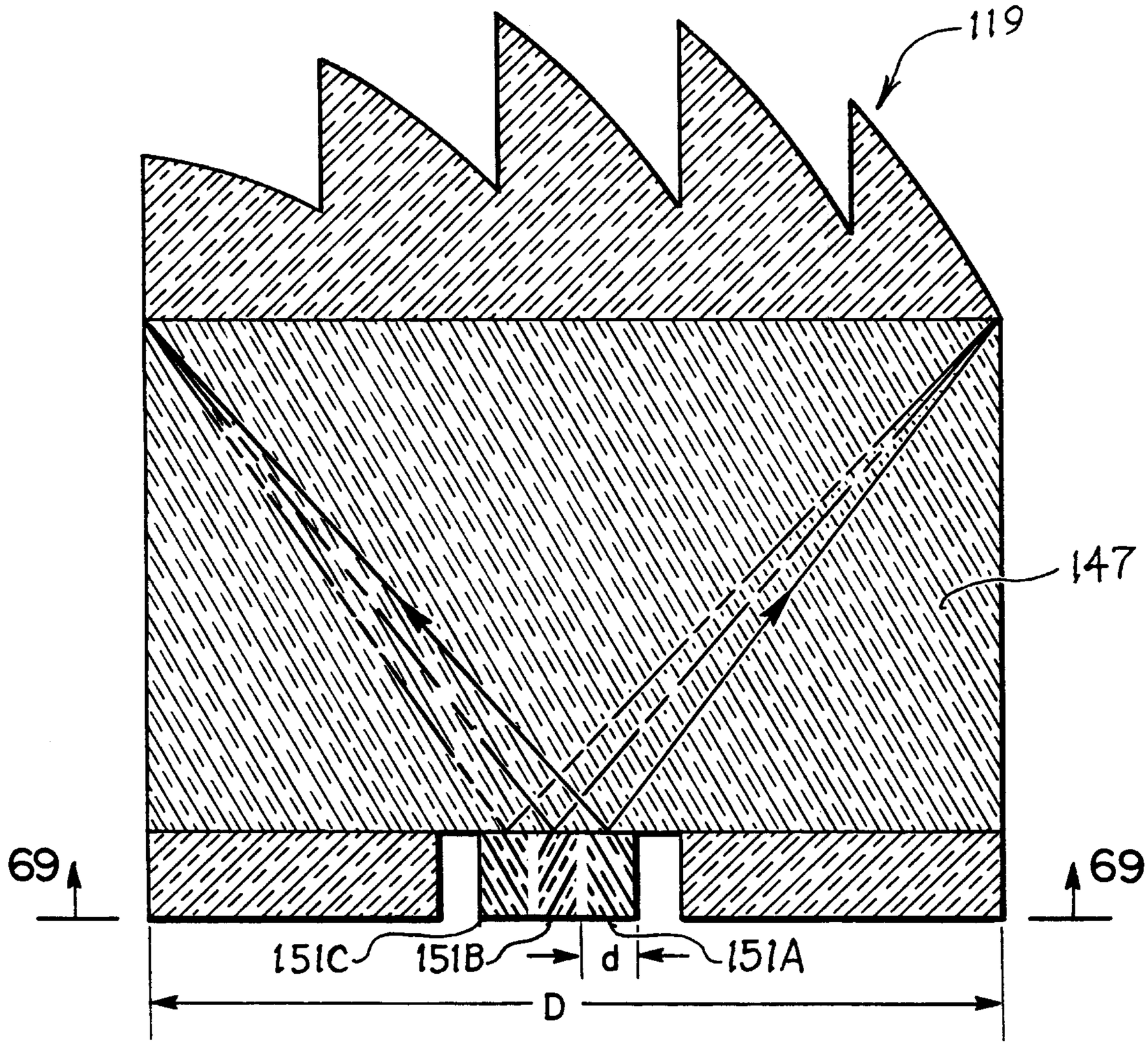


FIG_69

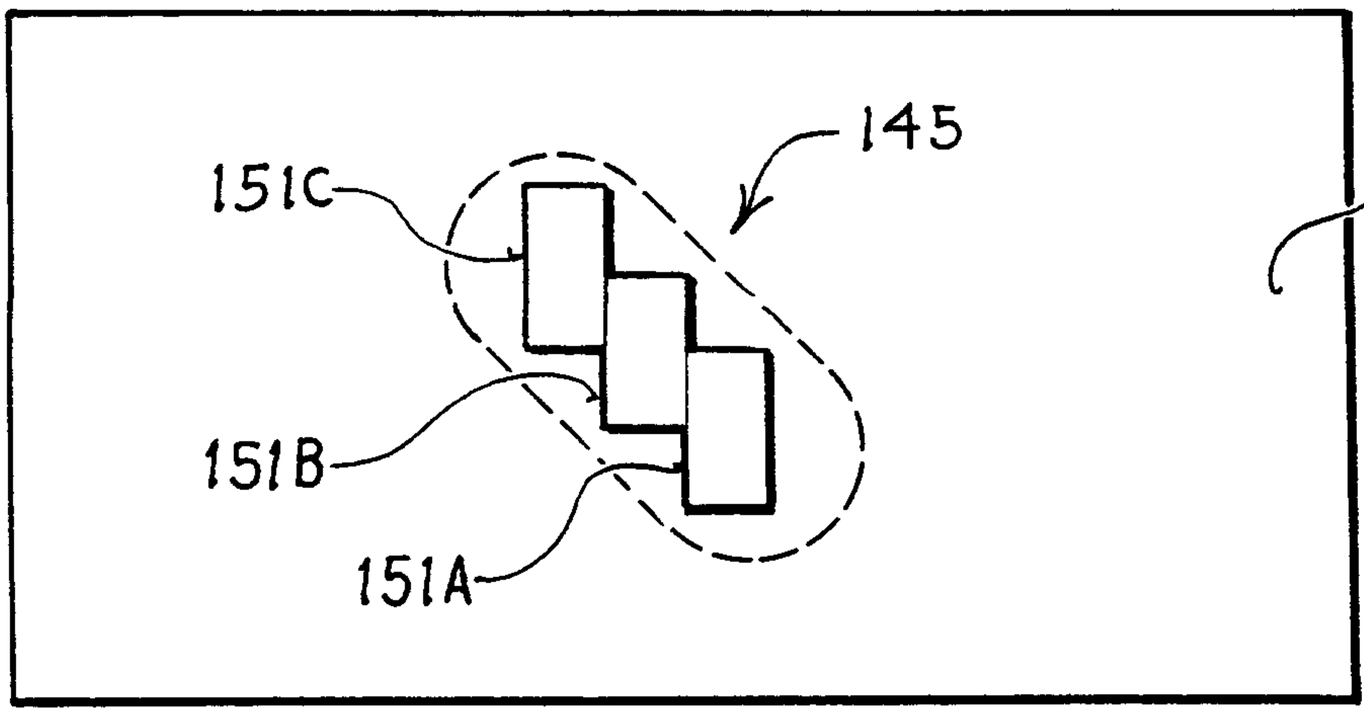


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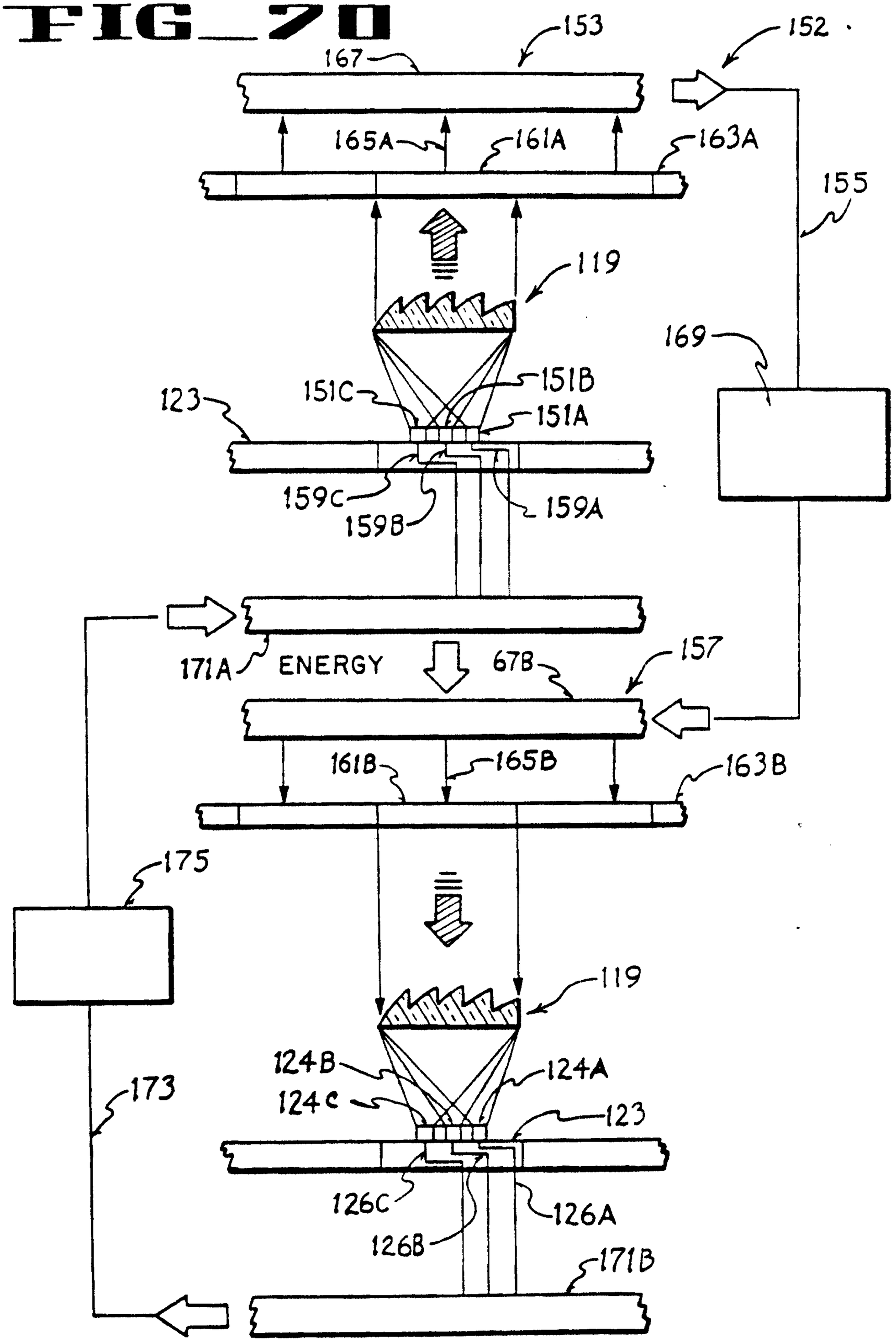
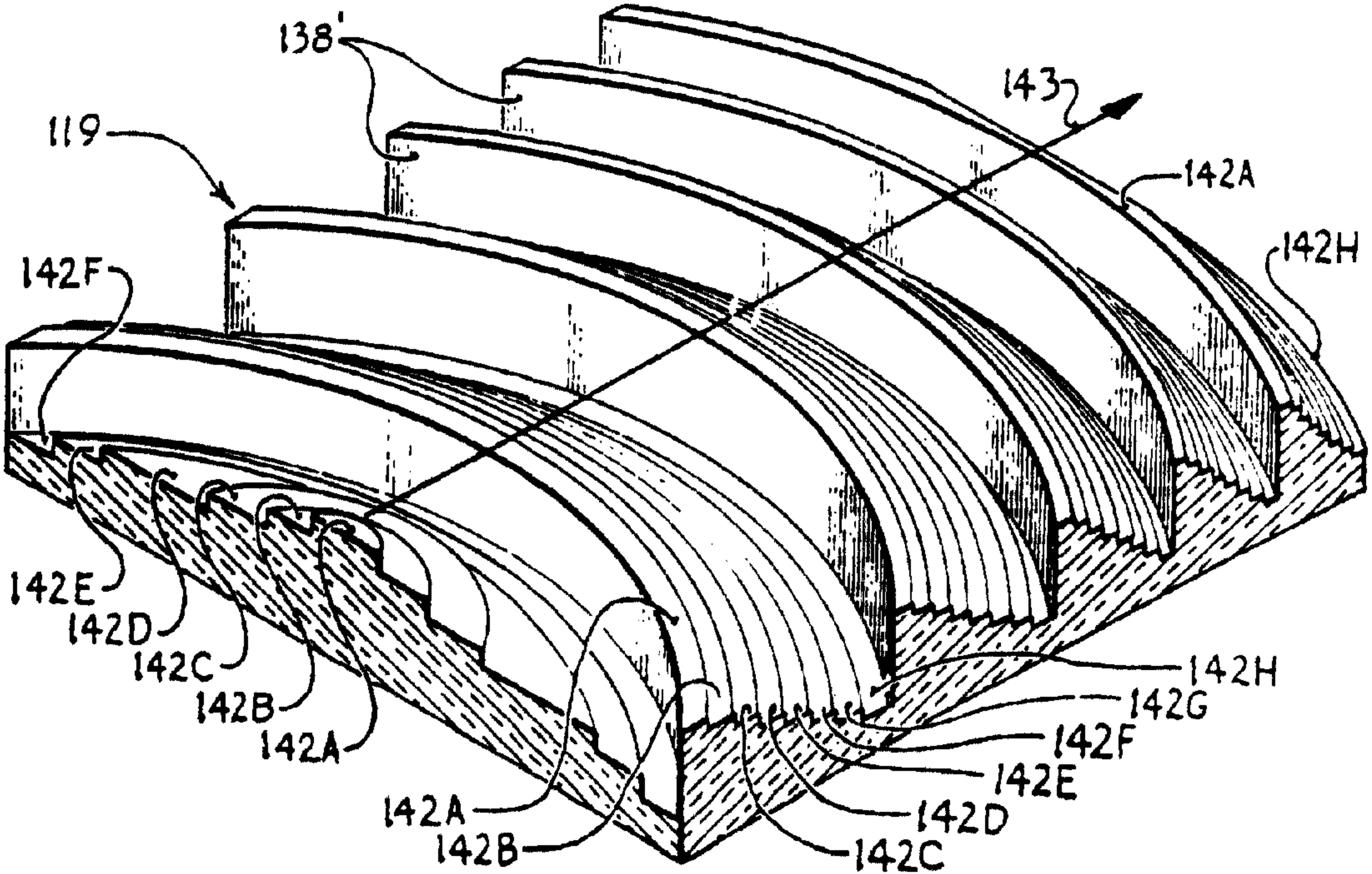
FIG_7D



AMENDED SHEET


138'
119
143
142A
142H
142F
142E
142D
142C
142B
142A
142A
142B
142H
142G
142F
142E
142D
142C