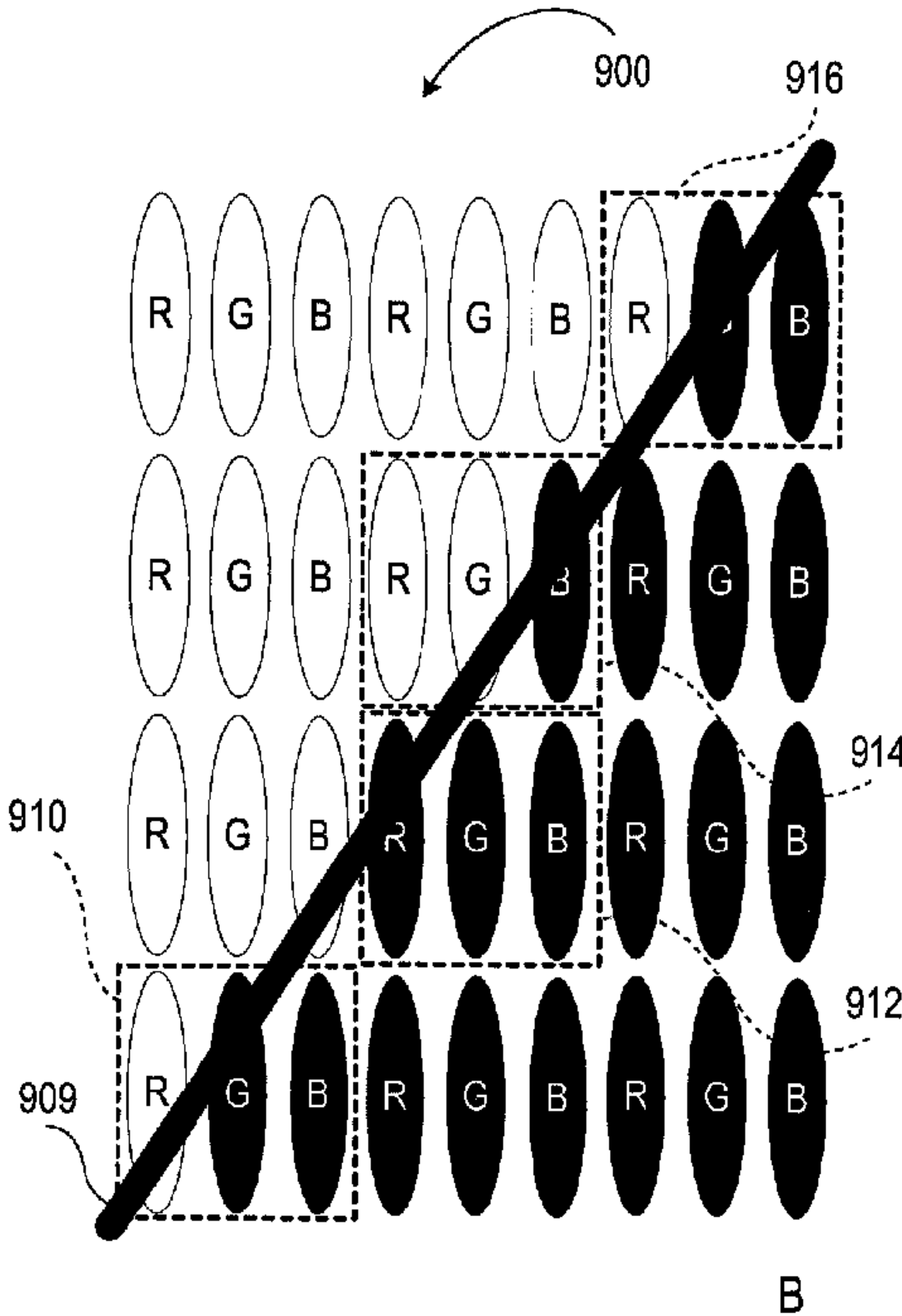




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(54) Titre : SYSTEME ET METHODE DE CORRECTION DE LA VISION, AFFICHAGE DE CHAMP LUMINEUX ET COUCHE DE FORMATION D'UN CHAMP LUMINEUX ASSOCIE AU MOYEN D'UN RENDU DE SOUS-PIXEL  
(54) Title: VISION CORRECTION SYSTEM AND METHOD, LIGHT FIELD DISPLAY AND LIGHT FIELD SHAPING LAYER THEREFOR USING SUBPIXEL RENDERING



(57) **Abrégé/Abstract:**  
Described are various embodiments of a digital display device for use by a user having reduced visual acuity. In one embodiment, a digital display device is described to render an image for viewing by a viewer having reduced visual acuity. The device comprises: a

(57) **Abrégé(suite)/Abstract(continued):**

digital display medium comprising an array of pixels and operable to render a pixelated image accordingly, wherein each of said pixels comprises a combination of sub pixels geometrically disposed and associated therewith; a light field shaping layer defined by an array of light field shaping elements and disposed relative to said digital display so to align each of said light field shaping elements with a corresponding set of said pixels to shape a light field emanating therefrom and thereby at least partially govern a projection thereof from said display medium toward the user; and a hardware processor operable on pixel data for the image to be displayed to output corrected image pixel data to be rendered as a function of a designated characteristic of said light field shaping layer and a selected vision correction parameter related to the viewer's reduced visual acuity such that said processed image is rendered via said light field shaping layer to at least partially compensate for the user's reduced visual acuity. The hardware processor is operable to calculate light field components associated with each of said subpixels to output said corrected image pixel data such that at least some of said subpixels are independently controlled accordingly.

## ABSTRACT

Described are various embodiments of a digital display device for use by a user having reduced visual acuity. In one embodiment, a digital display device is described to render  
5 an image for viewing by a viewer having reduced visual acuity. The device comprises: a digital display medium comprising an array of pixels and operable to render a pixelated image accordingly, wherein each of said pixels comprises a combination of sub pixels geometrically disposed and associated therewith; a light field shaping layer defined by an array of light field shaping elements and disposed relative to said digital display so to  
10 align each of said light field shaping elements with a corresponding set of said pixels to shape a light field emanating therefrom and thereby at least partially govern a projection thereof from said display medium toward the user; and a hardware processor operable on pixel data for the image to be displayed to output corrected image pixel data to be rendered as a function of a designated characteristic of said light field shaping layer and a  
15 selected vision correction parameter related to the viewer's reduced visual acuity such that said processed image is rendered via said light field shaping layer to at least partially compensate for the user's reduced visual acuity. The hardware processor is operable to calculate light field components associated with each of said subpixels to output said corrected image pixel data such that at least some of said subpixels are independently  
20 controlled accordingly.

VISION CORRECTION SYSTEM AND METHOD, LIGHT FIELD DISPLAY AND  
LIGHT FIELD SHAPING LAYER THEREFOR USING SUBPIXEL RENDERING

FIELD OF THE DISCLOSURE

5    **[001]**       The present disclosure relates to digital displays, and in particular, to a vision correction system and method, light field display and light field shaping layer therefor, for instance, using subpixel rendering.

BACKGROUND

10   **[002]**       Individuals routinely wear corrective lenses to accommodate for reduced vision acuity in consuming images and/or information rendered, for example, on digital displays provided, for example, in day-to-day electronic devices such as smartphones, smart watches, electronic readers, tablets, laptop computers and the like, but also provided as part of vehicular dashboard displays and entertainment systems, to name a few examples. The use of bifocals or progresses corrective lenses is also commonplace  
15   for individuals suffering from near and far sightedness.

20   **[003]**       The operating systems of current electronic devices having graphical displays offer certain “Accessibility” features built into the software of the device to attempt to provide users with reduced vision the ability to read and view content on the electronic device. Specifically, current accessibility options include the ability to invert images, increase the image size, adjust brightness and contrast settings, bold text, view the device display only in grey, and for those with legal blindness, the use of speech technology. These techniques focus on the limited ability of software to manipulate display images through conventional image manipulation, with limited success.

25   **[004]**       The use of 4D light field displays with lenslet arrays or parallax barriers to correct visual aberrations have since been proposed by Pamplona et al. (PAMPLONA, V., OLIVEIRA, M., ALIAGA, D., AND RASKAR, R.2012. “Tailored displays to compensate for visual aberrations.” ACM Trans. Graph. (SIGGRAPH) 31.).

Unfortunately, conventional light field displays as used by Pamplona et al. are subject to a spatio-angular resolution trade-off; that is, an increased angular resolution decreases the spatial resolution. Hence, the viewer sees a sharp image but at the expense of a significantly lower resolution than that of the screen. To mitigate this effect, Huang et al.  
5 (see, HUANG, F.-C., AND BARSKY, B. 2011. A framework for aberration compensated displays. Tech. Rep. UCB/EECS-2011-162, University of California, Berkeley, December; and HUANG, F.-C., LANMAN, D., BARSKY, B. A., AND RASKAR, R. 2012. Correcting for optical aberrations using multi layer displays. ACM Trans. Graph. (SIGGRAPH Asia) 31, 6, 185:1-185:12. proposed the use of multilayer display designs  
10 together with prefiltering. The combination of prefiltering and these particular optical setups, however, significantly reduces the contrast of the resulting image.

[005] Finally, in U.S. Patent Application Publication No. 2016/0042501 and Fu-Chung Huang, Gordon Wetzstein, Brian A. Barsky, and Ramesh Raskar. "Eyeglasses-free Display: Towards Correcting Visual Aberrations with Computational Light Field  
15 Displays". *ACM Transaction on Graphics*, xx:0, Aug. 2014, the entire contents of each of which are hereby incorporated herein by reference, the combination of viewer-adaptive pre-filtering with off-the-shelf parallax barriers has been proposed to increase contrast and resolution, at the expense however, of computation time and power.

[006] This background information is provided to reveal information believed by the  
20 applicant to be of possible relevance. No admission is necessarily intended, nor should be construed, that any of the preceding information constitutes prior art.

## SUMMARY

[007] The following presents a simplified summary of the general inventive concept(s) described herein to provide a basic understanding of some aspects of the  
25 invention. This summary is not an extensive overview of the invention. It is not intended to restrict key or critical elements of the invention or to delineate the scope of the invention beyond that which is explicitly or implicitly described by the following description and claims.

[008] A need exists for a vision correction system and method, light field display and optical element array therefor, that overcome some of the drawbacks of known techniques, or at least, provide a useful alternative thereto. Some aspects of disclosure provide embodiments of such systems, methods, displays and optical element arrays, for instance, using subpixel rendering.

[009] In accordance with one aspect, there is provided a digital display device to render an image for viewing by a viewer having reduced visual acuity, the device comprising: a digital display medium comprising an array of pixels and operable to render a pixelated image accordingly, wherein each of said pixels comprises a combination of sub pixels geometrically disposed and associated therewith; a light field shaping layer defined by an array of light field shaping elements and disposed relative to said digital display so to align each of said light field shaping elements with a corresponding set of said pixels to shape a light field emanating therefrom and thereby at least partially govern a projection thereof from said display medium toward the user; and a hardware processor operable on pixel data for the image to be displayed to output corrected image pixel data to be rendered as a function of a designated characteristic of said light field shaping layer and a selected vision correction parameter related to the viewer's reduced visual acuity such that said processed image is rendered via said light field shaping layer to at least partially compensate for the user's reduced visual acuity; wherein said hardware processor is operable to calculate light field components associated with each of said subpixels to output said corrected image pixel data such that at least some of said subpixels are independently controlled accordingly.

[0010] In one embodiment, each of said subpixels is associated with a subpixel location on said digital display, and wherein said hardware processor is operable to calculate said light field components associated with each of said subpixels based on each said subpixel location.

[0011] In one embodiment, each of said pixels is associated with a pixel location on said digital display, wherein each of said subpixels for a given pixel is disposed at a designated subpixel offset relative to said pixel location of said given pixel, and wherein

said hardware processor is operable to calculate said light field components associated with each of said subpixels for each said given pixel by offsetting light field calculations based on said pixel location in accordance with each said designated subpixel offset.

5 [0012] In one embodiment, each of said subpixels is associated with one of distinct colour channels, and wherein said hardware processor is operable to distinctly compute light fields for each of said distinct colour channels in a compressive light field optimization process.

10 [0013] Other aspects, features and/or advantages will become more apparent upon reading of the following non-restrictive description of specific embodiments thereof, given by way of example only with reference to the accompanying drawings.

#### BRIEF DESCRIPTION OF THE FIGURES

[0014] Several embodiments of the present disclosure will be provided, by way of examples only, with reference to the appended drawings, wherein:

15 [0015] Figure 1 is a diagrammatical view of an electronic device having a digital display, in accordance with one embodiment;

[0016] Figures 2A and 2B are exploded and side views, respectively, of an assembly of a light field display for an electronic device, in accordance with one embodiment;

20 [0017] Figures 3A, 3B and 3C schematically illustrate normal vision, blurred vision, and corrected vision in accordance with one embodiment, respectively;

[0018] Figure 4 is a schematic diagram of a single light field pixel defined by a convex lenslet or microlens overlaying an underlying pixel array and disposed at or near its focus to produce a substantially collimated beam, in accordance with one embodiment;

25 [0019] Figure 5 is another schematic exploded view of an assembly of a light field display in which respective pixel subsets are aligned to emit light through a corresponding microlens or lenslet, in accordance with one embodiment;

[0020] Figure 6 is an exemplary diagram of a light field pattern that, when properly projected by a light field display, produces a corrected image exhibiting reduced blurring for a viewer having reduced visual acuity, in accordance with one embodiment;

[0021] Figures 7A and 7B are photographs of a Snellen chart, as illustratively viewed  
5 by a viewer with reduced acuity without image correction (blurry image in Figure 7A) and with image correction via a light field display (corrected image in Figure 7B), in accordance with one embodiment;

[0022] Figure 8 is a schematic diagram of a portion of hexagonal lenslet array disposed at an angle relative to an underlying pixel array and having an irregular pitch  
10 mismatch offset, in accordance with one embodiment;

[0023] Figures 9A and 9B are schematic diagrams of an LCD pixel array defined by respective red (R), green (G) and blue (B) subpixels, and rendering an angular image edge using standard pixel and subpixel rendering, respectively, in accordance with one embodiment;

15 [0024] Figure 10 is a schematic diagram of one of the pixels of Figure 8A, showing measures for independently accounting for subpixels thereof apply subpixel rendering to the display of a corrected image through a light field display, in accordance with one embodiment;

[0025] Figures 11A and 11B are photographs as illustratively viewed by a viewer  
20 with reduced visual acuity without image correction (blurry image in Figure 11A) and with image correction via a light field display having an angularly mismatched lenslet array (corrected image in Figure 11B), in accordance with one embodiment; and

[0026] Figures 12A and 12B are photographs as illustratively viewed by a viewer with reduced visual acuity without image correction (blurry image in Figure 12A) and  
25 with image correction via a light field display having an angularly mismatched lenslet array (corrected image in Figure 12B), in accordance with one embodiment.

## DETAILED DESCRIPTION

[0027] The systems and methods described herein provide, in accordance with different embodiments, different examples of a vision correction system and method, light field display and optical element array therefor. For instance, the devices, displays  
5 and methods described herein may allow users who would otherwise require corrective eyewear such as glasses or contact lenses, or again bifocals, to consume images produced by such devices, displays and methods in clear or improved focus without the use of such eyewear.

[0028] For example, the embodiments described herein provide for digital display  
10 devices, or devices encompassing such displays, for use by users having reduced visual acuity, whereby images ultimately rendered by such devices can be dynamically processed to accommodate the user's reduced visual acuity so that they may consume rendered images without the use of corrective eyewear, as would otherwise be required. Generally, digital displays as considered herein will comprise a set of image rendering  
15 pixels and a light field shaping layer disposed at a preset distance therefrom so to controllably shape or influence a light field emanating therefrom. For instance, each light field shaping layer will be defined by an array of optical elements centered over a corresponding subset of the display's pixel array to optically influence a light field emanating therefrom and thereby govern a projection thereof from the display medium  
20 toward the user, for instance, providing some control over how each pixel or pixel group will be viewed by the viewer's eye(s). As will be further detailed below, arrayed optical elements may include, but are not limited to, lenslets, microlenses or other such diffractive optical elements that together form, for example, a lenslet array; pinholes or like apertures or windows that together form, for example, a parallax or like barrier;  
25 concentrically patterned barriers, e.g. cut outs and/or windows, such as a to define a Fresnel zone plate or optical sieve, for example, and that together form a diffractive optical barrier (as described, for example, in Applicant's co-pending U.S. Application Serial No. 15/910,908, the entire contents of which are hereby incorporated herein by reference; and/or a combination thereof, such as for example, a lenslet array whose  
30 respective lenses or lenslets are partially shadowed or barriered around a periphery

thereof so to combine the refractive properties of the lenslet with some of the advantages provided by a pinhole barrier.

5 [0029] In operation, the display device will also generally invoke a hardware processor operable on image pixel data for an image to be displayed to output corrected image pixel data to be rendered as a function of a stored characteristic of the light field shaping layer (e.g. layer distance from display screen, distance between optical elements (pitch), absolute relative location of each pixel or subpixel to a corresponding optical element, properties of the optical elements (size, diffractive and/or refractive properties, etc.), or other such properties, and a selected vision correction parameter related to the user's reduced visual acuity. While light field display characteristics will generally remain static for a given implementation (i.e. a given shaping layer will be used and set for each device irrespective of the user), image processing can, in some embodiments, be dynamically adjusted as a function of the user's visual acuity so to actively adjust a distance of the virtual image plane induced upon rendering the corrected image pixel data via the static optical layer, for example, or otherwise actively adjust image processing parameters as may be considered, for example, when implementing a viewer-adaptive pre-filtering algorithm or like approach (e.g. compressive light field optimization), so to at least in part govern an image perceived by the user's eye(s) given pixel-specific light visible thereby through the layer.

20 [0030] Accordingly, a given device may be adapted to compensate for different visual acuity levels and thus accommodate different users and/or uses. For instance, a particular device may be configured to implement and/or render an interactive graphical user interface (GUI) that incorporates a dynamic vision correction scaling function that dynamically adjusts one or more designated vision correction parameter(s) in real-time in response to a designated user interaction therewith via the GUI. For example, a dynamic vision correction scaling function may comprise a graphically rendered scaling function controlled by a (continuous or discrete) user slide motion or like operation, whereby the GUI can be configured to capture and translate a user's given slide motion operation to a corresponding adjustment to the designated vision correction parameter(s) scalable with a degree of the user's given slide motion operation. These and other examples are

described in Applicant's co-pending U.S. Patent Application Serial No. 15/246,255, the entire contents of which are hereby incorporated herein by reference.

[0031] With reference to Figure 1, and in accordance with one embodiment, a digital display device, generally referred to using the numeral 100, will now be described. In this example, the device 100 is generally depicted as a smartphone or the like, though other devices encompassing a graphical display may equally be considered, such as tablets, e-readers, watches, televisions, GPS devices, laptops, desktop computer monitors, televisions, smart televisions, handheld video game consoles and controllers, vehicular dashboard and/or entertainment displays, and the like.

[0032] In the illustrated embodiment, the device 100 comprises a processing unit 110, a digital display 120, and internal memory 130. Display 120 can be an LCD screen, a monitor, a plasma display panel, an LED or OLED screen, or any other type of digital display defined by a set of pixels for rendering a pixelated image or other like media or information. Internal memory 130 can be any form of electronic storage, including a disk drive, optical drive, read-only memory, random-access memory, or flash memory, to name a few examples. For illustrative purposes, memory 130 has stored in it vision correction application 140, though various methods and techniques may be implemented to provide computer-readable code and instructions for execution by the processing unit in order to process pixel data for an image to be rendered in producing corrected pixel data amenable to producing a corrected image accommodating the user's reduced visual acuity (e.g. stored and executable image correction application, tool, utility or engine, etc.). Other components of the electronic device 100 may optionally include, but are not limited to, one or more rear and/or front-facing camera(s) 150, an accelerometer 160 and/or other device positioning/orientation devices capable of determining the tilt and/or orientation of electronic device 100, and the like.

[0033] With reference to Figures 2A and 2B, the electronic device 100, such as that illustrated in Figure 1, is further shown to include a light field shaping layer 200 overlaid atop a display 120 thereof and spaced therefrom via a transparent spacer 310 or other

such means as may be readily apparent to the skilled artisan. An optional transparent screen protector is also included atop the layer 200.

[0034] For the sake of illustration, the following embodiments will be described within the context of a light field shaping layer defined, at least in part, by a lenslet array comprising an array of microlenses (also interchangeably referred to herein as lenslets) that are each disposed at a distance from a corresponding subset of image rendering pixels in an underlying digital display. It will be appreciated that while a light field shaping layer may be manufactured and disposed as a digital screen overlay, other integrated concepts may also be considered, for example, where light field shaping elements are integrally formed or manufactured within a digital screen's integral components such as a textured or masked glass plate, beam-shaping light sources or like component. Accordingly, each lenslet will predictively shape light emanating from these pixel subsets to at least partially govern light rays being projected toward the user by the display device. As noted above, other light field shaping layers may also be considered herein without departing from the general scope and nature of the present disclosure, whereby light field shaping will be understood by the person of ordinary skill in the art to reference measures by which light, that would otherwise emanate indiscriminately (i.e. isotropic ally) from each pixel group, is deliberately controlled to define predictable light rays that can be traced between the user and the device's pixels through the shaping layer.

[0035] For greater clarity, a light field is generally defined as a vector function that describes the amount of light flowing in every direction through every point in space. In other words, anything that produces or reflects light has an associated light field. The embodiments described herein produce light fields from an object that are not "natural" vector functions one would expect to observe from that object. This gives it the ability to emulate the "natural" light fields of objects that do not physically exist, such as a virtual display located far behind the light field display, which will be referred to now as the 'virtual image'.

[0036] To apply this technology to vision correction, consider first the normal ability of the lens in an eye, as schematically illustrated in Figure 3A, where, for normal vision,

the image is to the right of the eye (C) and is projected through the lens (B) to the retina at the back of the eye (A). As comparatively shown in Figure 3B, the poor lens shape (F) in presbyopia causes the image to be focused past the retina (D) forming a blurry image on the retina (E). The dotted lines outline the path of a beam of light (G). Naturally, other  
5 visual aberrations can and will have different impacts on image formation on the retina. To address these aberrations, a light field display (K), in accordance with some embodiments, projects the correct sharp image (H) to the back of the retina for an eye with a lens which otherwise could not adjust sufficiently to produce a sharp image. The other two light field pixels (I) and (J) are drawn lightly, but would otherwise fill out the  
10 rest of the image.

[0037] As will be appreciated by the skilled artisan, a light field as seen in Figure 3C cannot be produced with a 'normal' two-dimensional display because the pixels' light field emits light isotropically. Instead it is necessary to exercise tight control on the angle and origin of the light emitted, for example, using a microlens array or other light field  
15 shaping layer such as a parallax barrier, or combination thereof.

[0038] Following with the example of a microlens array, Figure 4 schematically illustrates a single light field pixel defined by a convex microlens (B) disposed at its focus from a corresponding subset pixels in an LCD display (C) to produce a substantially collimated beam of light emitted by these pixels, whereby the direction of  
20 the beam is controlled by the location of the pixel(s) relative to the microlens. The single light field pixel produces a beam similar to that shown in Figure 3C where the outside rays are lighter and the majority inside rays are darker. The LCD display (C) emits light which hits the microlens (B) and it results in a beam of substantially collimated light (A).

[0039] Accordingly, upon predictably aligning a particular microlens array with a  
25 pixel array, a designated "circle" of pixels will correspond with each microlens and be responsible for delivering light to the pupil through that lens. Figure 5 schematically illustrates an example of a light field display assembly in which a microlens array (A) sits above an LCD display on a cellphone (C) to have pixels (B) emit light through the microlens array. A ray-tracing algorithm can thus be used to produce a pattern to be

displayed on the pixel array below the microlens in order to create the desired virtual image that will effectively correct for the viewer's reduced visual acuity. Figure 6 provides an example of such a pattern for the letter "Z".

5 [0040] As will be detailed further below, the separation between the microlens array and the pixel array as well as the pitch of the lenses can be selected as a function of various operating characteristics, such as the normal or average operating distance of the display.

10 [0041] Further, as producing a light field with angular resolution sufficient for accommodation correction over the full viewing 'zone' of a display would generally require an astronomical pixel density, instead, a correct light field can be produced, in some embodiments, only at the location of the user's pupils. To do so, the light field display can be paired with pupil tracking technology to track a location of the user's eyes/pupils relative to the display. The display can then compensate for the user's eye location and produce the correct virtual image, for example, in real time.

15 [0042] In some embodiments, the light field display can render dynamic images at over 30 frames per second on the hardware in a smartphone.

[0043] In some embodiments, the light field display can display a virtual image at optical infinity, meaning that any level of accommodation-based presbyopia (e.g. first order) can be corrected for.

20 [0044] In some further embodiments, the light field display can both push the image back and forward, thus allowing for selective image corrections for both hyperopia (far-sightedness) and myopia (nearsightedness).

25 [0045] In order to demonstrate a working light field solution, and in accordance with one embodiment, the following test was set up. A camera was equipped with a simple lens, to simulate the lens in a human eye and the aperture was set to simulate a normal pupil diameter. The lens was focused to 50cm away and a phone was mounted 25cm away. This would approximate a user whose minimal seeing distance is 50 cm and is attempting to use a phone at 25cm.

[0046] With reading glasses, +2.0 diopters would be necessary for the vision correction. A scaled Snellen chart was displayed on the cellphone and a picture was taken, as shown in Figure 7A. Using the same cellphone, but with a light field assembly in front that uses that cellphone's pixel array, a virtual image compensating for the lens focus is displayed. A picture was again taken, as shown in Figure 7B, showing a clear improvement.

[0047] Figures 11A and 11B provide another example of results achieved using an exemplary embodiment, in which a colour image was displayed on the LCD display of a Sony™ Xperia™ XZ Premium phone (reported screen resolution of 3840x2160 pixels with 16:9 ratio and approximately 807 pixel-per-inch (ppi) density) without image correction (Figure 11A) and with image correction through a square fused silica microlens array set at a 2 degree angle relative to the screen's square pixel array and defined by microlenses having a 7.0mm focus and 200µm pitch. In this example, the camera lens was again focused at 50cm with the phone positioned 30cm away. Another microlens array was used to produce similar results, and consisted of microlenses having a 10.0mm focus and 150µm pitch.

[0048] Figures 12A and 12B provide yet another example of results achieved using an exemplary embodiment, in which a colour image was displayed on the LCD display of a the Sony™ Xperia™ XZ Premium phone without image correction (Figure 12A) and with image correction through a square fused silica microlens array set at a 2 degree angle relative to the screen's square pixel array and defined by microlenses having a 10.0mm focus and 150µm pitch. In this example, the camera lens was focused at 66cm with the phone positioned 40cm away.

[0049] Accordingly, a display device as described above and further exemplified below, can be configured to render a corrected image via the light field shaping layer that accommodates for the user's visual acuity. By adjusting the image correction in accordance with the user's actual predefined, set or selected visual acuity level, different users and visual acuity may be accommodated using a same device configuration. That is, in one example, by adjusting corrective image pixel data to dynamically adjust a virtual

image distance below/above the display as rendered via the light field shaping layer, different visual acuity levels may be accommodated.

[0050] As will be appreciated by the skilled artisan, different image processing techniques may be considered, such as those introduced above and taught by Pamplona and/or Huang, for example, which may also influence other light field parameters to achieve appropriate image correction, virtual image resolution, brightness and the like.

[0051] With reference to Figure 8, and in accordance with one embodiment, an microlens array configuration will now be described, in accordance with another embodiment, to provide light field shaping elements in a corrective light field implementation. In this embodiment, the microlens array 800 is defined by a hexagonal array of microlenses 802 disposed so to overlay a corresponding square pixel array 804. In doing so, while each microlens 802 can be aligned with a designated subset of pixels to produce light field pixels as described above, the hexagonal-to-square array mismatch can alleviate certain periodic optical artifacts that may otherwise be manifested given the periodic nature of the optical elements and principles being relied upon to produce the desired optical image corrections. Conversely, a square microlens array may be favoured when operating a digital display comprising a hexagonal pixel array.

[0052] In some embodiments, as illustrated in Figure 8, the microlens array 800 may further or alternatively overlaid at an angle 806 relative to the underlying pixel array, which can further or alternatively alleviate period optical artifacts.

[0053] In yet some further or alternative embodiments, a pitch ratio between the microlens array and pixel array may be deliberately selected to further or alternatively alleviate periodic optical artifacts. For example, a perfectly matched pitch ratio (i.e. an exact integer number of display pixels per microlens) is most likely to induce periodic optical artifacts, whereas a pitch ratio mismatch can help reduce such occurrences. Accordingly, in some embodiments, the pitch ratio will be selected to define an irrational number, or at least, a irregular ratio, so to minimize periodic optical artifacts. For instance, a structural periodicity can be defined so to reduce the number of periodic

occurrences within the dimensions of the display screen at hand, e.g. ideally selected so to define a structural period that is greater than the size of the display screen being used.

5 [0054] In some embodiments, the microlens array may further or alternatively be defined by a designated irregular or pseudo-random distribution of microlenses so to further or alternatively mitigate periodic optical artifacts. For example, the microlens array distribution may be specifically set and stored in memory so to precisely identify display pixels aligning and thus corresponding with each irregularly or pseudo-randomly distributed microlens to predictively produce a desired light field output, while benefiting from the aperiodic or mismatched array alignments.

10 [0055] While this example is provided within the context of a microlens array, similar structural design considerations may be applied with in the context of a parallax barrier, diffractive barrier or combination thereof.

[0056] With reference to Figures 9A and 9B, a (LCD) pixel array 900 is schematically illustrated to be composed of an array of display pixels 902 each comprising red (R) 904, green (G) 906, and blue (B) 908 subpixels. As with the examples provided above, to produce a light field display, a light field shaping layer, such as a microlens array, is to be aligned to overlay these pixels such that a corresponding subset of these pixels can be used to predictably produce respective light field rays to be computed and adjusted in providing a corrected image. To do so, the light field ray ultimately produced by each pixel can be calculated knowing a location of the pixel (e.g. x,y coordinate on the screen), a location of a corresponding light field element through which light emanating from the pixel will travel to reach the user's eye, and optical characteristics of that light field element. Based on those calculations, the image correction algorithm will compute which pixels to light, and output pixel lighting parameters (e.g. R, G and B values) accordingly. As noted above, to reduce computation load, only those pixels producing rays that will interface with the user's eyes or pupils may be considered, for instance, using a complementary eye tracking engine and hardware.

**[0057]** In the example shown in Figure 9A, an angular edge 909 is being rendered that crosses the surfaces of affected pixels 910, 912, 914 and 916. Using standard pixel rendering, each affected pixel is either turned on or off, which to some extent dictates a relative smoothness of the angular edge 909.

5 **[0058]** In the example shown in Figure 9B, subpixel rendering is instead favoured, whereby the red subpixel in pixel 910, the red and green subpixels in pixel 914 and the red subpixel in pixel 916 are deliberately set to zero (0) to produce a smoother representation of the angular edge 909 at the expense of colour trueness along that edge, which will not be perceptible to the human eye given the scale at which these  
10 modifications are being applied. Accordingly, image correction can benefit from greater subpixel control while delivering sharper images.

**[0059]** In order to implement subpixel rendering in the context of light field image correction, in some embodiments, ray tracing calculations must be executed in respect of each subpixel, as opposed to in respect of each pixel as a whole, based on a location (x,y  
15 coordinates on the screen) of each subpixel. Beyond providing for greater rendering accuracy and sharpness, subpixel control and ray tracing computations may accommodate different subpixel configurations, for example, where subpixel mixing or overlap is invoked to increase a perceived resolution of a high resolution screen and/or where non-uniform subpixel arrangements are provided or relied upon in different digital display  
20 technologies.

**[0060]** In some embodiments, however, in order to avoid or reduce a computation load increase imparted by the distinct consideration of each subpixel, some computation efficiencies may be leveraged by taking into account the regular subpixel distribution from pixel to pixel, or in the context of subpixel sharing and/or overlap, for certain pixel  
25 groups, lines, columns, etc. With reference to Figure 10, a given pixel 1000, much as those illustrated in Figures 9A and 9B, is shown to include horizontally distributed red (R) 1004, green (G) 1006, and blue (B) 1008 subpixels. Using standard pixel rendering and ray tracing, light emanating from this pixel can more or less be considered to emanate from a point located at the geometric center 1010 of the pixel 1000. To

implement subpixel rendering, ray tracing could otherwise be calculated in triplicate by specifically addressing the geometric location of each subpixel. Knowing the distribution of subpixels within each pixel, however, calculations can be simplified by maintaining pixel-centered computations and applying appropriate offsets given known geometric subpixel offsets (i.e. negative horizontal offset 1014 for the red subpixel 1004, a zero offset for the green 1006 and a positive horizontal offset 1018 for the blue subpixel 1008). In doing so, light field image correction can still benefit from subpixel processing without significantly increased computation load.

[0061] While this example contemplates a linear (horizontal) subpixel distribution, other 2D distributions may also be considered without departing from the general scope and nature of the present disclosure. For example, for a given digital display screen and pixel and subpixel distribution, different subpixel mappings can be determined to define respective pixel subcoordinate systems that, when applied to standard pixel-centric ray tracing and image correction algorithms, can allow for subpixel processing and increase image correction resolution and sharpness without undue processing load increases.

[0062] Likewise, while the above focuses on standard ray tracing light field correction methods, compressive light field methods may also be advantageously computed at a subpixel level, for example, by distinctly computing R, G, and B channels for light field optimizations based on subpixel locations and/or subpixel offsets.

[0063] While the present disclosure describes various exemplary embodiments, the disclosure is not so limited. To the contrary, the disclosure is intended to cover various modifications and equivalent arrangements included within the general scope of the present disclosure.

## CLAIMS

What is claimed is:

- 5 1. A digital display device to render an image for viewing by a viewer having reduced visual acuity, the device comprising:
  - a digital display medium comprising an array of pixels and operable to render a pixelated image accordingly, wherein each of said pixels comprises a combination of sub pixels geometrically disposed and associated therewith;
  - 10 a light field shaping layer defined by an array of light field shaping elements and disposed relative to said digital display so to align each of said light field shaping elements with a corresponding set of said pixels to shape a light field emanating therefrom and thereby at least partially govern a projection thereof from said display medium toward the user; and
  - 15 a hardware processor operable on pixel data for the image to be displayed to output corrected image pixel data to be rendered as a function of a designated characteristic of said light field shaping layer and a selected vision correction parameter related to the viewer's reduced visual acuity such that said processed image is rendered via said light field shaping layer to at least partially compensate for the user's reduced
  - 20 visual acuity;
    - wherein said hardware processor is operable to calculate light field components associated with each of said subpixels to output said corrected image pixel data such that at least some of said subpixels are independently controlled accordingly.
- 25 2. The digital display device of claim 1, wherein each of said subpixels is associated with a subpixel location on said digital display, and wherein said hardware processor is operable to calculate said light field components associated with each of said subpixels based on each said subpixel location.
- 30 3. The digital display device of claim 1, wherein each of said pixels is associated with a pixel location on said digital display, wherein each of said subpixels for a given

pixel is disposed at a designated subpixel offset relative to said pixel location of said given pixel, and wherein said hardware processor is operable to calculate said light field components associated with each of said subpixels for each said given pixel by offsetting light field calculations based on said pixel location in accordance with each said  
5 designated subpixel offset.

4. The digital display of any one of claims 1 to 3, wherein each of said subpixels is associated with one of distinct colour channels, and wherein said hardware processor is operable to distinctly compute light fields for each of said distinct colour channels in a  
10 compressive light field optimization process.

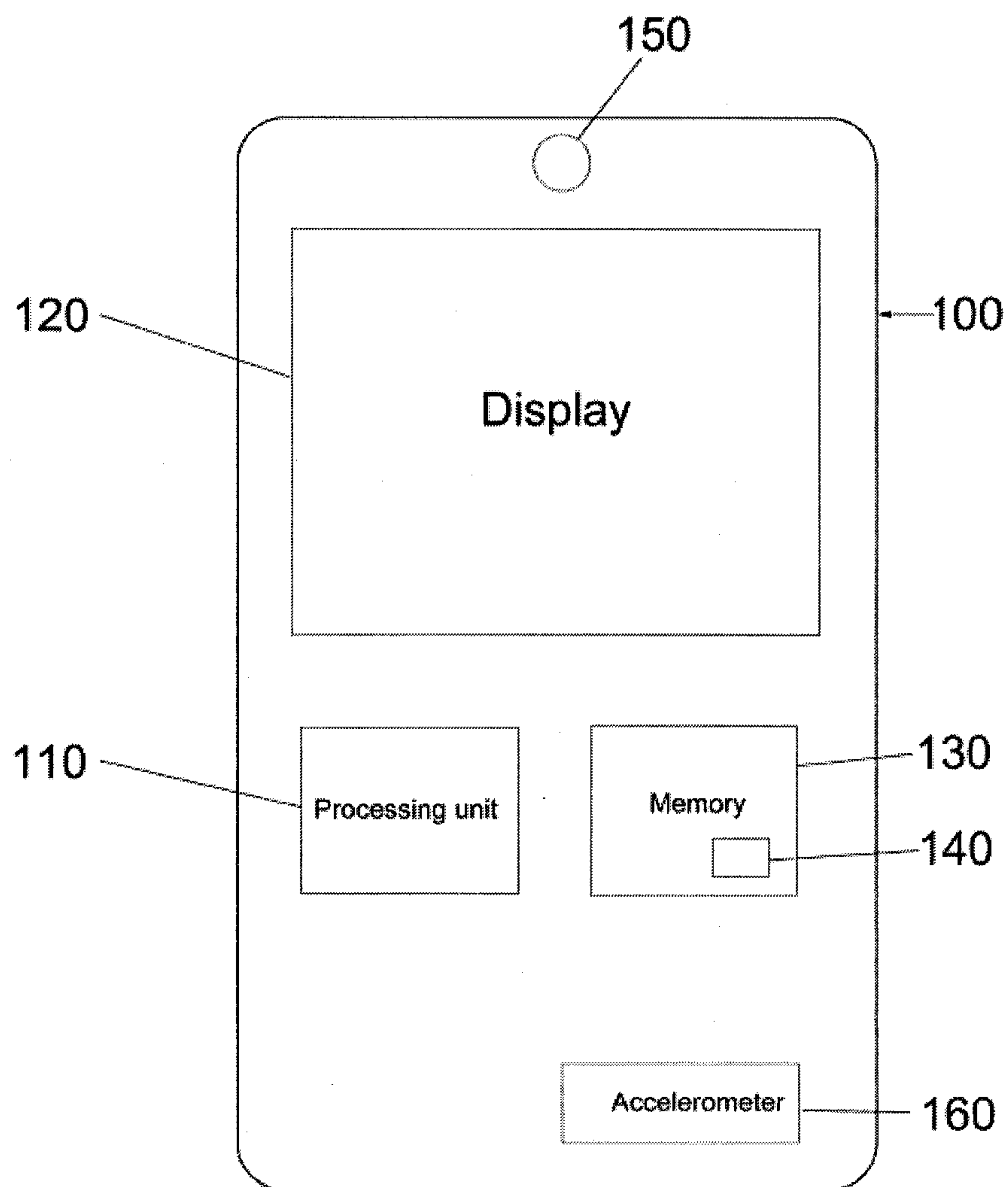
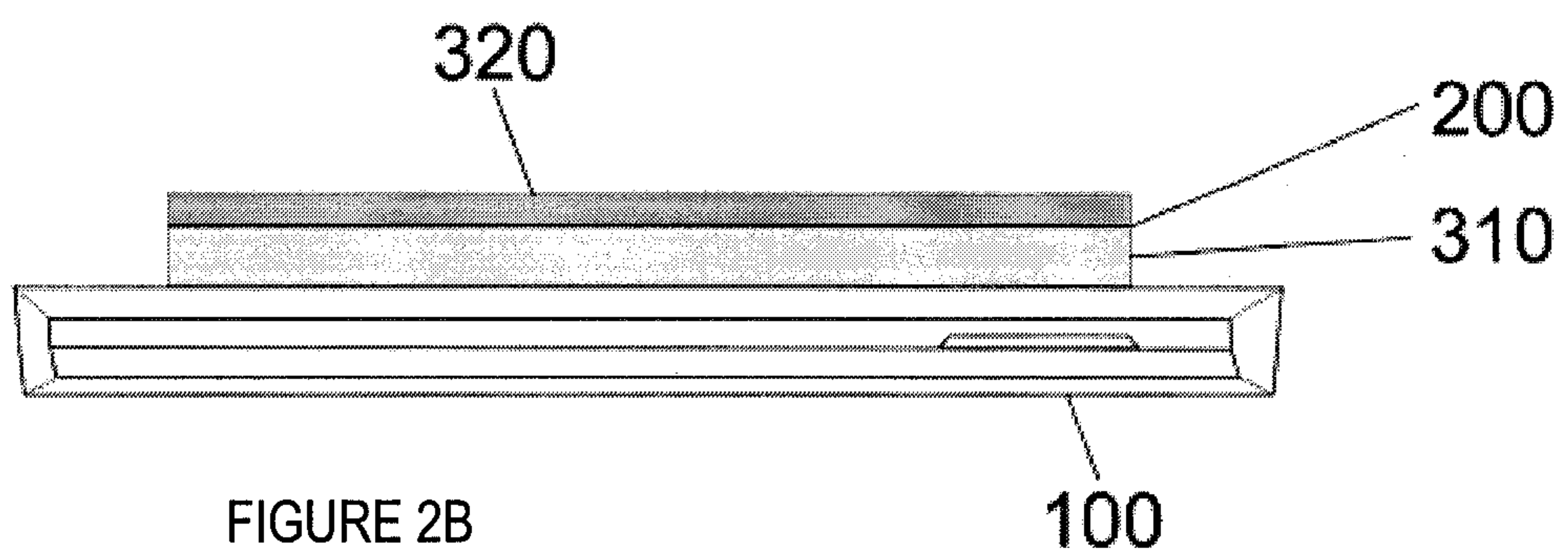
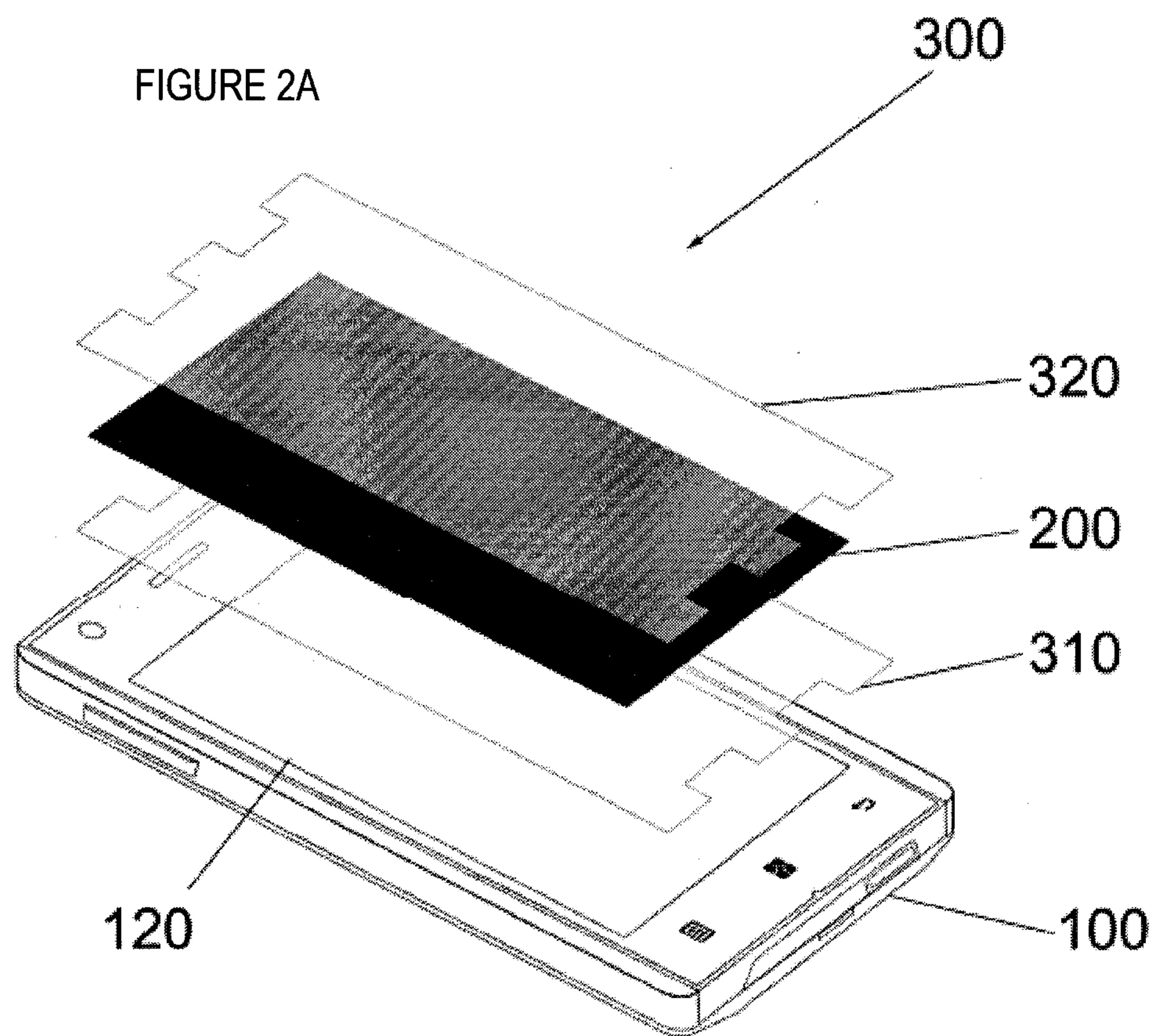


FIGURE 1



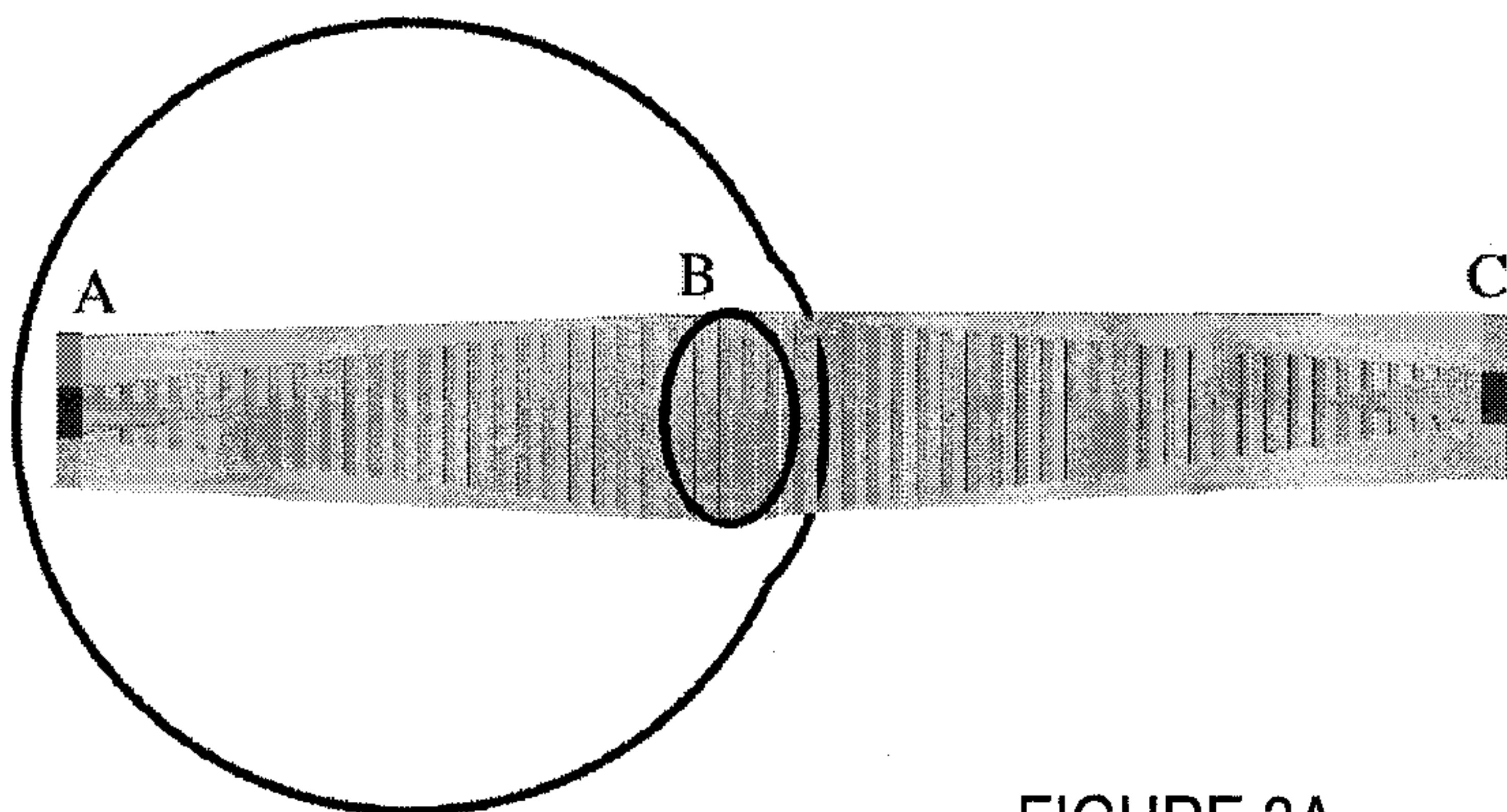


FIGURE 3A

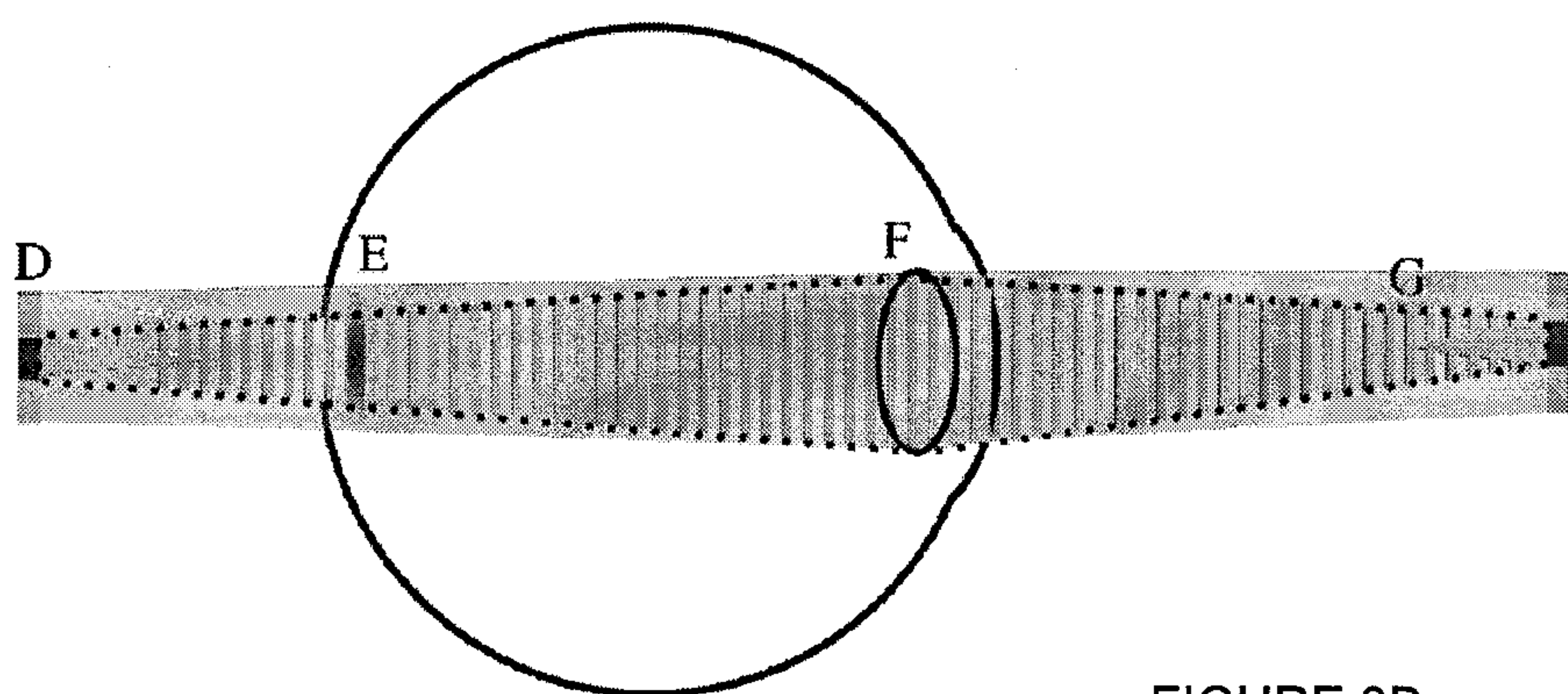


FIGURE 3B

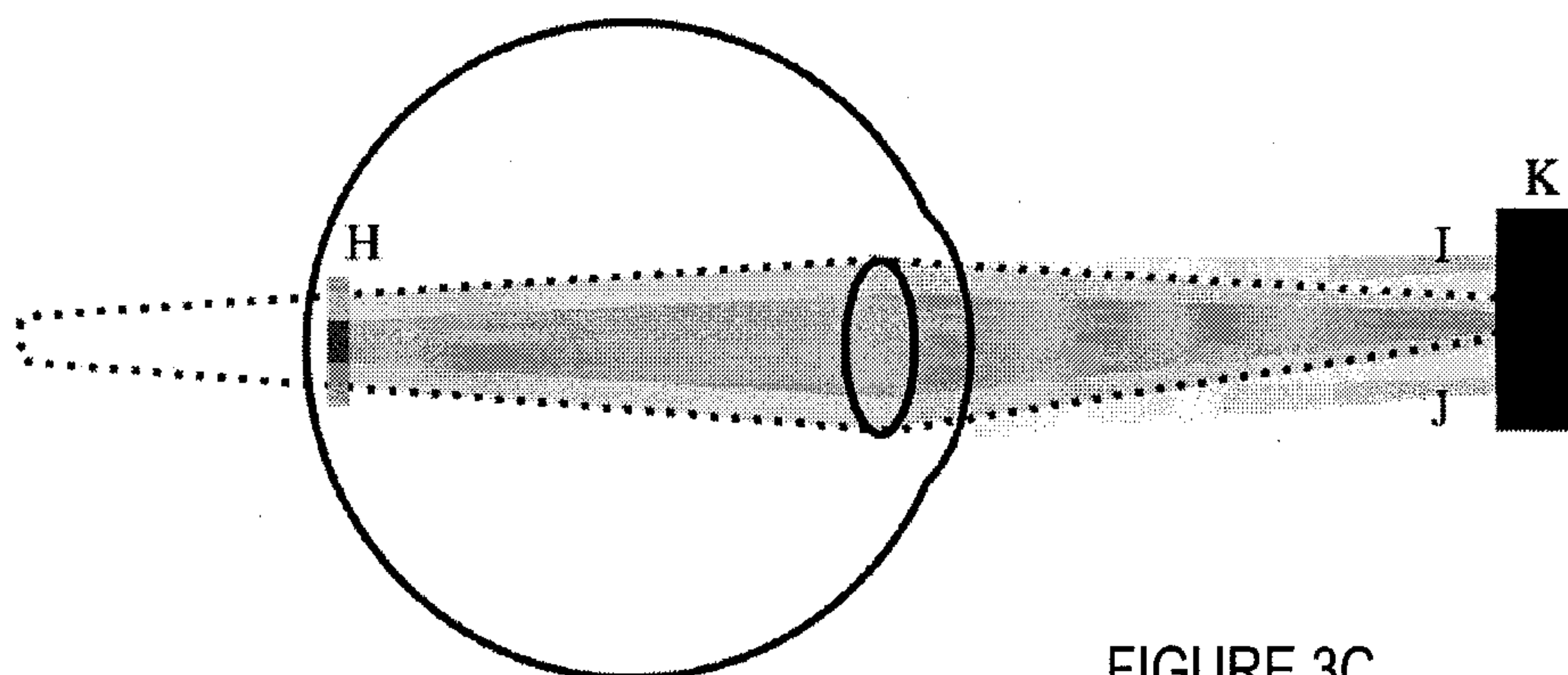


FIGURE 3C

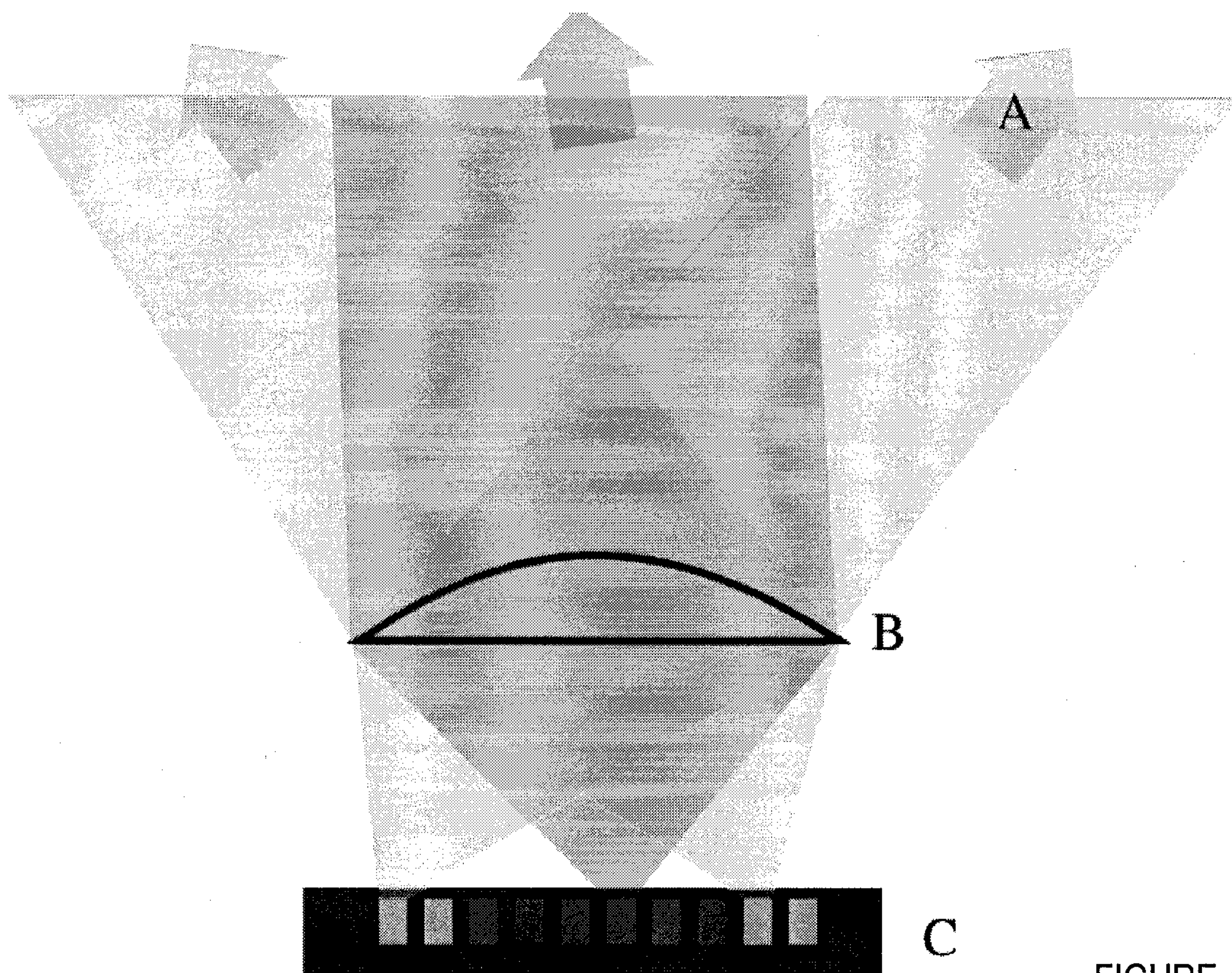


FIGURE 4

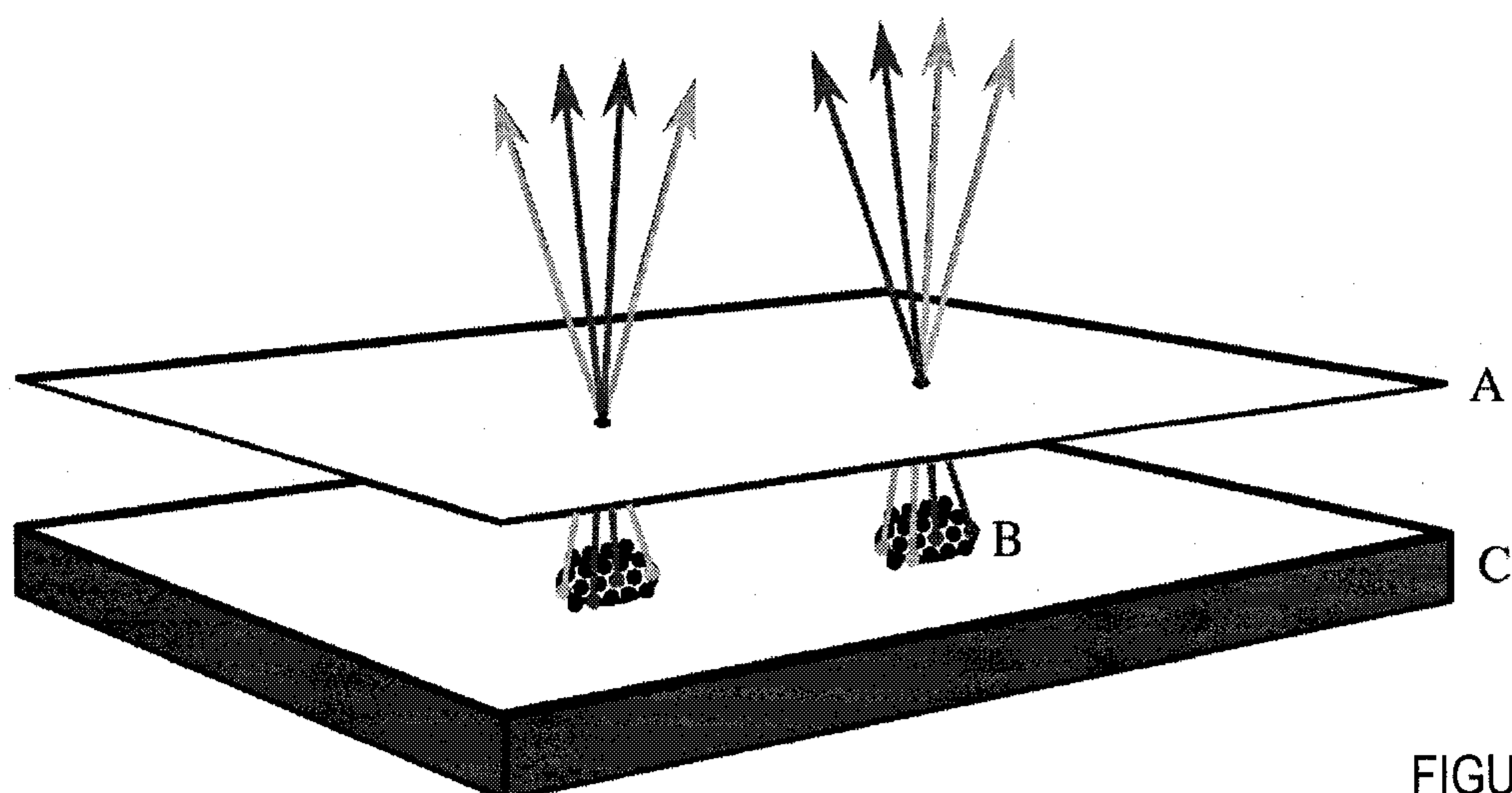


FIGURE 5

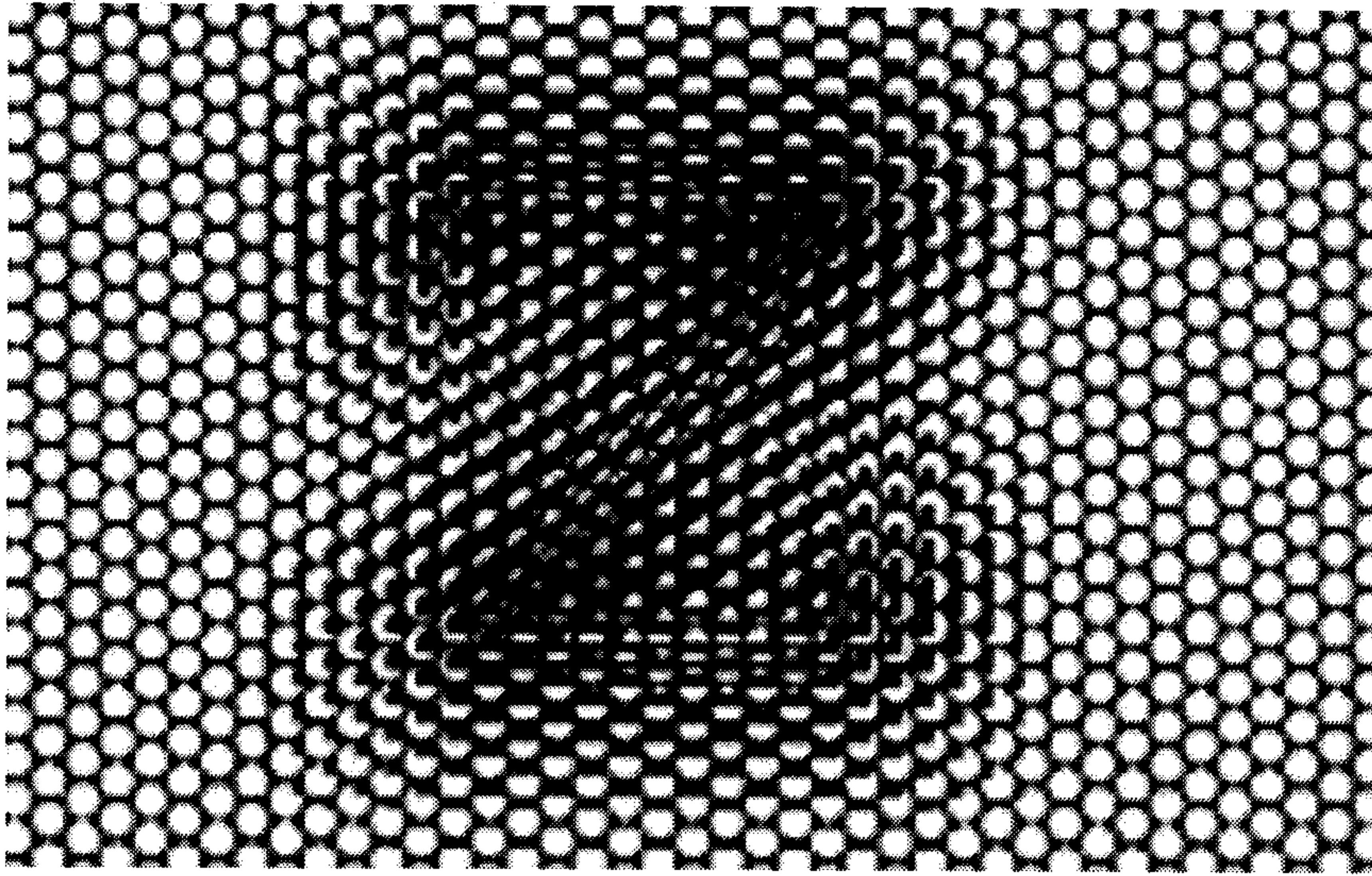


FIGURE 6

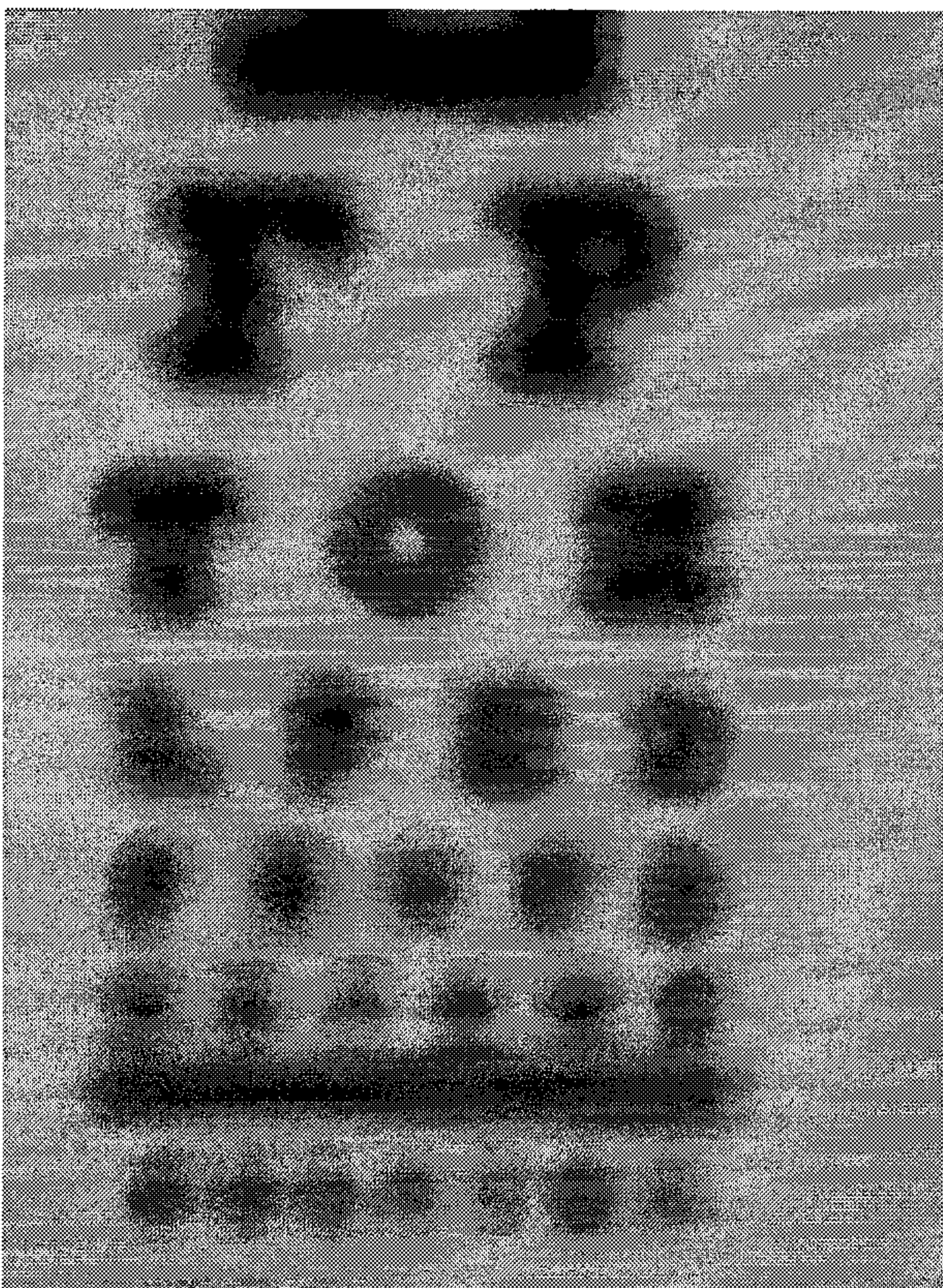


FIGURE 7A

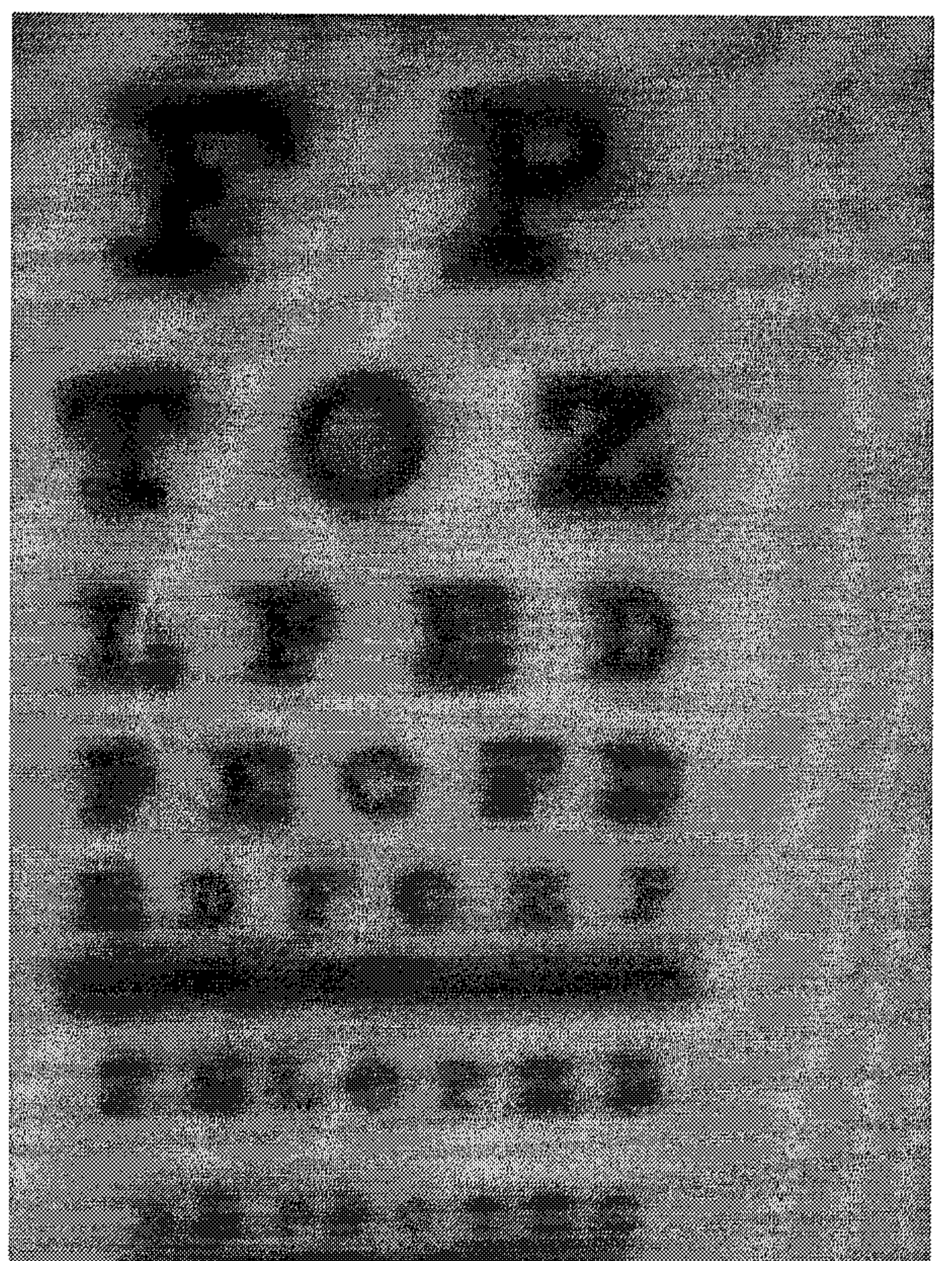


FIGURE 7B

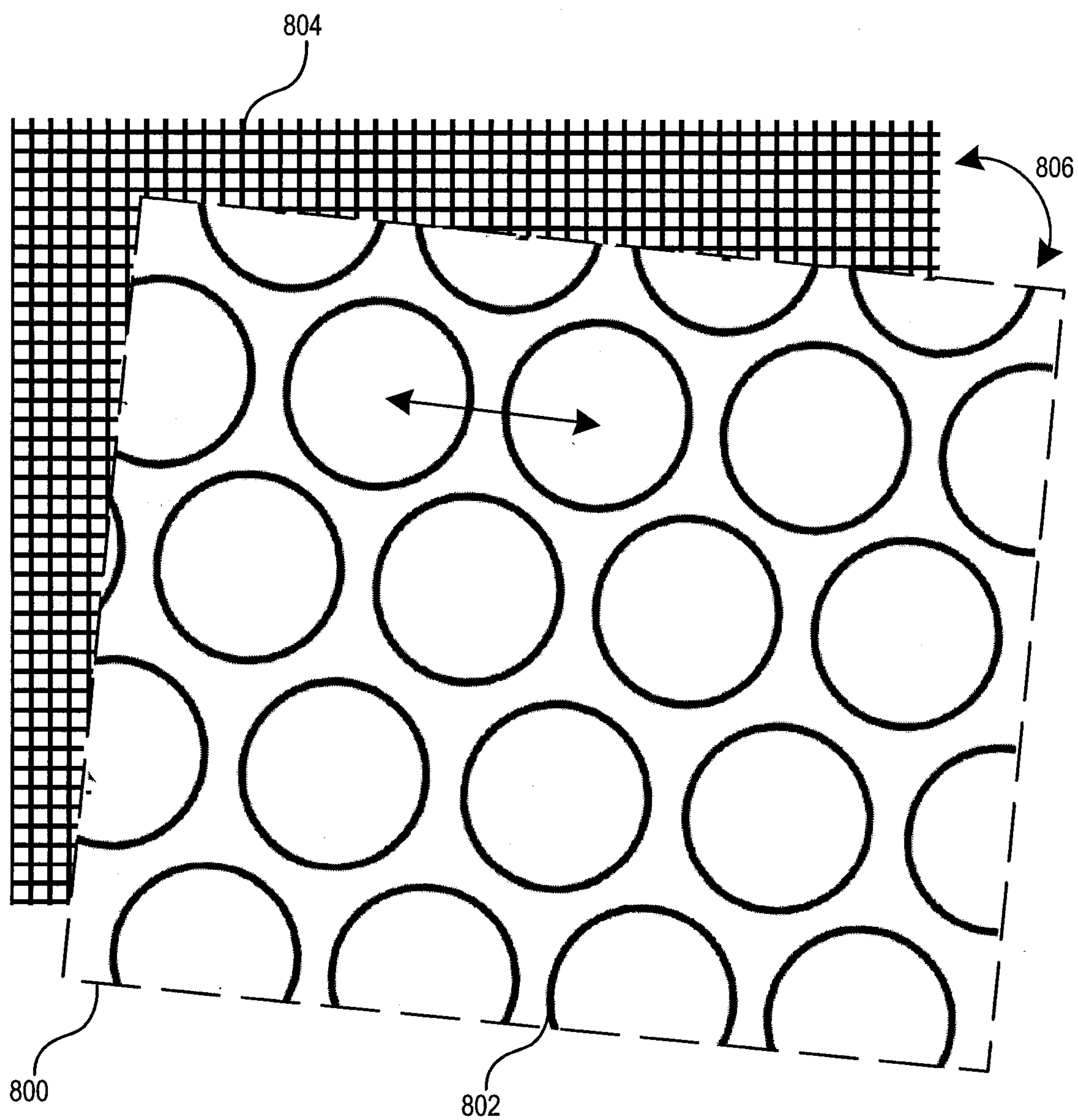


FIGURE 8

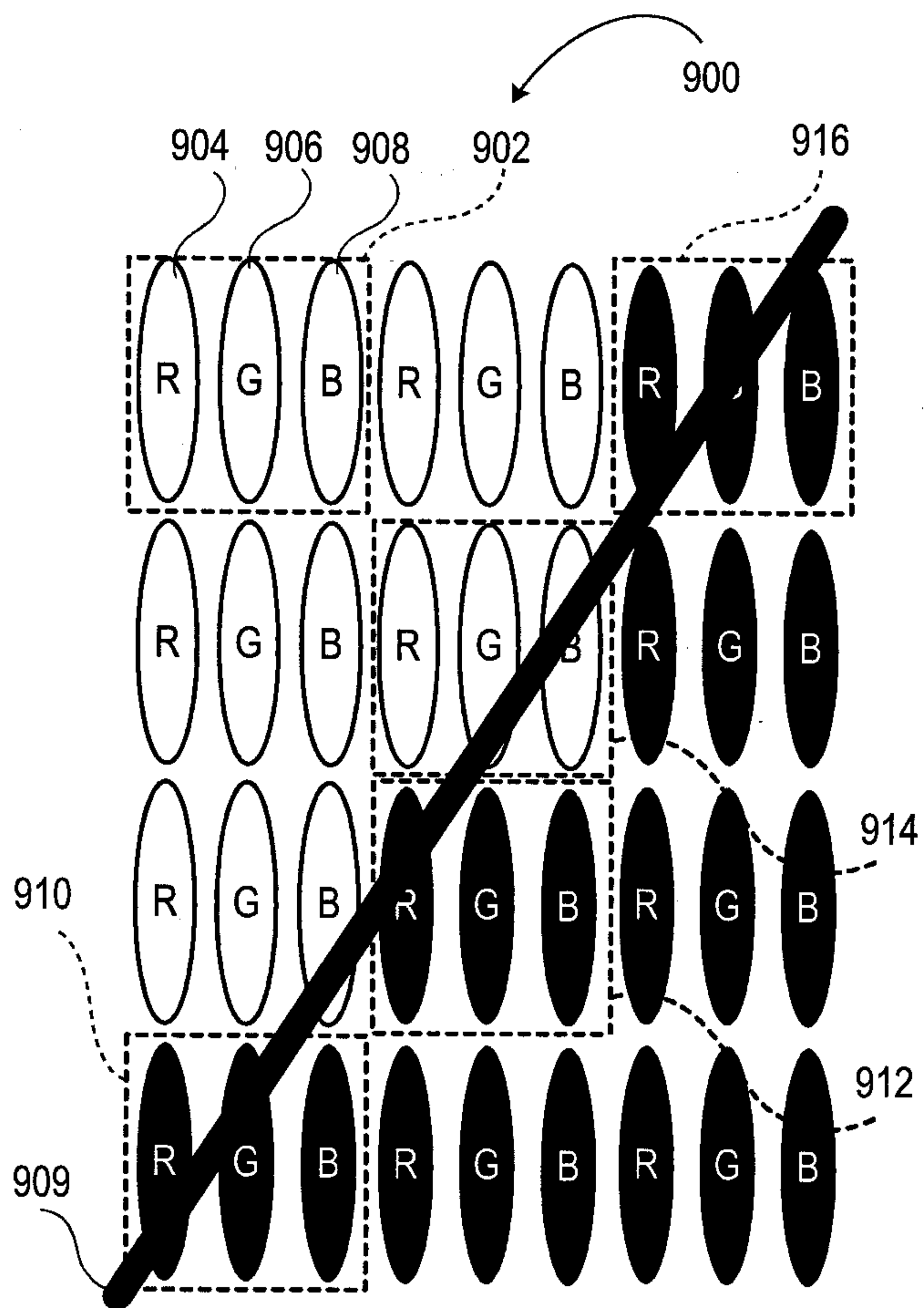


FIGURE 9A

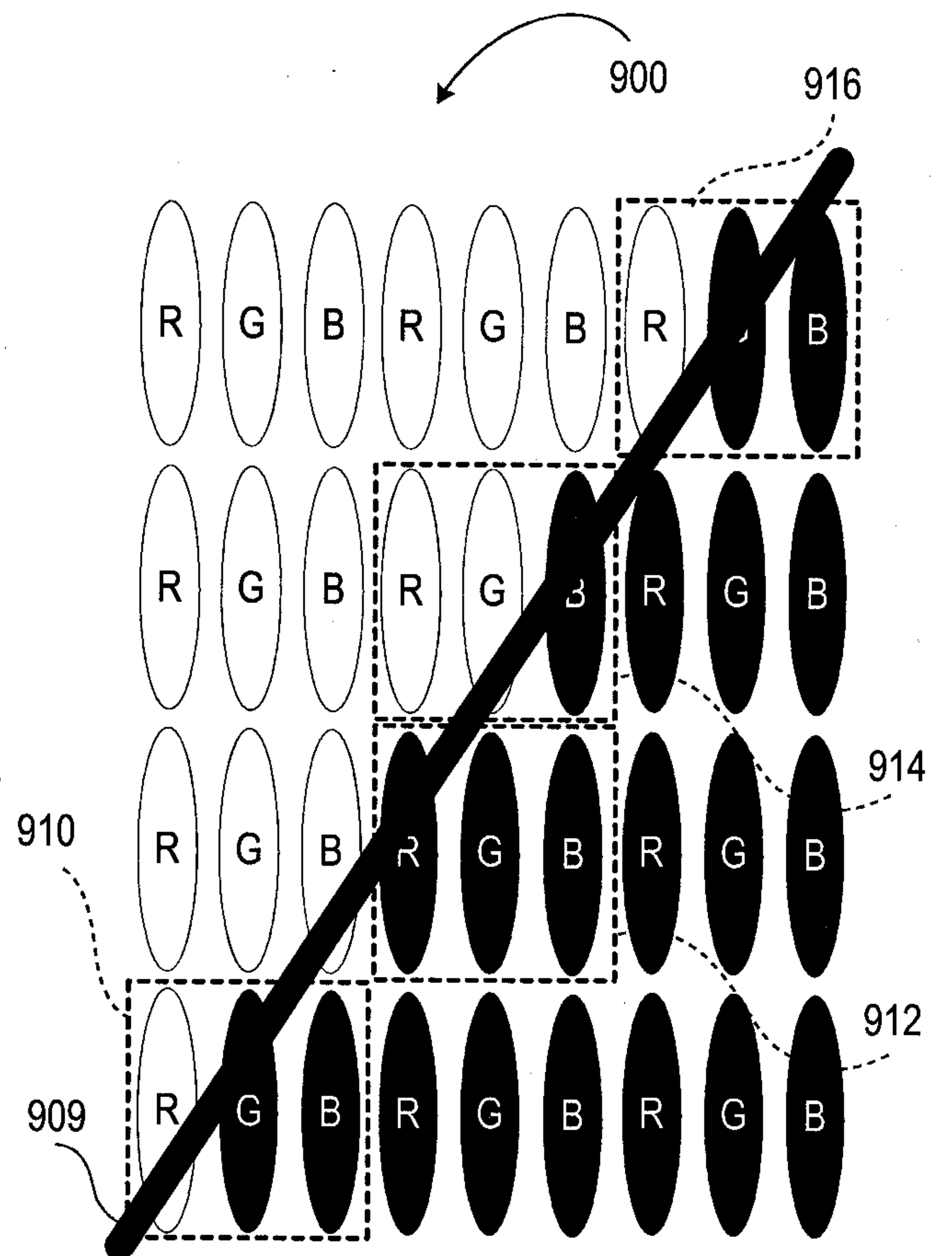


FIGURE 9B

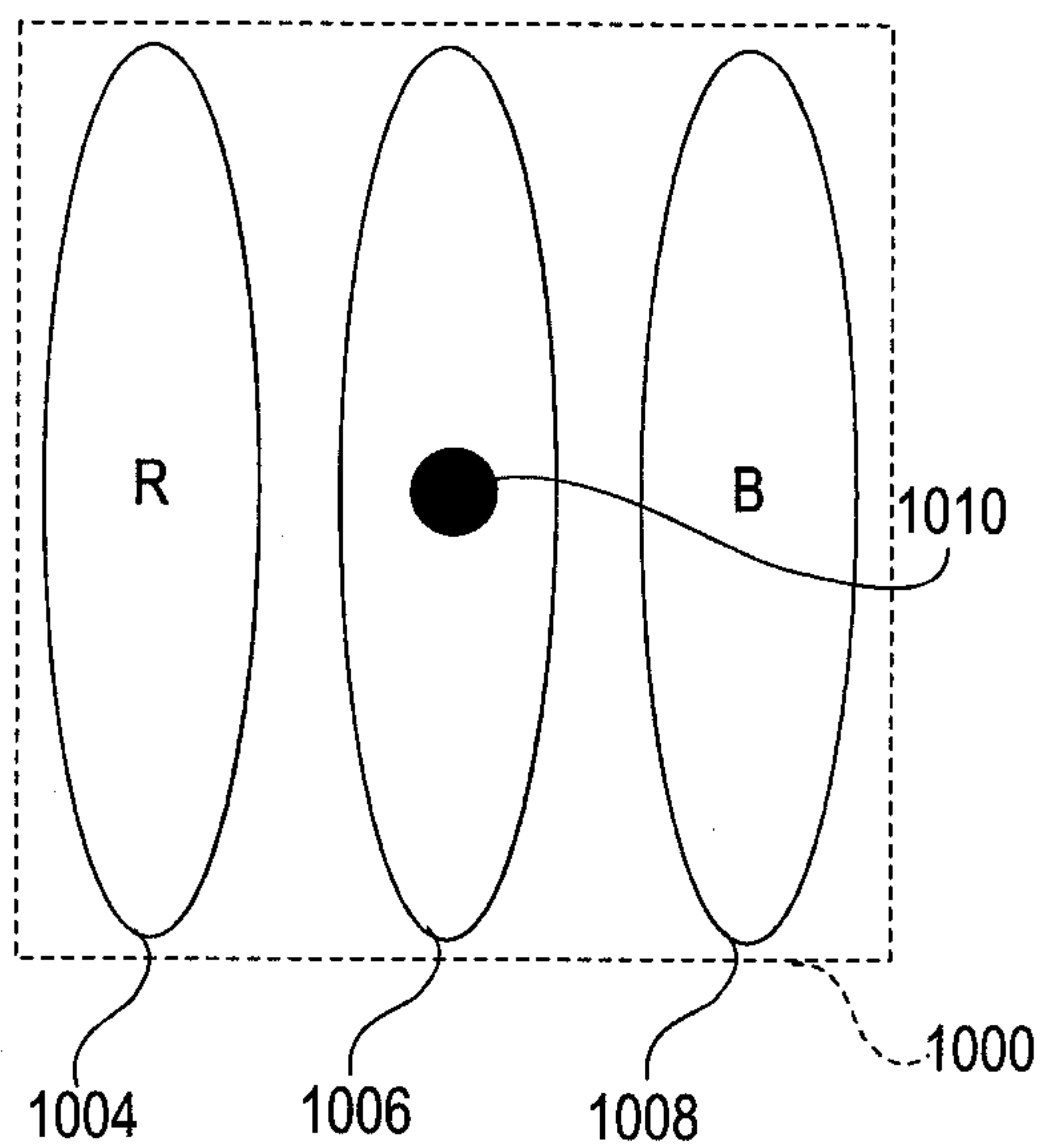
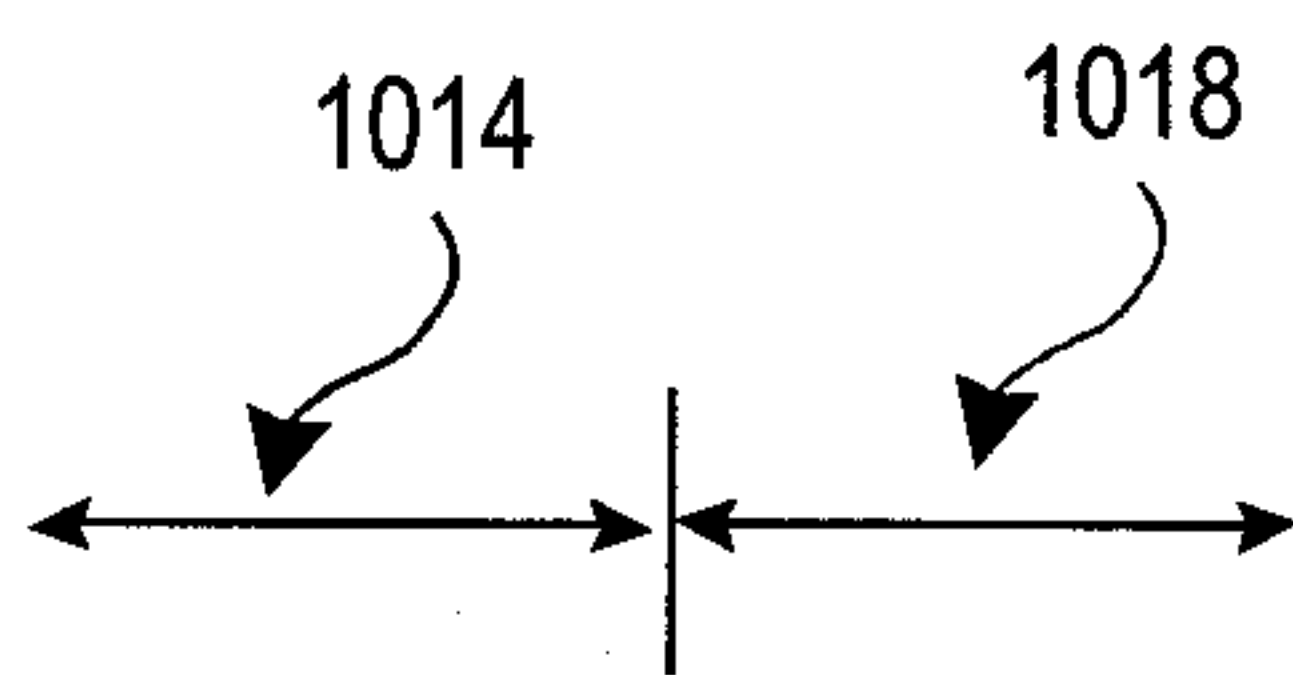


FIGURE 10



FIGURE 11B

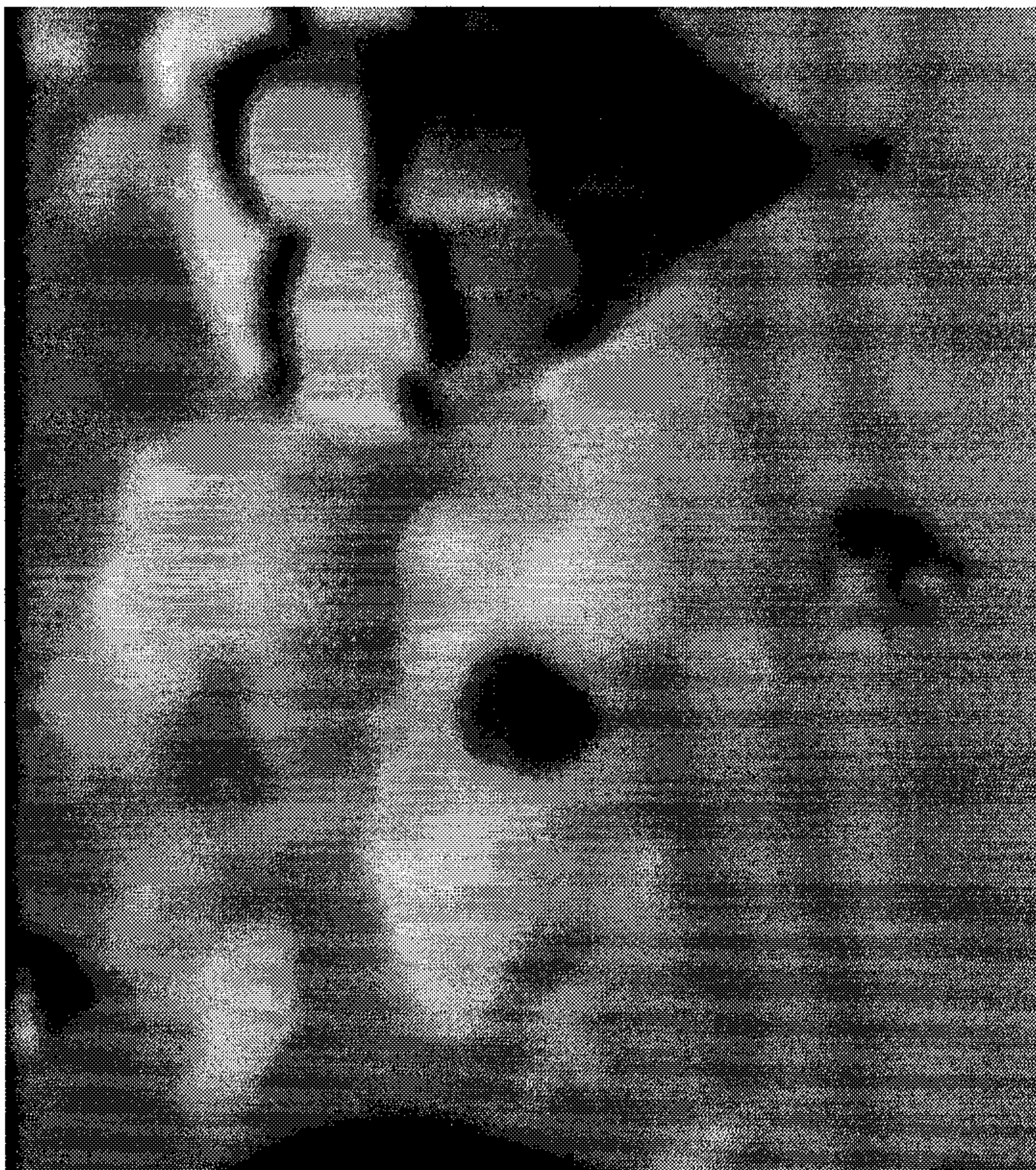


FIGURE 11A



FIGURE 12B



FIGURE 12A

