US 20200139153A1

(19) **United States**
(12) **Patent Application Publication**
Deisseroth et al.
(10) **Pub. No.: US 2020/0139153 A1**
(43) **Pub. Date: May 7, 2020**

(54) **IMPLANTABLE OPTICAL STIMULATORS**

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(21) Appl. No.: **16/541,845**

(22) Filed: **Aug. 15, 2019**

Related U.S. Application Data

(60) Continuation of application No. 13/850,428, filed on Mar. 26, 2013, now Pat. No. 10,426,970, which is a division of application No. 12/263,044, filed on Oct. 31, 2008, now Pat. No. 10,434,327.

(60) Provisional application No. 60/984,231, filed on Oct. 31, 2007.

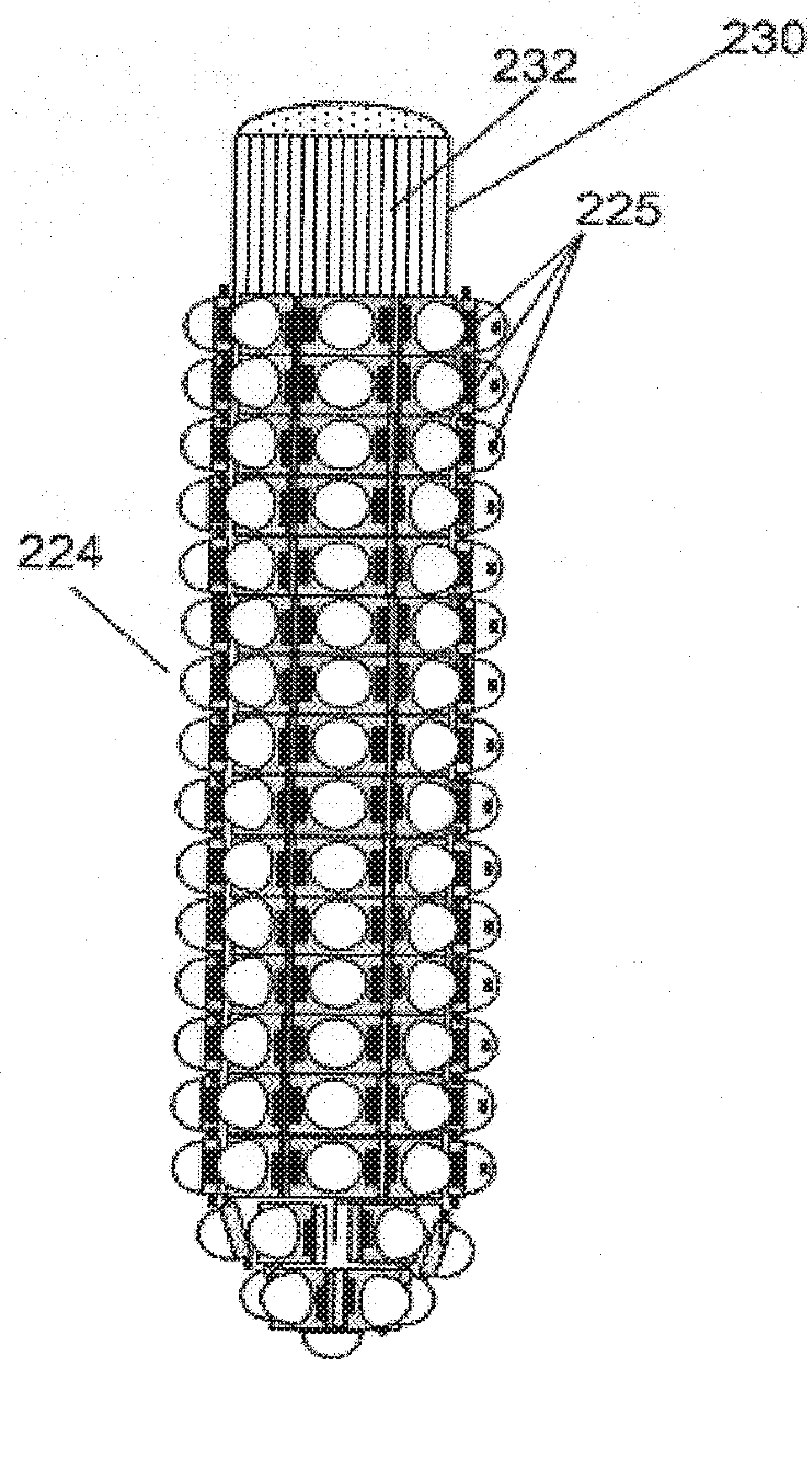
Publication Classification

(51) **Int. Cl.**
A61N 5/06 (2006.01)

(52) **U.S. Cl.**
CPC ***A61N 5/0622*** (2013.01); *A61N 2005/0645* (2013.01); *A61N 2005/063* (2013.01); ***A61N 5/0603*** (2013.01)

(57) **ABSTRACT**

Various systems and methods are implemented for in vivo use in a living animal. One such method involves stimulating target cells having light-responsive proteins and includes providing an elongated light-delivery structure in a narrow passageway in the animal, the elongated light-delivery structure having separately-activatable light sources located along the length of the elongated light-delivery structure. The method also includes activating less than all the light sources to deliver light to light-responsive proteins adjacent to the activated light sources along the length of the elongated light-delivery structure, thereby stimulating target cells in vivo.



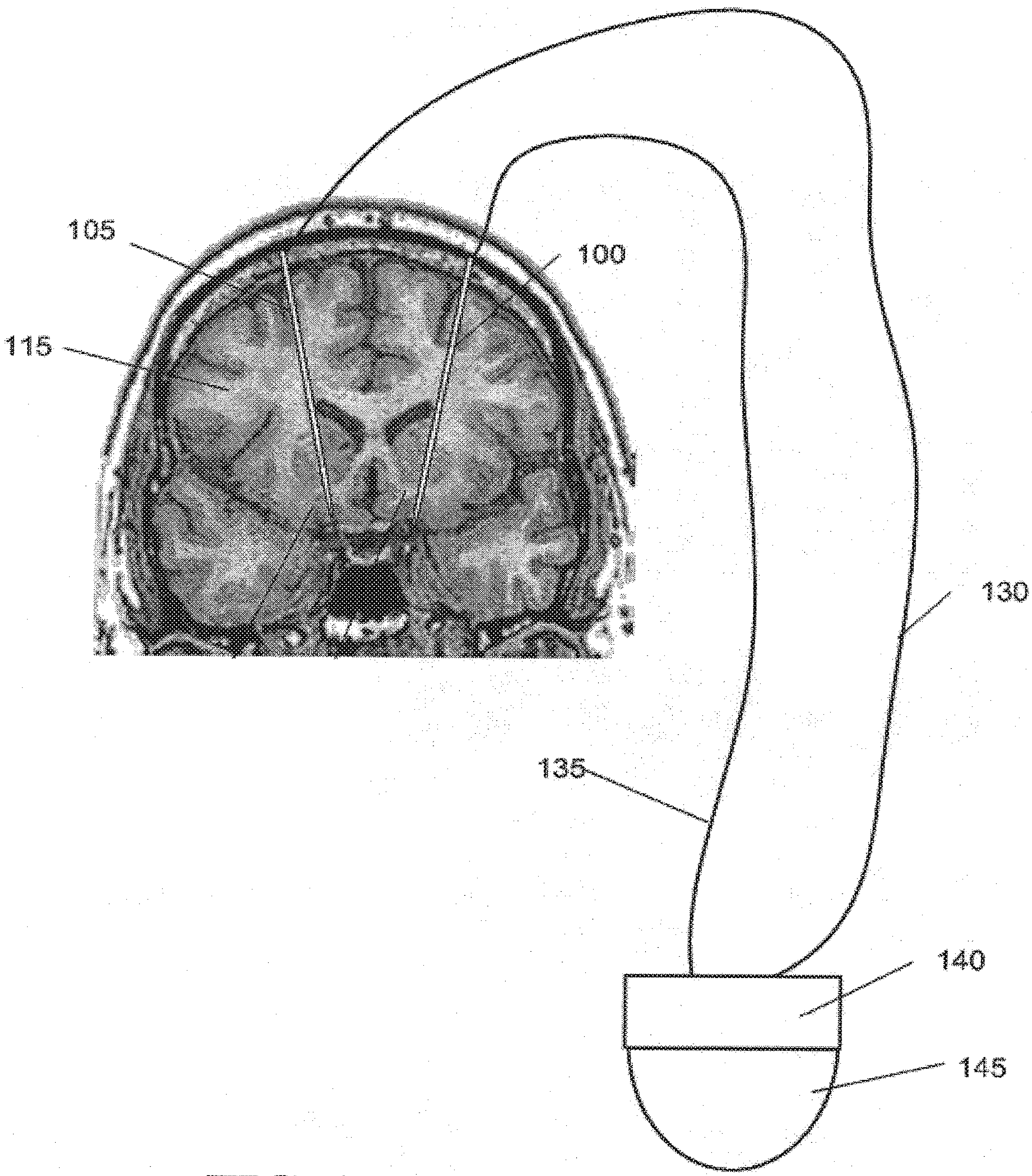


FIG. 1

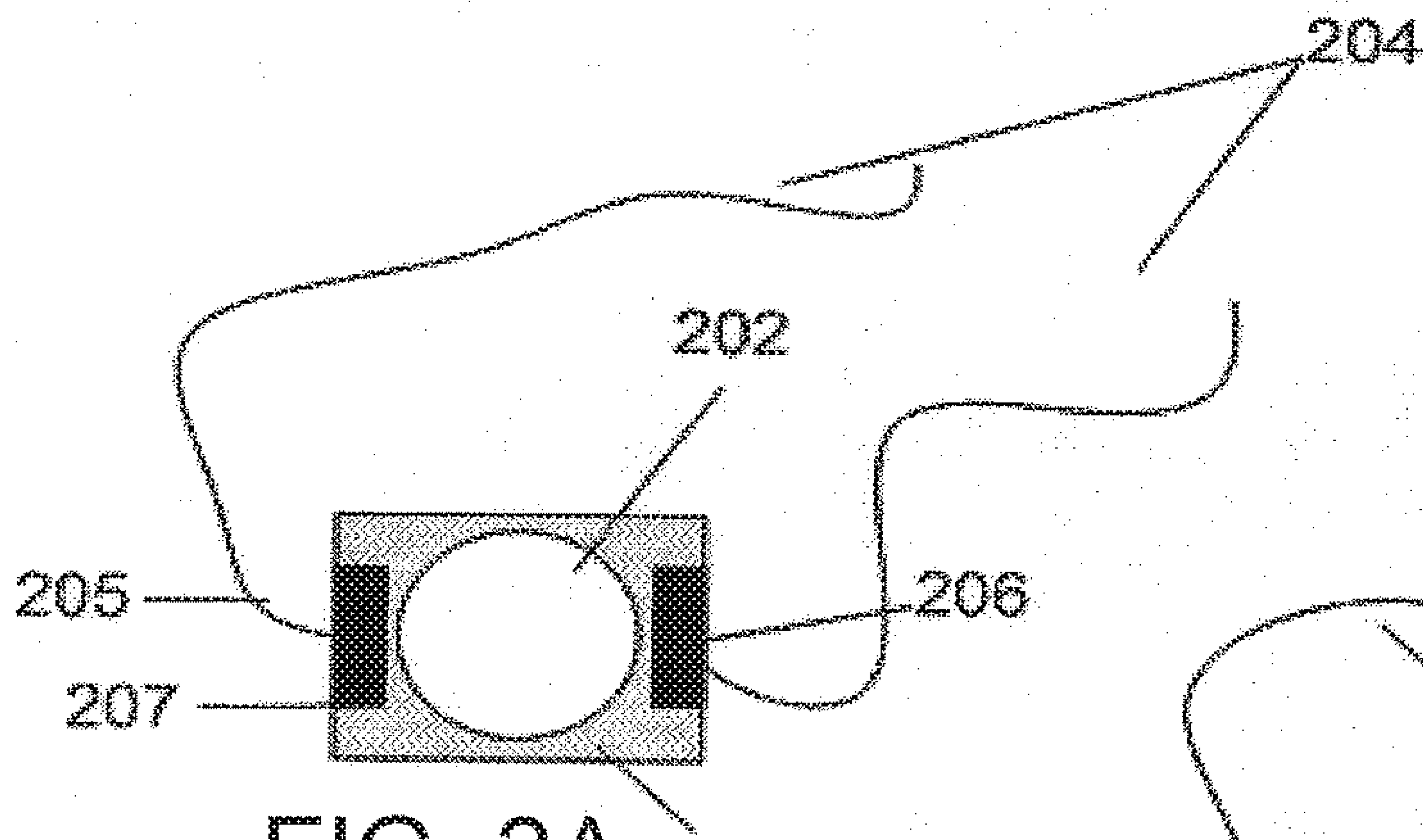


FIG. 2A

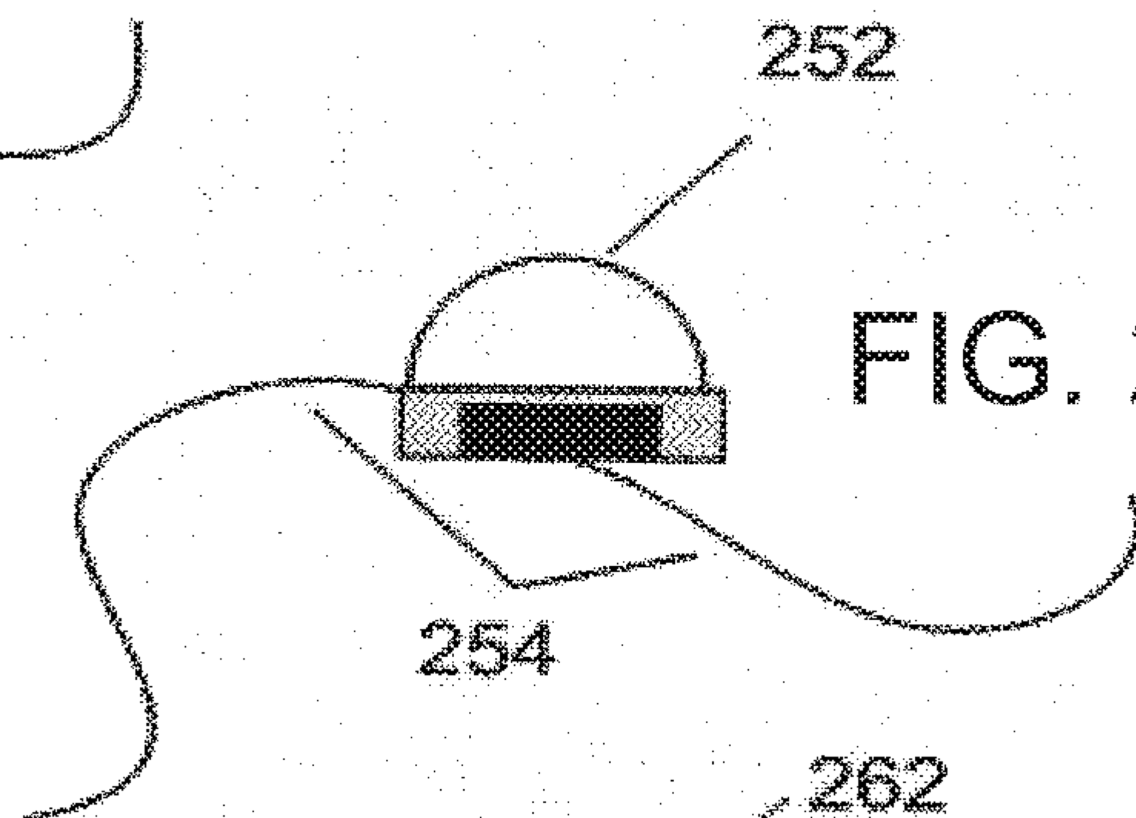


FIG. 2B

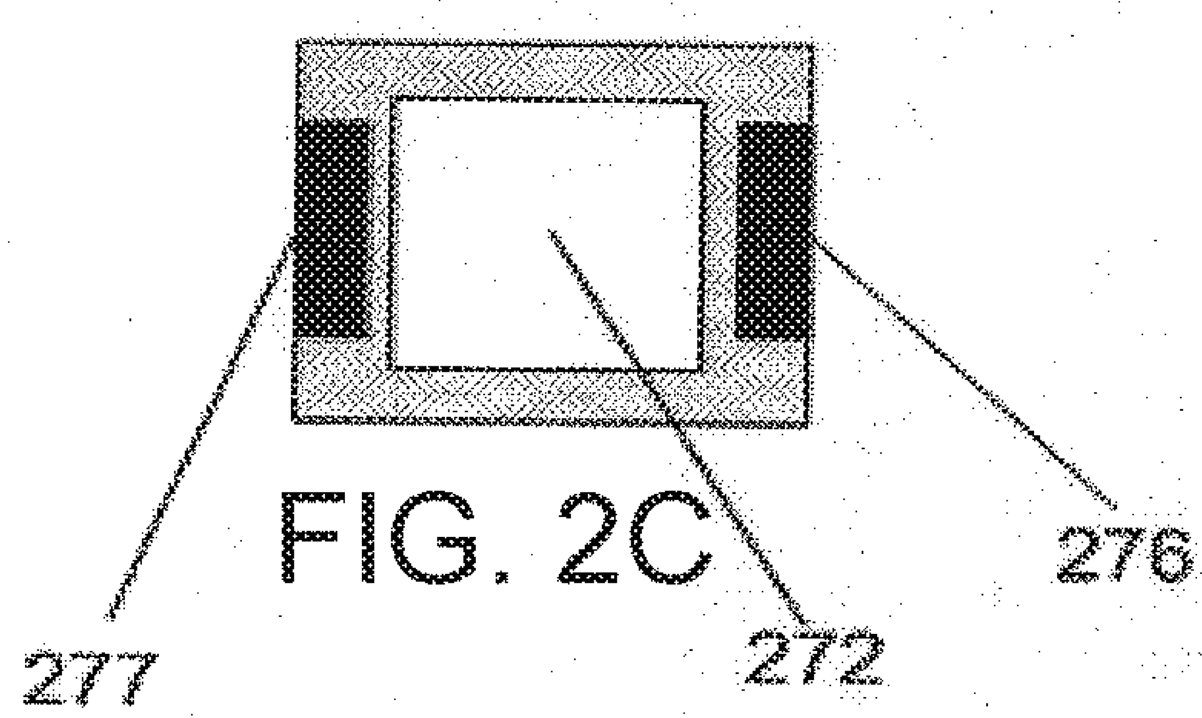


FIG. 2C

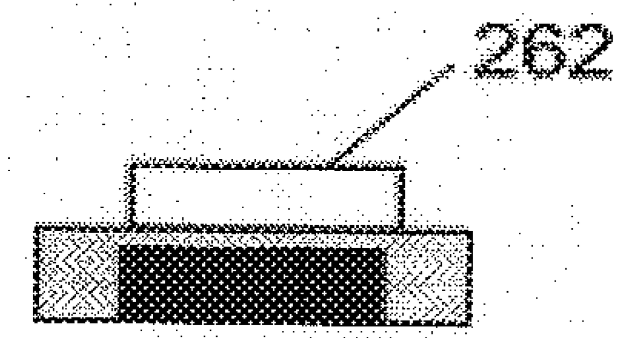


FIG. 2D

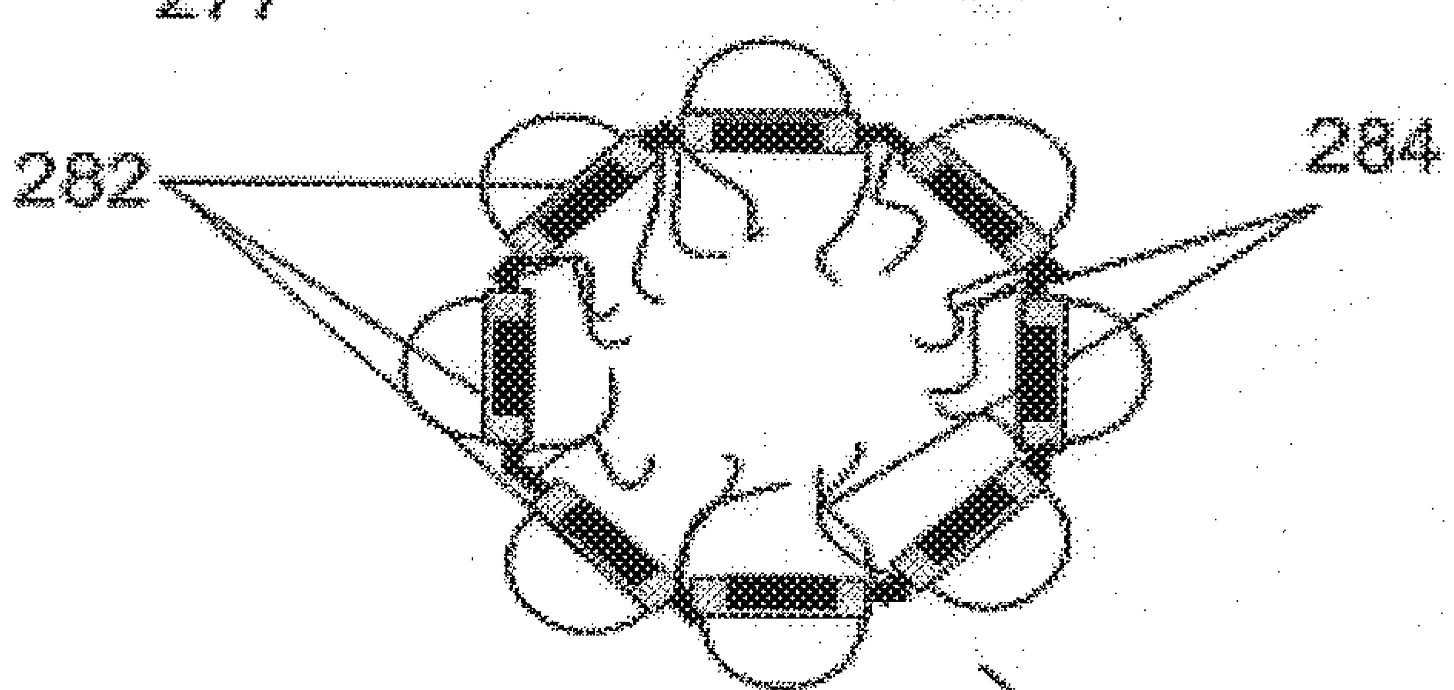


FIG. 2E

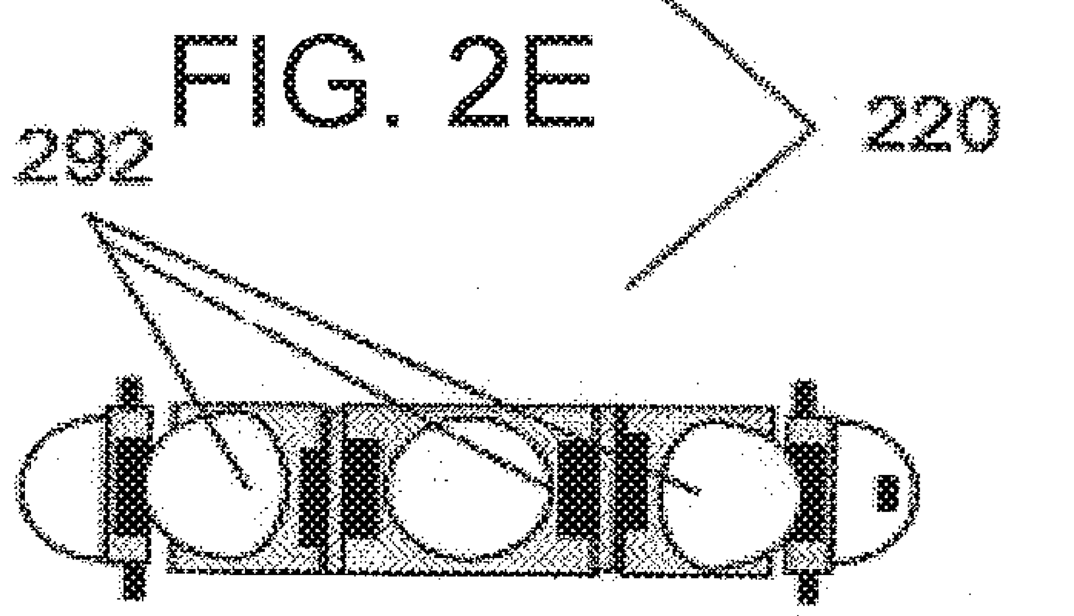


FIG. 2F

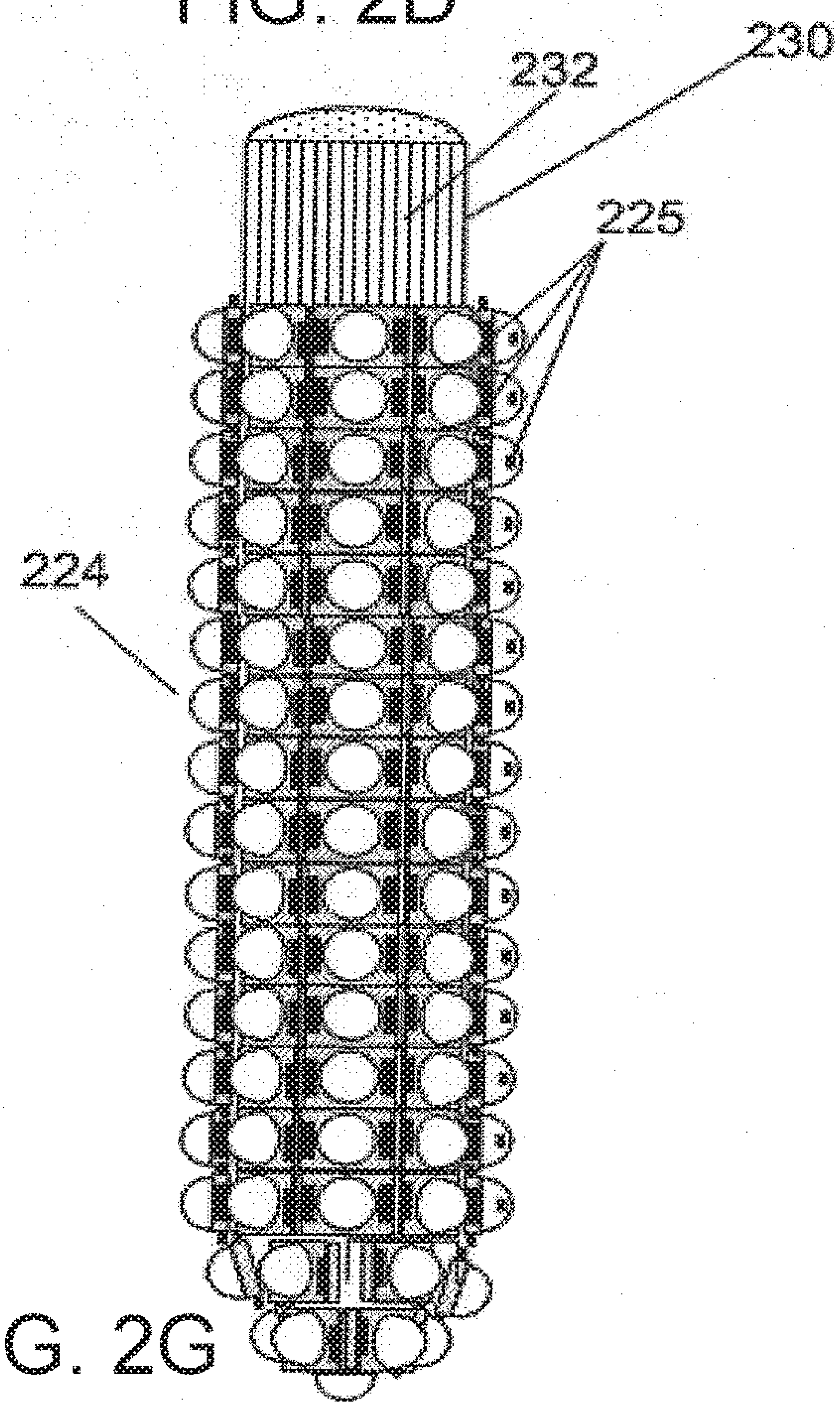


FIG. 2G

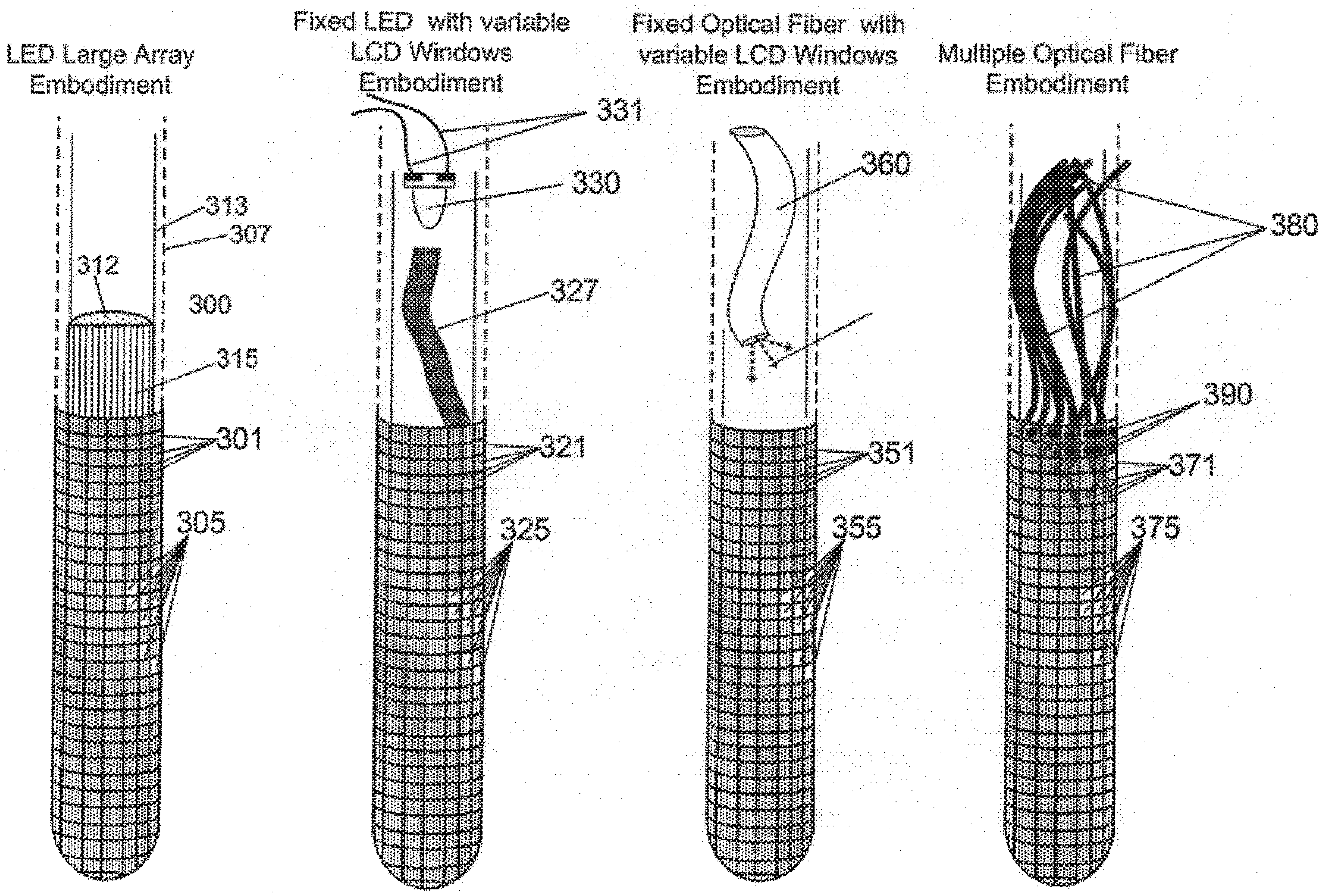


Fig. 3A Fig. 3B Fig. 3C Fig. 3D

FIGURES 3A through 3D

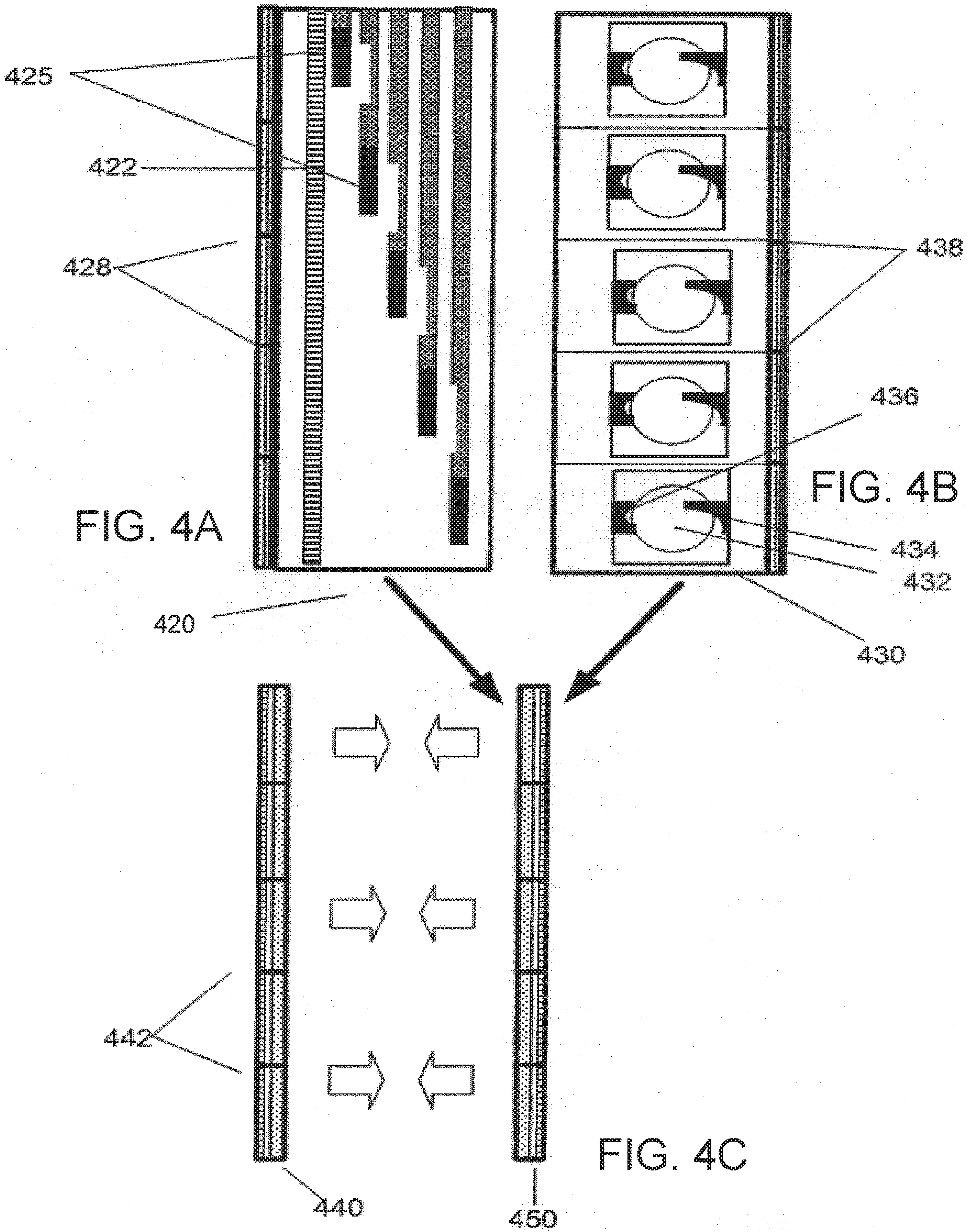


FIG. 4A

FIG. 4B

FIG. 4C

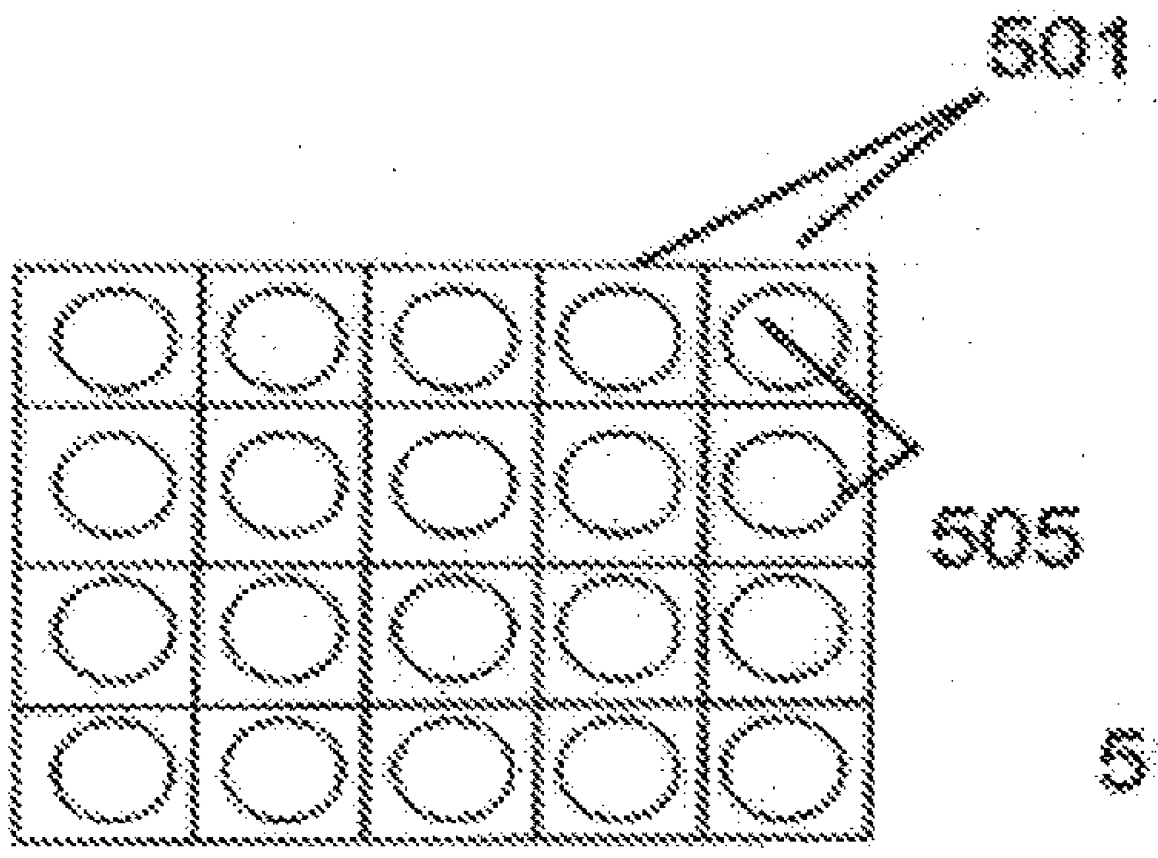


FIG. 5A

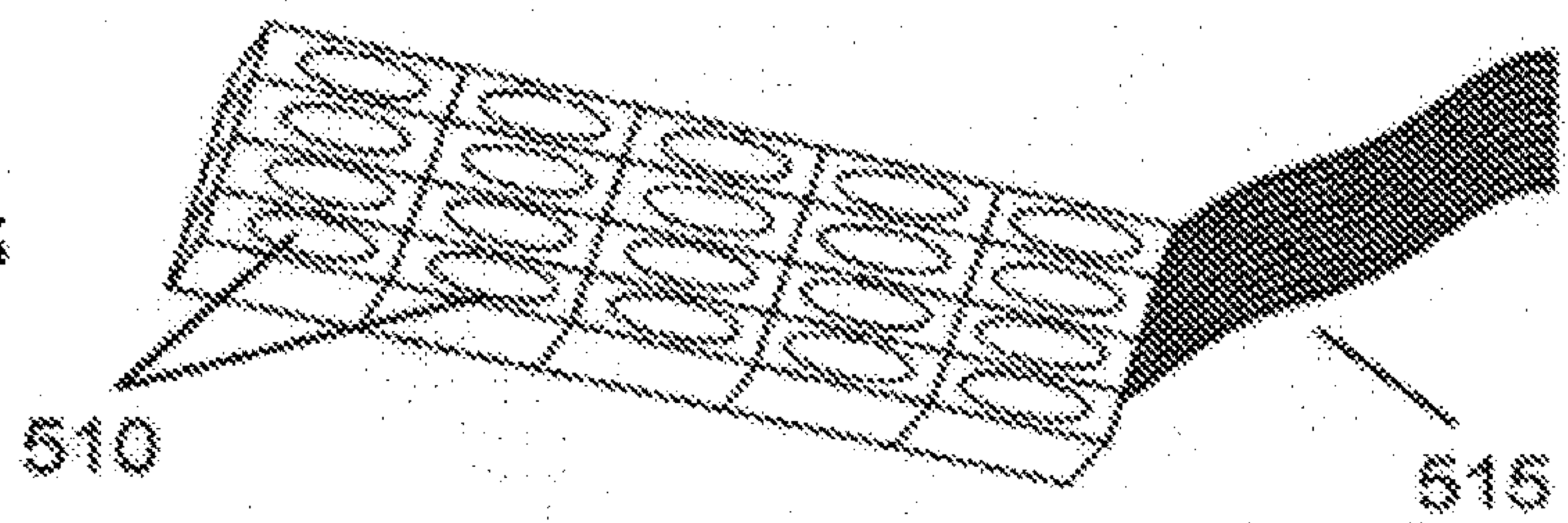


FIG. 5B

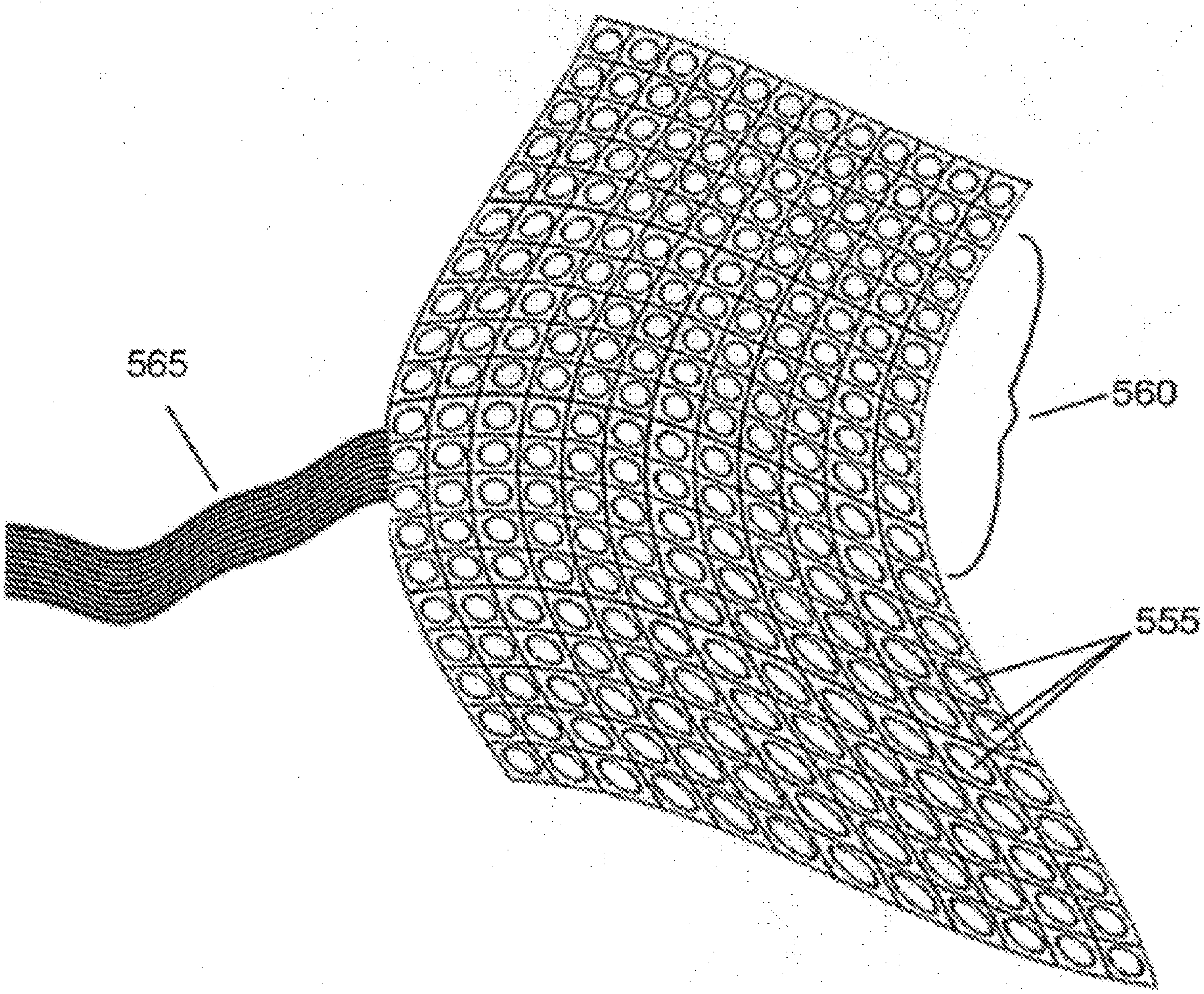


FIG. 5C

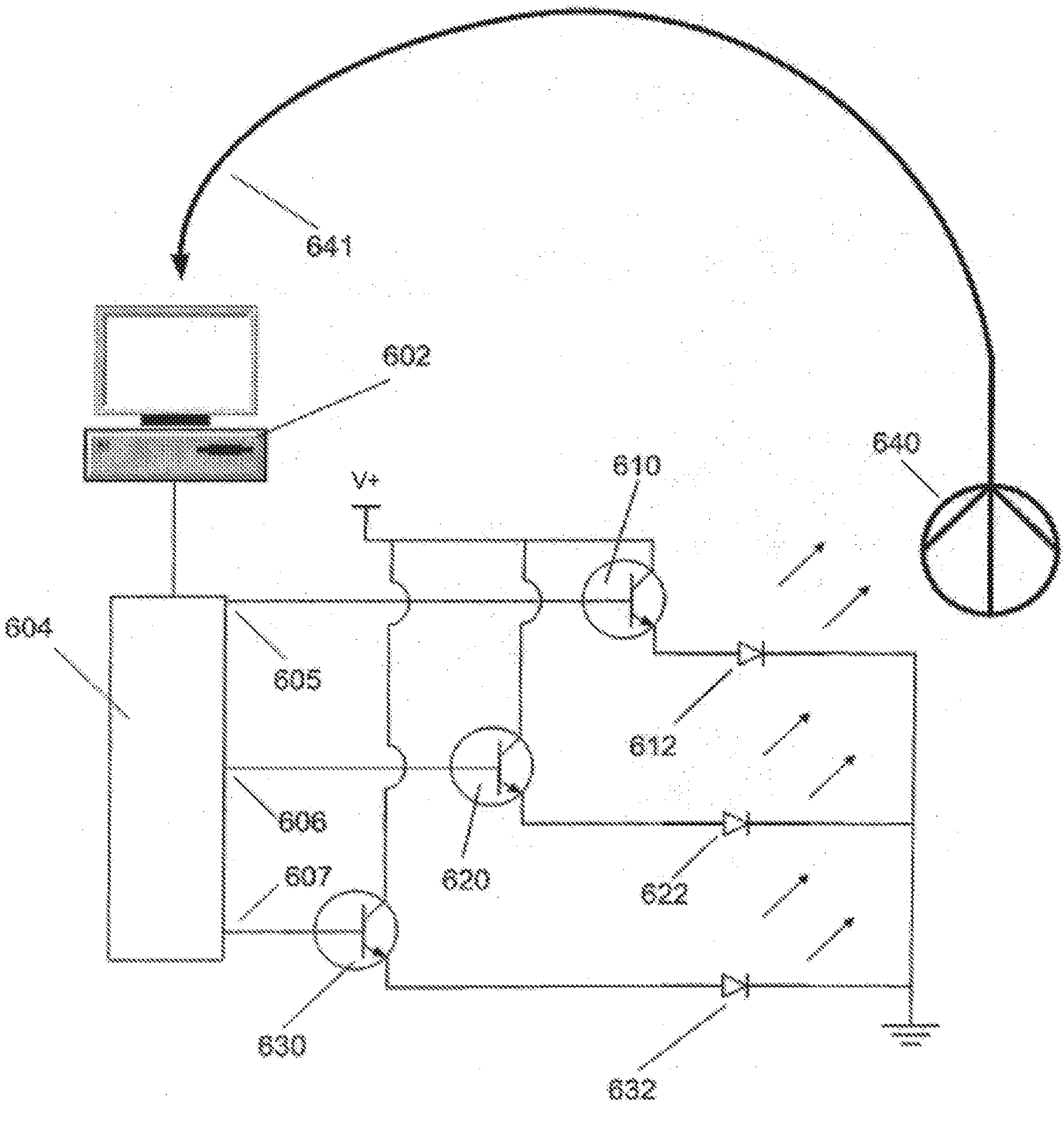


FIG. 6

IMPLANTABLE OPTICAL STIMULATORS

RELATED PATENT DOCUMENTS

[0001] This application is a continuation of U.S. patent application Ser. No. 13/850,428, filed Mar. 26, 2013, now U.S. Pat. No. 10,426,970, which is a divisional of U.S. patent application Ser. No. 12/263,044, filed Oct. 31, 2008, now U.S. Pat. No. 10,434,327, which claims priority to U.S. Provisional Patent Application Ser. No. 60/984,231, entitled "Implantable Optical Stimulators," and filed on Oct. 31, 2007, which applications are incorporated by reference herein in their entirety. This patent document makes reference to various pending U.S. Patent Documents, by Karl Deisseroth et al., including: U.S. Application Ser. No. 60/953,920 filed on Aug. 3, 2007 and entitled "Optical Tissue Interface"; U.S. Patent Application No. 60/955,116 filed on Aug. 10, 2007 and entitled "Cell Line, System And Method For Optical-Based Screening Of Ion-Channel Modulators"; U.S. patent application Ser. No. 11/459,636 filed on Jul. 24, 2006 and entitled "Light-Activated Cation Channel and Uses Thereof" (and to its underlying patent documents); U.S. patent application Ser. No. 11/651,422; U.S. patent application Ser. No. 11/459,638; U.S. patent application Ser. No. 11/459,637; U.S. Provisional application Nos. 60/901,178, 60/904,303, and 60/701,799; and PCT Patent Application No. US2006/028868. These above-listed patent documents are fully incorporated by reference and are referred to at various pages of this patent document.

FIELD OF THE INVENTION

[0002] The present invention relates generally to optically-based stimulus systems for biological applications and to systems, devices and methods for effecting such stimulus.

BACKGROUND

[0003] The stimulation of various cells of the body has been used to produce a number of beneficial effects. One method of stimulation involves the use of electrodes to introduce an externally generated signal into cells. One problem faced by electrode-based brain stimulation techniques is the distributed nature of neurons responsible for a given mental or neurological process. Conversely, different types of neurons reside close to one another such that only certain cells in a given region of the brain are activated while performing a specific task. Alternatively stated, not only do heterogeneous nerve tracts move in parallel through tight spatial confines, but the cell bodies themselves may exist in mixed, sparsely embedded configurations. This distributed manner of processing impedes attempts to understand order within the central nervous system (CNS), and makes neuromodulation a difficult therapeutic endeavor. This architecture of the brain poses a problem for electrode-based stimulation because electrodes are relatively indiscriminate with regards to the underlying physiology of the neurons that they stimulate. Instead, physical proximity of the electrode poles to the neuron is often the single largest determining factor as to which neurons will be stimulated. Accordingly, it is generally not feasible to absolutely restrict stimulation to a single class of neuron using electrodes.

[0004] Another issue with the use of electrodes for stimulation is that because electrode placement dictates which neurons will be stimulated, mechanical stability is frequently inadequate, and results in lead migration of the electrodes from the targeted area. Moreover, after a period of time within the body, electrode leads frequently become encapsulated with glial cells, raising the effective electrical resistance of the electrodes, and hence the electrical power delivery required to reach targeted cells. Compensatory increases in voltage, frequency or pulse width, however, may spread the effects of the electrical current and thereby increase the level of unintended stimulation of additional cells.

[0005] Another method of stimulus uses photosensitive bio-molecular structures to stimulate target cells in response to light. For instance, light activated proteins can be used to control the flow of ions through cell membranes. By facilitating the flow of ions through cell membranes, the cell can be depolarized while inhibiting the flow of ions which can cause the cell to polarize. Neurons are an example of a type of cell that uses the electrical currents created by depolarization to generate communication signals (i.e., nerve impulses). Recently discovered techniques allow for stimulation of cells resulting in the rapid depolarization of cells (e.g., in the millisecond range). Such techniques can be used to control the depolarization of cells such as neurons. Neurons use rapid depolarization to transmit signals throughout the body and for various purposes, such as motor control (e.g., muscle contractions), sensory responses (e.g., touch, hearing, and other senses) and computational functions (e.g., brain functions). Thus, the control of the depolarization of cells can be beneficial for a number of different purposes, including (but not limited to) psychological therapy, muscle control and sensory functions. An advantage of this "optogenetic" approach is that specific neuronal populations may be selectively targeted for the light-mediated effects, while non-targeted populations remain unaffected. For further details on specific implementations of photosensitive bio-molecular structures and methods, reference can be made to "Millisecond-Timescale, Genetically Optical Control of Neural Activity", by Boyden, Edward S. et al., *Nature Neuroscience* 8, 1263-1268 (2005), which is fully incorporated herein be reference.

[0006] While these and other methods are promising scientific discoveries, there is room for improvement, such as innovations that permit such technology to be used in the context of in vivo neuromodulation, for example, to treat diseases in humans. Often, the specific location at which the photosensitive bio-molecular structure is applied to is critical. Moreover, the process by which light reaches the photosensitive bio-molecular structures can be problematic in many practical contexts, particularly for in vivo applications in which minimal invasiveness of the procedure is paramount. For instance, the brain is a delicate organ and less disruption is usually a paramount issue for surgeries and similar procedures on the brain. Thus, it is sometimes desirable that the extent of any surgical procedure be kept to a minimum. This can be difficult, however, where large devices are needed for the administration of treatment. In some applications the comfort of the patient is also important. Thus, external apparatus can be less than ideal.

[0007] These and other issues have presented challenges to the implementation of the stimulus of target cells, including those involving photosensitive bio-molecular structures and those used in similar applications.

SUMMARY

[0008] Consistent with an example embodiment of the present invention, a method is implemented for in vivo use in a living animal, including use in a human. The method involves stimulating target cells having light-responsive proteins and includes providing an elongated light-delivery structure in a narrow passageway in the animal, the elongated light-delivery structure having separately-activatable light sources located along the length of the elongated light-delivery structure. The method also includes activating less than all the light sources to deliver light to light-responsive proteins adjacent to the activated light sources along the length of the elongated light-delivery structure, thereby stimulating target cells in vivo.

[0009] Consistent with another example embodiment of the present invention, a method is implemented for in vivo stimulation of cells in a living animal. The method includes identifying target cells including neurons genetically altered to express at least one of ChR2 and NpHR, the neurons being responsive to light. The method also includes selecting the target cells for light stimulation by inserting an elongated light-delivery structure into a narrow passageway in the animal and situating at least one of the plurality light-delivery elements near the target cells to deliver stimulation thereto. While the elongated structure is in the narrow passageway, light is delivered from the at least one of the plurality light-delivery elements to the light-responsive proteins in the selected target cells, thereby stimulating the selected target cells.

[0010] Consistent with another example embodiment of the present invention, a device is used in a living animal in vivo. The device stimulates target cells having light-responsive proteins. The device includes an elongated light-delivery structure in a narrow passageway in the animal, the elongated light-delivery structure having separately-activatable light sources located along the length, width and/or circumference of the elongated light-delivery structure. The device also has a control circuit for activating less than all the light sources to deliver light to light-responsive proteins adjacent to the activated light sources along the length of the elongated light-delivery structure, thereby stimulating target cells in vivo.

[0011] The above summary of the present invention is not intended to describe each illustrated embodiment or every implementation of the present invention. The figures in the detailed description that follow more particularly exemplify these embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The invention may be more completely understood in consideration of the detailed description of various embodiments of the invention that follows in connection with the accompanying drawings, in which:

[0013] FIG. **1** illustrates the manner in which the present invention may be implanted within the brain to stimulate areas of brain, according to an example embodiment of the present invention;

[0014] FIGS. **2**A-**2**G show embodiments of the present invention in which multiple LEDs are arranged into an array, according to an example embodiment of the present invention;

[0015] FIGS. **3**A, **3**B, **3**C and **3**D illustrate four different methods by which light may be delivered to and from discrete locations along the body of an implantable device, according to an example embodiment of the present invention;

[0016] FIGS. **4**A-**4**C show two sides of a multi-LED wafer in the context of an embodiment of the present invention;

[0017] FIGS. **5**A, **5**B and **5**C show a 2-dimensional matrix (array) of light emitting elements, suited to applying to surfaces of the brain, such as the cortical surface, and analogous to the electrical recording and stimulation "grids" commonly used in contemporary functional neurosurgery, according to an example embodiment of the present invention; and

[0018] FIG. **6** illustrates a configurable and optionally self-configuring control circuit by which power can be selectively applied to specific LEDs in the array, while others are left unused, according to an example embodiment of the present invention.

[0019] While the invention is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention.

DETAILED DESCRIPTION

[0020] The present invention is believed to be useful for enabling practical application of a variety of in vivo and optically-based stimulus systems, and the invention has been found to be particularly suited for use in systems and methods dealing with stimulation of target cells using an optical stimulus. While the present invention is not necessarily limited to such applications, various aspects of the invention may be appreciated through a discussion of various examples using this context.

[0021] Recently discovered techniques allow for light-based stimulation of cells resulting in the rapid depolarization of cells (e.g., in the millisecond range). Such techniques can be used to control the depolarization of cells such as neurons. Neurons use rapid depolarization to transmit signals throughout the body and for various purposes, such as motor control (e.g., muscle contractions), sensory responses (e.g., touch, hearing, and other senses) and computational functions (e.g., brain functions). Thus, the control of the depolarization of cells can be beneficial for a number of different biological applications, among others including psychological therapy, muscle control and sensory functions. For further details on specific implementations of photosensitive bio-molecular structures and methods, reference can be made to one or more of the above-referenced patent documents by Karl Deisseroth et al. These references discuss use of blue-light-activated ion-channel channelrhodopsin-2 (ChR2) to cause cation-mediated neural depolarization. Also discussed in one or more of these references are other applicable light-activated ion channels including, for example, halorhodopsin (NpHR) in which amber light affects chloride (Cl—) ion flow (via a chloride pump) so as to hyperpolarize neuronal membrane, and make it resistant to firing.

[0022] Consistent with one example embodiment of the present invention, a system is implemented for providing in vivo stimulus to target cells. The system includes an implantable light-delivery device for selectively delivering optical stimulus to target cells. The light-delivery device includes an array of controllable light-delivery elements. These light-delivery elements can be individually controlled with regard their ability to deliver light. This can be particularly useful for selectively stimulating different areas/target cells or for modifying the level of stimulation provided to the target cells. The light-delivery elements each provide optical stimulus in a manner different from other elements (e.g., at different location, in different direction, at different intensities or at different wavelengths). The array of light-delivery elements can be controlled electronically using various selection circuits. For instance, each array element can be assigned an address. Address decoders can be used to select column and rows for the particular element within the array. In another instance, individually addressable lines can be used to select each element within the array.

[0023] Interfaces for stimulating such cells in vivo include those described in the above-referenced patent documents, perhaps with particular reference to those above-referenced patent documents entitled, "Optical Tissue Interface Method And Apparatus For Stimulating Cells", U.S. application Ser. No. 12/185,624, and "Inductive Light Generator", U.S. application Ser. No. 11/651,422.

[0024] According to one embodiment, the light-delivery elements each provide light to targeted cells. This can be accomplished, for example, using an array of light-emitting-diodes (LEDs). The LEDs are located at different positions on the light-delivery device. In one instance, the LEDs can have different attributes including, but not limited to size, intensity or wavelength. In another instance, the LEDs can be nearly identical. Light sources other than LEDs, although not explicitly mentioned, are also possible. For example, the source of light may be a remote LED, xenon lamp, or other known light generation devices. Moreover, the light may be transmitted from a light source by an optical fiber or other optical arrangement.

[0025] According to another embodiment, the light-delivery elements function in conjunction with one or more back-lights. The light-delivery elements selectively allow or block the light from the back-lights. In a specific embodiment, the liquid crystal display (LCD) technology can be used to provide this functionality. Various other light-emitting arrays can be used including, but not limited to, field emission displays or surface-conduction electron-emitter displays.

[0026] FIG. **1** illustrates the manner in which the present invention may be implanted within brain **115** so as to stimulate areas of brain **115** that lie near to the shaft-like optical stimulator probes **105** and **100**. Control unit **140**, **145** communicates with the stimulator probes **105** and **100**. In a specific embodiment the control unit **140**, **145** includes a pacemaker-like battery unit **145** and control circuitry **140**, which is attached by electrical wire bundles **130** and **135**. In an alternative embodiment **130** and **135** may represent optical fibers, carrying light from a source in control circuitry **140**, into probes **105** and **110**, and into neural tissue. Each of these combinations can be implanted or attached externally to the patient, where the patient is an animal, such as a human.

[0027] FIGS. **2**A to **2**G show an embodiment of the present invention in which multiple LEDs are arranged into an array. In one instance, the LED array includes surface-mount LEDs that are soldered to the delivery device.

[0028] As discussed above, the LED array can be controlled using various circuits. A specific example involves using individual wire pairs for each LED. In this example, wires **232** for controlling the array of LEDs pass through the probe shaft **224** and are connected to power and ground, respectively. Surface-mount LED **201**, which is illustrated with a dome diffuser, includes anode **207** and cathode **206** that are each connected to one of leads **204**, **284**. LED **202** emits light in response to a bias voltage being applied to contacts **206** and **207**. LED **252** and leads **254** show the same LED from a different angle. LED diffuser **262** and **272** and contacts **276** and **277** show the corresponding parts in a flat-diffuser LED. LEDs **282** and **292**, may be affixed together in the desired shape, such as in a ring shape **220**. Multi-LED rings **220**, **225** may be built into a longitudinally-extending probe **224**, with associated conductor or leads **232** passing through central area **230** to an area where they can be attached to external control equipment. In one embodiment, a smooth, thin-walled external sleeve or cannula surrounds probe **224**. This can be particularly useful for reducing insertion-related tissue trauma due to an irregular surface of probe **224**. After the shaft of the array is in place, this cannula can be removed by slipping it off of the shaft retrograde to the direction in which it was introduced. In another instance, the cannula can be constructed from a transparent or translucent material allowing it to be left in place.

[0029] FIGS. **3**A, **3**B, **3**C and **3**D illustrate four different methods by which light may be delivered to and from discrete locations along the body of an implantable device. FIG. **3**A shows an embodiment in which the outer perimeter of the implantable device is a micro-fabricated array in which the (representative example) LEDs **301** are formed in situ, and collectively assume a flat smooth surface profile on the probe. These LED components may be associated conductor or leads **312** passing through central area **315** to an area where they can be attached to external equipment. Line **307** indicates the continuity of the outer perimeter of this long, cylindrical structure, and line **313** indicates the upward continuity of the inner lumen, as in all four of the figures comprising FIG. **3**. The lumen of the device, bounded by **313**, carries leads **312** away from LEDs **301**, and toward power and ground sources. Lighted LEDs **305** are shown at their location of origin.

[0030] The various embodiments discussed in connection with FIG. **3** can be manufactured using any number of different processes. A specific example of such a manufacturing process for producing the embodiment described in connection with FIG. **3**A is presented in the following discussion. The LEDs can be formed by producing a semiconductor wafer using, for example, the Czochralski crystal growth method. The semiconductor wafer can be made from a number of suitable materials (e.g., GaAs, GaP, or GaAsP) that determine properties of the light produced, including the wavelength (color). Additional dopants may subsequently be added to optimize the color characteristics of the output light. The LEDs dies can be affixed together to form an array. The entire assembly can then be sealed. The sealant for the probe and associated circuitry and connectors may be composed of a material such as polysulphone. Polysupfone has previously been used for fracture fixation devices and dental supports demonstrating its mechanical integrity, with negligible effects on biological tissue. Polysulphone is also translucent, easily machinable and sterilizable with gas, heat, or X-rays. Electrical or connectors, such as Omnetics dual-row NANO connector (Omnetics Corp., Minneapolis, Minn.), can be used to connect to wires extending from the otherwise sealed device.

[0031] FIG. **3**B illustrates another embodiment that uses light-delivery elements that function as light inhibiters, such as liquid crystal display (LCD) elements. Such elements selectively block or allow light to pass outward through each element. One or more light generators, such as LED **330** with electrical leads **331**, are inside the hollow core of an implantable device. Light passes outward through transparent (e.g., LCD) windows **325**. The outer perimeter is a matrix of (LCD) windows **321**. In one embodiment of the invention, (LCD) windows **321** becoming opaque or transparent in accordance with the electrical signals provided to them via ribbon cable **327**.

[0032] FIG. **3**C is a variant of FIG. **3**B, in which back light is provided from an internal light source, such as is optical fiber **360**. Representative example LCD windows **351** are made transparent or remain opaque in accordance with the desired stimulation pattern. The optical stimulation is controlled by transitioning the LCD windows **351** and **355** between transparent and opaque states through the application of electrical fields. This can be particularly useful for selective control of the optical array without the need for electrical signals to be passed through the implantable device, or for segregating the heat-producing light-generation process distant from the neural targets.

[0033] FIG. **3**D is another embodiment, in which there are multiple optical fibers **380**, each one separately terminating at an aperture (e.g., **390**, **371** or **375**) at specific grid locations on the outer margin of the implantable device. Each fiber **380** has the potential to carry light from an external source to one of the grid locations (e.g., **390**, **371** or **375**). This can also be particularly useful for selective control of the optical array without the need for electrical signals to be passed through the implantable device, or for segregating the heat-producing light-generation process distant from the neural targets.

[0034] The embodiments shown in FIGS. **3**A, **3**B, **3**C and **3**D show a few specific examples of how to control the light-delivery elements. In other embodiments, the electrical control signals could be sent using other methods including, but not limited to, (serial/parallel) data lines, wireless transmissions or using a row/column addressing array. For example, circuit logic or a microcontroller could decode received data that indicates the appropriate light-delivery elements to activate.

[0035] In another example, row and column lines could be routed between to the light-delivery elements. In such an example, individual delivery elements could be controlled. In a simple example, there may not be a mechanism to enable each delivery element simultaneously. The effect of simultaneous activation of delivery elements can be approximated by triggering of the desired delivery elements in rapid succession. Thus, if the desired effect is a pulse having a duration of 200 milliseconds from each of light-delivery elements A, B and C, respectively, element A can be activated for several milliseconds followed by B and then C. This pattern can then be repeated for the 200 milliseconds. In some instances, a similar type of pulse control could be used to control the average intensity of the delivered light using principles similar to principles used in pulse-width-modulation techniques.

[0036] In yet another example, techniques similar to active matrix addressing used in television displays could be used. One such example includes the use of storage components at each delivery element to maintain the state of the delivery element. A capacitor or other memory element can store the current state of the delivery element while other delivery elements are updated. The entire matrix can then be controlled by setting the desired value in each delivery element through a refresh process.

[0037] FIGS. **4**A to **4**C show two sides of a multi-LED wafer in the context of an embodiment of the present invention. On the side **420** of the wafer, electrical traces **422** carry supply voltages, such as ground or power. In FIG. **4**A traces **422** extend roughly the length of the wafer, while control leads **425** are staggered in accordance with the positions of the light-emitting portions on the opposite side of the wafers. The spaces between the light-emitting portions are demarcated by partial cuts or fractures **428** and **438**. On the light-emitting side **430**, anode **434** and cathode **436** sit opposite one another across packaging lens **432**. Wafers **440** and **450**, each having a lead tracing side **420** and a light-emitting side **430**, can be affixed back-to-back, with an edge connector or leads (not shown) in between the two wafers, and extending upward to an accessible location. Scores or cuts **442** can be used to functionally separate the different LED elements.

[0038] FIGS. **5**A, **5**B and **5**C show a **2**-dimensional matrix (array) of light-emitting elements, suited to applying to surfaces of the brain, such as the cortical surface, and analogous to the electrical recording and stimulation "grids" commonly used in contemporary functional neurosurgery. In FIG. **5**A, the array is shown to be composed of LED elements **501**, each with lens **505**. FIG. **5**B shows the same embodiment from a side view, including LED lenses **510** and ribbon cable **515**. Ribbon cable **515** provides electrical power to each LED. FIG. **5**C shows a larger array embodiment, demonstrating the physical flexibility and deformability of this embodiment via flexion curve **560**. Ribbon cable **565** provides power and/or control to LEDs **555**. Lens **510** can be designed (e.g., convex, concave or flat) for various purposes of simple transmission including, but not limited to, focusing or diffusing the emitted light. The physically flexible design permits the array to conform to the contours of a brain surface to which it is applied. This can be particularly useful for facilitating optical coupling between the device and target cells on or near that surface.

[0039] FIG. **6** illustrates a configurable and optionally self-configuring control circuit by which power can be selectively applied to specific LEDs in the array, while others are left unused. Computer **602** oversees the performance of multichannel driver **604**, ensuring that pulses are delivered at the right time, and to the proper LEDs. Multichannel driver **604** controls LED **612** via channel control line **605**, and transistor **610**. Likewise, LED **622** controlled via channel control line **606** using transistor **620**, and LED **632** is controlled via channel control line **607** using transistor **630**. When transistors (**610**, **620**, **630**) are activated by a corresponding control signal, they activate the corresponding LED. In this manner, individual LED circuits may be switched on or off. The LED activation time can also be controlled by supplying different frequencies of control pulses.

[0040] Various methods may be used to provide feed back **641** to computer **602** regarding which light positions should be activated, and which should remain inactive. In the case of Parkinson's disease, an empiric testing procedure may be conducted with an accelerometer **640** or other motion sensor held in the patient's hand. The patient is then asked to engage in specific tasks, such as attempting to remain still. Meanwhile, a signal processor examines the signal from the accelerometer, and determines how much tremor is associated with each task, as well as how accurate and rapid the assigned movements are. During this process, a wide range of candidate light stimulus configurations may be tested, either by automated or manual empirical processes. The optimal stimulus configuration can be determined empirically, for example, using a hierarchical algorithm to identify the optimal light position configuration for the specific patient. This optimization process can be carried out in an ongoing fashion, by monitoring over a period of days as the patient engages in their normal activities. The optimization process can thus gradually determine the best stimulus profile for the particular patient. At its extremes, all possible parameter configurations of all channels may be automatically tested over a period of time. In a more complex approach, rule-based, or artificial intelligence algorithms may be used to determine optimal parameters for each of the channels.

[0041] Various other input and testing procedures can be used depending upon the specific problem being treated. In the case of optical stimulator implants for the treatment of depression, for example, feedback can be provided through patient questionnaires. The answers of the patient can be entered into a computer and used to optimize light configuration. Various other brain-machine interfaces may also be used as part of the testing and optimization routine. It will be appreciated that the optimization process may be conducted in an open-loop (manual device configuration) or closed loop (full automated device configuration) manner.

[0042] If appropriate measures of patient performance (for example freedom from tremor as measured by an accelerometer) are detected, this information can be automatically fed back to computer **602** for storage in a database. Computer **602** can use the stored information in accordance with algorithms and artificial intelligence methods to determine a suitable stimulation solution using driver **604**.

[0043] In a particular embodiment of the present invention, an arrangement ascertains optimal neuromodulation parameters for a plurality of control channels. The control channels provide control of respective light-delivery elements. The neuromodulation effects are sensed using, for example, an empiric testing procedure conducted with an accelerometer, monitoring of electrical activity or related sensing. Sets of candidate parameters are generated by a computer, wherein the sets include control information for the light-delivery elements. Optical stimuli are delivered to using the plurality of control channels to control the light-delivery elements. A processing circuit can be used to correlate the candidate parameter settings to the sensed neuromodulation effects and to compare respective results. A processing circuit can select one of the candidate parameter set as a treatment regimen. A processing circuit can be used in combination with the control channels to implement the selected candidate parameter set.

[0044] The various embodiments described above are provided by way of illustration only and should not be construed to limit the invention. Based on the above discussion and illustrations, those skilled in the art will readily recognize that various modifications and changes may be made to the present invention without strictly following the exemplary embodiments and applications illustrated and described herein. For instance, such changes may include variations in driver circuits for controlling the optical stimulation or variations in the light-delivery elements. In another instance, aspects of the invention can be used for animal testing or treatments, and more specifically, human testing or treatments. Such modifications and changes do not depart from the true spirit and scope of the present invention, which is set forth in the following claims.

1.-**16**. (canceled)

17. A circuit arrangement for selecting and implementing neuromodulation parameters corresponding to a plurality of control channels, the plurality of control channels providing control of respective light-delivery elements, the circuit arrangement comprising:

a sensor for sensing effects of neuromodulation due to stimuli from the light-delivery elements; and

a computer operatively connected to the sensor,

wherein the computer is configured to:

generate sets of control data, wherein each of the sets include control information for use with the plurality of control channels;

deliver optical stimuli in response to the candidate specification settings;

generate correlation data about the sets of control data with the sensed neuromodulation effects;

select one set of control data from the sets of control data, the selection responsive to the data that correlation data; and

implement the selected candidate parameter setting as a treatment regimen.

18. The circuit arrangement of claim **17**, further comprising a multichannel driver configured to individually control the light-delivery elements.

19. The circuit arrangement of claim **17**, wherein the of light-delivery elements comprise liquid crystal display (LCD) elements, and wherein the LCD elements are responsive to the plurality of control channels.

20. The circuit arrangement of claim **17**, wherein the light-delivery elements each include a separate light-generating element, and wherein each light-generating element is responsive to a separate control channel of the plurality of control channels.

21. The circuit arrangement of claim **17**, wherein each of the light-delivery elements comprises a light-emitting diode.

22. The circuit arrangement of claim **17**, wherein each of the light-delivery elements comprises a fiber optic cable.

23. The circuit arrangement of claim **17**, whereine control data comprise a neuromodulation parameter.

24. The circuit arrangement of claim **23**, wherein the neuromodulation parameter further comprises one or more of a location of the light-delivery element, an intensity of the light from the light-delivery element, and a wavelength of the light from the light-delivery element.

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