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(54) Title: WAVEGUIDE WITH INTEGRATED LENS

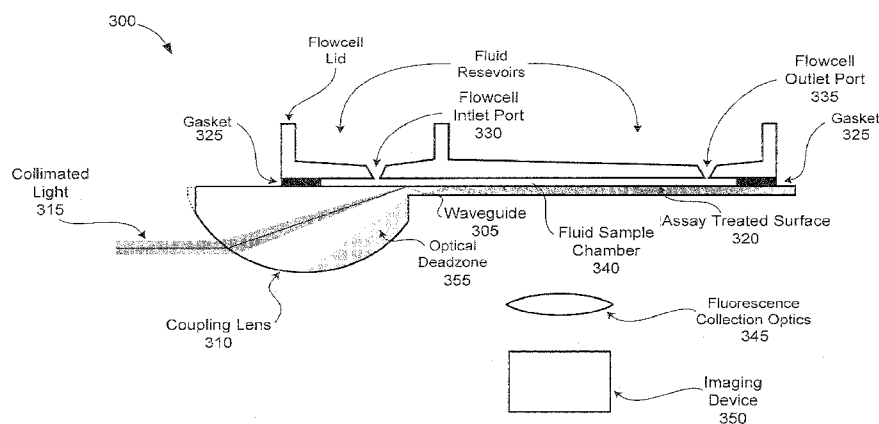


FIGURE 3

(57) Abstract: A sample can be illuminated for analysis using apparatus including a light source, a planar waveguide, and a refractive volume. The light source provides light along a propagation vector. The planar waveguide is oriented such that the propagation vector is perpendicular to the normal vector of the planar waveguide and offset from the planar waveguide in a direction parallel to the normal vector of the planar waveguide. The refractive volume is positioned proximate to the planar waveguide and can optically coupling light provided by the light source to the planar waveguide.

WAVEGUIDE WITH INTEGRATED LENS

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the priority benefit of U.S. provisional patent application number 61/156,586 filed March 2, 2009 and entitled "Waveguide with Integrated Lens," and U.S. utility application number 12/617,535 filed November 12, 2009 the disclosure of which is incorporated herein by reference.

GOVERNMENT INTEREST

[0002] This invention was made with government support under contract 70NANB7H7053 awarded by the U.S. Department of Commerce. The Government has certain rights in this invention.

BACKGROUND OF THE INVENTION

Field of the Invention

[0003] The present invention generally relates to waveguides for sample illumination. More specifically, the present invention relates to planar waveguides proximate to refractive volumes.

Description of the Related Art

[0004] Fluorescently labeled probes provide a convenient method of characterizing the content of biological samples. By tailoring binding chemistry of a fluorescent probe, high specificity can be achieved for detection of complex molecules such as RNA, DNA, proteins, and cellular structures. Since fluorophores typically absorb and re-emit Stokes-shifted radiation regardless of being bound or unbound to a species to be detected, the bound and unbound fluorophores must be separated.

[0005] One common method to separate the bound fluorophores from the unbound fluorophores relies on spatial localization of the fluorescently labeled species. For example, in a 'sandwich immunoassay' a surface is chemically treated to bind a species to be detected to the surface. The fluorescent probes then attach to the species that are bound to the surface. Unbound fluorophores can then be removed from the system with a wash step.

[0006] Background fluorescence can be further reduced if the excitation light can be confined to the surface. Total internal reflection fluorescence (TIRF) is one method of reducing background fluorescence. In general, when light propagates from one medium to another, a portion of the light will be reflected at the interface. If the light is propagating into a material with a lower index of optical refraction, however, all the light will be reflected if the angle at which the beam is incident on the surface is greater than the 'critical angle' (relative to the surface normal). In the lower index material, the light intensity exponentially decays with distance from the surface. This exponentially decaying field – known as an 'evanescent field' – has a characteristic decay length on the order of 100 nanometers to 1 micrometer for visible light. The light of the evanescent field will, therefore, only excite fluorophores that are localized at the surface.

[0007] In a simplified implementation, TIRF is performed with a laser beam reflecting once from the surface. This is the basis of well established TIRF microscopy and other biosensing techniques. By confining the laser beam inside a waveguide, however, multiple reflections can be realized and larger areas can be illuminated. Several waveguide geometries are possible, each having certain tradeoffs.

[0008] Single-mode planar waveguides, also called thin film waveguides or integrated optical waveguides, confine light into a small cross sectional area with the thin dimension smaller than the wavelength of propagating light. The advantage of single-mode waveguides is that significantly stronger evanescent fields are generated. A disadvantage of single-mode waveguides is that for efficient light coupling, they typically require a prism or grating with precise alignment tolerances. In addition, single-mode planar waveguides are expensive to manufacture because the guiding layer is typically a thin-film with strict thickness tolerances deposited on a substrate. In contrast, a multimode planar waveguide is substantially easier to couple a laser beam to and simpler to construct than single-mode planar waveguides. For example, a standard 1 millimeter thick microscope slide makes an effective waveguide to which light can be coupled through the edge of the slide.

Additionally, dimensions for multimode waveguides are compatible with current plastic injection-molding techniques.

[0009] For a fluorescence-based assay system, a uniform evanescent field is desired in the detection region. By definition, the strength of the evanescent field is uniform along the direction of light propagation for a single-mode planar waveguide (neglecting scattering losses and absorption inside the waveguide). For a disposable clinical device, however, cost, robustness, and ease of use are of similar importance. By adjusting input coupling to a multimode waveguide, uniformity and field strength can be optimized.

[0010] While each individual mode in a multimode waveguide has a uniform intensity along the direction of propagation, a distribution of modes will be excited when coupling to a multimode waveguide; this distribution of modes will constructively and destructively interfere on the surface and lead to a spatially varying field strength. When the thickness of the waveguide is much larger than the wavelength of light, the mode structure of the waveguide can be neglected, and the intensity in the waveguide can be treated as a conventional diffracting beam that totally-internally reflects from the two surfaces of the waveguide and interferes with neighboring reflections.

[0011] FIGURE 1 illustrates several examples of existing coupling schemes 105-115 involving multimode waveguides. The coupling scheme 105 using a multimode waveguide 120 involves focusing a laser beam 125 that propagates parallel to the waveguide 120 into the edge of the waveguide 120 with a cylindrical lens 130. The field strength of a TIR beam, however, is maximized for a beam that is incident at the critical angle and zero for a beam with an incident angle 90° from the surface normal (*i.e.*, grazing incidence). Thus, an incident beam that is parallel to the TIR surface will have small evanescent field strength when coupled to the waveguide 120 with the cylindrical lens 130 in the configuration of the scheme 105.

[0012] A variation on the coupling scheme 105 is illustrated by the coupling scheme 110. In the scheme 110, a laser beam 135 focused by a cylindrical lens 140 is incident on the edge of a waveguide 145 with an appropriate angle such that the central ray of the beam 135 inside the waveguide impinges on the surface near the critical angle for

TIR to maximize the evanescent field strength. A compromise between field strength and uniformity may be made by the choice of focusing optics. If a nearly collimated beam is used to achieve high field intensity by operating near the critical angle for TIR, the beam must make many reflections within the waveguide before the surface intensity becomes sufficiently uniform, thus requiring a longer waveguide. If the beam is highly focused, however, then the surface intensity normalizes in very few reflections, but a significant amount of power is contained in rays propagating outside the critical angle and leads to reduced evanescent field strength down the length of the waveguide.

[0013] Precise alignment of a cylindrical lens, such as the lenses 130 and 140, relative to the input face of a waveguide, such as the waveguides 120 and 145, respectively, must be made in order to have a laser beam focused on the input face. One proposed solution to this problem is illustrated by the coupling scheme 115. In the coupling scheme 115, a lens 150 is incorporated with a waveguide 155 as a single optical component, made, for example, by bonding the lens element to the planar waveguide or by molding a single optical component. While this allows the focus of the lens 150 to be precisely distanced from the edge of the waveguide 155, careful alignment of a laser beam 160 relative to the lens 150 of the waveguide 155 must still be made to couple the beam 160 to the waveguide 155. For applications requiring repeated placement of a waveguide component relative to the light source, it is highly desirable for the light coupling to be relatively insensitive to misalignment.

SUMMARY OF THE CLAIMED INVENTION

[0014] Embodiments of the present invention allow light to be coupled to a planar waveguide providing a strong evanescent field for sample illumination, while eliminating or greatly reducing inadvertent misalignment by a user. Embodiments of the present invention further allow facile tuning of the internal propagation angle inside the waveguide, providing simple adjustment of evanescent field strength. Embodiments of the present invention also provide apparatus for performing assays involving placement of a fluidic chamber on a planar waveguide in a manner that is insensitive to the optical properties of the chamber.

[0015] In a claimed embodiment, apparatus for illuminating a sample for analysis is disclosed. The apparatus includes a light source, a planar waveguide, and a refractive volume. The light source provides light along a propagation vector. The planar waveguide is oriented such that the propagation vector is perpendicular to the normal vector of the planar waveguide and offset from the planar waveguide in a direction parallel to the normal vector of the planar waveguide. The refractive volume, which is positioned proximate to the planar waveguide, optically couples light provided by the light source to the planar waveguide.

[0016] Another claimed embodiment sets forth a method for performing sample analysis. Light is provided from a light source along a propagation vector. A refractive volume positioned proximate to a planar waveguide is illuminated with the light. The waveguide is oriented such that the propagation vector is perpendicular to the normal vector of the planar waveguide and offset from the planar waveguide in a direction parallel to the normal vector of the planar waveguide. The light is then coupled to the planar waveguide via the refractive volume.

[0017] Apparatus for performing biological assays is disclosed in yet another claimed embodiment. The apparatus includes a light source, a planar waveguide, a refractive volume, and a detector. The light source provides light along a propagation vector. The planar waveguide has a plurality of specific binding molecules bound to a face thereof. The planar waveguide could further have an array of two or more dissimilar specific binding molecules bound to the face thereof. Additionally, the optical axis of the planar waveguide is oriented parallel to the propagation vector and offset from the propagation vector in a direction perpendicular to a face of the planar waveguide. The refractive volume optically couples light provided by the light source to the planar waveguide and is positioned proximate to the planar waveguide. The refractive volume includes at least a section of a plano-convex cylindrical lens. The detector is positioned to detect light emitted from a region proximate to the face of the planar waveguide having the plurality of specific binding molecules bound thereto.

BRIEF DESCRIPTION OF THE FIGURES

[0018] FIGURE 1 illustrates several examples of existing coupling schemes involving multimode waveguides.

[0019] FIGURE 2 illustrates a generalized configuration descriptive of exemplary embodiments.

[0020] FIGURE 3 illustrates a cross-sectional view of an exemplary waveguide with an integrated lens.

[0021] FIGURE 4 provides a detailed cross-sectional view of the waveguide with the integrated lens depicted in FIGURE 3.

[0022] FIGURE 5 is a cavalier projection view illustrating the exemplary waveguide with the integrated lens.

[0023] FIGURE 6 is a cavalier projection view illustrating an exemplary gasket with multiple channels.

[0024] FIGURE 7 is a flowchart of an exemplary method for performing sample analysis.

DETAILED DESCRIPTION

[0025] Embodiments of the present technology provide for sample illumination such as that involved in fluorescence detection and assay based on evanescent fields using apparatus comprising a waveguide with an integrated lens. The overall configuration of the apparatus may be such that fluorescence-emitting molecules bound to a waveguide surface are excited by an evanescent field penetrating into the adjacent solution from a light beam propagated within the waveguide, the propagated beam being introduced by an integrally connected lens. The collimated beam of light such as a laser beam may propagate parallel to the waveguide surface such that the system is insensitive to translation of the waveguide. The incident beam may be also appropriately offset from the optical axis of the waveguide such that refraction of the light at the lens surface directs the beam into the waveguide at an angle close to the critical angle for TIR. Additionally, a second integrated cylindrical lens may be added to the output end of the waveguide. This may

facilitate a second laser being coupled in the opposite direction, such as for multi-color fluorescence assays.

[0026] The apparatus may also allow a fluidic chamber to be bound to the planar waveguide such that the chamber contact with the planar waveguide is outside the optical path of the propagating light, eliminating restrictions on optical properties of material comprising the chamber. In some previous configurations, fluidic chambers have utilized low index of refraction materials in contact with the planar waveguide with mechanical clamping in order to limit optical losses at the waveguide / chamber contact area. By separating the waveguide / chamber contact from the optical path, traditional bonding methods such as adhesives or plastic welding can be used to attach the chamber to the waveguide. Moreover, the fluidic chamber may comprise or be formed in part by a second planar waveguide, wherein the fluidic chamber is disposed between two planar waveguides. In such an arrangement light may be coupled to both planar waveguides as well as the volume formed by the fluidic chamber.

[0027] FIGURE 2A illustrates a generalized configuration **200** descriptive of exemplary embodiments. The configuration **200** includes a light source **205**, a refractive volume **210**, and a planar waveguide **215**. The light source **205** can include a laser or any other source of collimated or near-collimated light that provides light along a propagation vector **220**. The refractive volume **210** is positioned proximate to the planar waveguide **215**. The refractive volume **210** and the planar waveguide **215** may lack a discontinuity in index of refraction therebetween. For example, the refractive volume **210** may be adjacent to or abutted to the waveguide **215** with an index matching fluid occupying any gap therebetween. Alternatively, the refractive volume **110** may be integrated with the planar waveguide **215** as a single unit or article. The planar waveguide **215** is oriented such that the propagation vector **220** is perpendicular to the normal vector **225** of the planar waveguide **215**. Furthermore, the planar waveguide has an offset **230** in a direction parallel to the normal vector **225** of the planar waveguide **215**.

[0028] FIGURE 3 illustrates an exemplary cross-sectional view **300** of a waveguide **305** with an integrated lens **310** according to one embodiment. Additionally, the

view 300 depicts a collimated light beam 315 such as that of a laser with a wavelength appropriate to excite fluorescent probes at an assay surface 320. The planar waveguide 305 with the associated lens 310 is configured to inject the excitation light 315 through the bottom of the planar waveguide 305. A flowcell comprising a sealing mechanism such as a gasket 325, an inlet port 330, an output port 335, and a fluid sample chamber 340 in which chemical compounds deposited on the top surface 320 of the waveguide may bind the desired target compound to the surface. Collection and filtering optics 345 can capture fluorescence from the top surface 320 of the waveguide. The fluorescence signal can then be directed to an imaging device 350 such as a CCD or CMOS camera. Furthermore, the roof, the floor, and/or the walls of the flow cell may be used as a surface on which compounds are deposited.

[0029] It is noteworthy that the fluidic sample chamber 340 may comprise or be formed in part by a second planar waveguide, similar to the waveguide 305, such that the fluidic sample chamber 340 is disposed between two planar waveguides. In such a configuration, light may be coupled to both planar waveguides as well as the volume formed by the fluidic sample chamber 340. The principles described herein are similarly applicable to configurations having multiple planar waveguides.

[0030] FIGURE 4 provides a detailed cross-sectional view 400 of the waveguide 305 with the integrated lens 310. For further reference, FIGURE 5 is a cavalier projection view 500 illustrating the exemplary waveguide 305 with the integrated lens 310. Referring back to FIGURE 4, the collimated light beam 315 propagates in a direction parallel or nearly parallel to the optical axis of the planar waveguide 305, but offset from the optical axis such that it strikes the curved surface of the cylindrical lens 310. For a clinical instrument in which the waveguide structure is a removable consumable item, this geometry may loosen the positional tolerances necessary to couple the collimated light 315 reproducibly to the waveguide 305. The light 315 impinges on the curved surface of the lens 310 at a non-zero angle α relative to the local surface normal of the lens 310, as illustrated in FIGURE 4.

[0031] As a result of refraction explained by Snell's law, the light beam 315 refracts such that it strikes the top surface of the waveguide 305 at an angle β relative to the

optical axis of the waveguide 305. The angle β is defined as the internal propagation angle. The vertical distance y between the center of the light beam 315 and the apex of the cylindrical lens 310 is chosen such that β is less than the complement of the critical angle allowing total internal reflection to occur. For a given radius R for the curved surface of the lens 310 and index of refraction n for the cylindrical lens 310, the distance y and angle β are related by the equation:

$$y = R \left[1 - \frac{n \sin \beta}{\sqrt{1 - 2n \cos \beta + n^2}} \right].$$

[0032] Since the light beam 315 has a spatial extent, the curved surface of the lens 310 will act to focus the light beam 315. The radius R of the curved surface of the lens 310 is chosen such that for a given beam diameter of the light beam 315, the range of angles incident on the top surface of the waveguide 305 is appropriate to provide a uniform evanescent field strength within the detection region while remaining outside the critical angle for TIR. It may be desired that the light beam 315 focus on the top surface of the waveguide 305 to allow for the greatest tolerance to misalignment. The total thickness t for the structure comprising the waveguide 305 and lens 310 that leads to a focused beam on the top surface may be given by:

$$t = R + \frac{(y - R)^3}{R^2 n^2}.$$

[0033] When an appropriate thickness t is used, the light beam 315 will focus at a horizontal distance L from the center of the circle defining the curved surface of the lens 310. L may be related to the previously defined quantities by the equation:

$$L = \frac{t - y}{\tan \beta} - \sqrt{2yR - y^2}.$$

[0034] The structure comprising the waveguide 305 and lens 310 may be manufactured in several different ways. One method is to have the entire assembly constructed in plastic by injection molding technology. An alternative method is to fabricate the planar waveguide and lens element separately from similar index

materials. The two elements may then be joined permanently by a transparent optical cement, optical contacting, or temporarily with index matching fluid/oil/gel.

[0035] Geometries such as those described in connection with FIGURE 3 easily allow the adjustment of the internal propagation angle (β) through a translation, rather than a rotation, of the incident laser beam. This allows for a less complicated mechanical design to couple the laser to the waveguide. Additionally, a new injection molded waveguide is not necessary when it is desired to change the incident angle because the focal point of the lens using the disclosed geometry of FIGURES 3 and 4 is very insensitive to the translation of a laser beam relative to the optical axis of the waveguide 305. Further, a desired change in the incident angle is accomplished without changing the readout instrument, allowing variation of cartridge function without physical changes in the instrument. A barcode on the cartridge may be utilized to identify information used to interpret signals from a given cartridge.

[0036] To prevent light from leaking from the waveguide 305 after the first reflection from the top surface, the cylindrical lens 310 is truncated such that it does not extend beyond the location of the focus. The area defined by the line connecting the apex of the cylindrical lens 310 and the point on the bottom surface opposite the focus (see, *e.g.*, 'optical deadzone 355' in FIGURE 3) will never have light propagate in it that successfully couples to the waveguide. As such, the precise shape of the lens in the area designated optical deadzone 355 can comprise any convenient shape provided the lens 310 does not extend beyond the vertical line passing through the focus. For a single injection molded device where minimizing material costs is important, removing all plastic in the area labeled optical deadzone 355 may be desirable. If two separate components made through conventional optical manufacturing processes are fabricated, a traditional cylindrical lens 310 that has been diced to remove material beyond the focus can be easily manufactured. A material that has low autofluorescence properties may be desirable to minimize background contributions in the signal collection.

[0037] Because the cylindrical lens 310 is used in off-axis geometry, minor optical aberrations at the focus may be exhibited if the curved surface is circular. While a

circular profile functionally works, the use of an aspheric surface may be employed to extend the range of the vertical position of the incident beam for which the beam will be coupled to the planar waveguide 305, allowing a larger range of adjustment of the angle β . The appropriate deviation from a circular profile can be calculated with optical ray tracing programs familiar to those skilled in the art.

[0038] The large area of the top surface of the waveguide 305 before the focus may allow for a sample chamber to be sealed. The gasket 325 sealing surface may be absent from the optical path. Therefore, a larger range of gasket materials may be possible that only need to be evaluated for their chemical/biological compatibility and not their optical properties. For example, an adhesive backed spacer can be utilized to form a sealed flowcell without a complicated clamping mechanism. Multiple flow cells can also be incorporated into a single biosensor by utilizing a gasket with multiple channels.

[0039] FIGURE 6 is a cavalier projection view illustrating an exemplary gasket 605 with multiple channels. The width of the channel may be chosen to match the unfocused dimension of the incident beam such that light coupling to the gasket along the length of the waveguide is minimized. A mechanism for translating the incident beam between channels may be included. In addition, the top surface of the waveguide 305 within the flow channels may be appropriately treated to allow for the capture of fluorescently labeled target molecules such as proteins, RNA, DNA, or cellular structures.

[0040] A lid attached to the gasket completes the flow cell. Fluid samples can be introduced through orifices in the lid and flow through the channels, allowing the fluid to interact with the top waveguide surface. Fluid reservoirs exterior to the flow channel can also be included to allow the introduction of fluids into the flow channel and an overflow reservoir at the outlet port of the flow channel to contain the fluid after it has passed through the flow channel. With plastic components, the gasket can be optionally eliminated by molding the channels into one of the plastic components and joining the two plastic components directly with methods known to those skilled in the art (e.g., laser or ultrasonic welding).

[0041] The evanescent field created by the light within the waveguide 305 can excite fluorophores that have attached to the top surface of the waveguide 305. As the fluorophores relax and emit frequency shifted radiation, the emitted light may be captured by a lens or series of lenses (*e.g.*, the collection optics 345) to transfer an image of the surface to a plane that is imaged by a light capturing device (*e.g.*, the imaging device 350) such as a CCD or CMOS sensor. An optical filter can also be placed between the waveguide surface and the imaging device to eliminate scattered incident light that has not been frequency shifted by the captured fluorophores.

[0042] FIGURE 7 is a flowchart of an exemplary method 700 for performing sample analysis. The steps of the method 700 may be performed in varying orders.

Furthermore, steps may be added or subtracted from the method 700 and still fall within the scope of the present technology. The methodology illustrated in FIGURE 7 may be performed for fluorescence detection and assay based on evanescent fields.

[0043] In step 705, light is provided from a light source along a propagation vector. The light source can include a laser or any other source of collimated or near-collimated light.

[0044] In step 710, a refractive volume is illuminated with the light. The refractive volume is positioned proximate to, and may be integrated with, a planar waveguide. In exemplary embodiments, the refractive volume may include at least a section of a plano-convex cylindrical lens, wherein the longitudinal axis of the refractive volume is oriented perpendicular to the optical axis and the normal vector of the planar waveguide.

[0045] In step 715, the light is coupled to the planar waveguide via the refractive volume. The waveguide is oriented such that the propagation vector is perpendicular to the normal vector of the planar waveguide and offset from the planar waveguide in a direction parallel to the normal vector of the planar waveguide.

[0046] In optional step 720, the optical coupling of the light provided by the light source to the planar waveguide is tuned by translating the light source in a direction parallel to the normal vector of the planar waveguide.

[0047] In step 725, consistent optical coupling of the light provided by the light source to the planar waveguide is maintained while translating the light source parallel to the optical axis of the planar waveguide.

[0048] In step 730, a biological sample is positioned in a reservoir formed at least in part by a face of the planar waveguide.

[0049] In step 735, light emitted from a region proximate to a face of the planar waveguide is detected. In some embodiments, a detector is positioned to detect light emitted from a region proximate to the face of the planar waveguide having a plurality of capture molecules bound thereto.

[0050] The present invention has been described above with reference to exemplary embodiments. It will be apparent to those skilled in the art that various modifications may be made and other embodiments can be used without departing from the broader scope of the invention. Therefore, these and other variations upon the exemplary embodiments are intended to be covered by the present invention.

CLAIMS

What is claimed is:

1. Apparatus for illuminating a sample for analysis, the apparatus comprising:
 - a light source for providing light along a propagation vector;
 - a planar waveguide oriented such that the propagation vector is perpendicular to the normal vector of the planar waveguide and offset from the planar waveguide in a direction parallel to the normal vector of the planar waveguide; and
 - a refractive volume for optically coupling light provided by the light source to the planar waveguide, the refractive volume positioned proximate to the planar waveguide.
2. The apparatus of claim 1, wherein a relative translation of the light source parallel to the optical axis of the planar waveguide is inconsequential to the optical coupling of the light provided by the light source to the planar waveguide.
3. The apparatus of claim 1, wherein an internal propagation angle of light in the planar waveguide is tuned by a relative translation of the light source in a direction parallel to the normal vector of the planar waveguide.
4. The apparatus of claim 1, wherein the planar waveguide has a plurality of capture molecules bound to a face thereof
5. The apparatus of claim 1, further comprising a detector positioned to detect light emitted from a region proximate to a face of the planar waveguide.
6. The apparatus of claim 1, wherein the refractive volume comprises at least a section of a plano-convex cylindrical lens.
7. The apparatus of claim 1, wherein the light source includes one or more of a laser, a white light source, or a light emitting diode.

8. The apparatus of claim 1, wherein the refractive volume is shaped to minimize an optical aberration.
9. The apparatus of claim 1, wherein the planar waveguide and the refractive volume are integrated as a single article.
10. The apparatus of claim 1, wherein the refractive volume and the planar waveguide lack a discontinuity in index of refraction therebetween.
11. The apparatus of claim 1, further comprising a fluidic chamber, a first side of the fluidic chamber abutted to a face of the planar waveguide having a plurality of capture molecules bound thereto.
12. The apparatus of claim 11, wherein a region defined at least partially by the face of the planar waveguide having the plurality of specific binding molecules bound thereto and the fluidic chamber forms a reservoir for biological samples.
13. The apparatus of claim 11, wherein the fluidic chamber further comprises a second planar waveguide.
14. The apparatus of claim 13, wherein the refractive volume is configured for optically coupling light into the planar waveguide and second planar waveguide, such that guided light illuminates the volume disposed between the planar waveguide and the second planar waveguide.
15. A method for performing sample analysis, the method comprising:
 - providing light from a light source along a propagation vector;
 - illuminating a refractive volume positioned proximate to a planar waveguide with the light; and
 - coupling the light to the planar waveguide via the refractive volume, the waveguide oriented such that the propagation vector is perpendicular to the normal

vector of the planar waveguide and offset from the planar waveguide in a direction parallel to the normal vector of the planar waveguide

16. The method of claim 15, further comprising tuning the optical coupling of the light provided by the light source to the planar waveguide by translating the light source in a direction parallel to the normal vector of the planar waveguide.

17. The method of claim 15, further comprising maintaining consistent optical coupling of the light provided by the light source to the planar waveguide while translating the light source parallel to the optical axis of the planar waveguide.

18. The method of claim 15, further comprising positioning a biological sample in a reservoir formed at least in part by a face of the planar waveguide.

19. The method of claim 15, further comprising detecting light emitted from a region proximate to a face of the planar waveguide.

20. Apparatus for performing biochemical assays, the apparatus comprising:

- a light source for providing light along a propagation vector;

- a planar waveguide having a plurality of capture molecules bound to a face thereof, the optical axis of the planar waveguide oriented parallel to the propagation vector and offset from the propagation vector in a direction perpendicular to a face of the planar waveguide;

- a refractive volume for optically coupling light provided by the light source to the planar waveguide, the refractive volume positioned proximate to the planar waveguide and comprising at least a section of a plano-convex cylindrical lens, the longitudinal axis of the refractive volume being oriented perpendicular to the optical axis of the planar waveguide; and

- a detector positioned to detect light emitted from a region proximate to the face of the planar waveguide having the plurality of capture molecules bound thereto.

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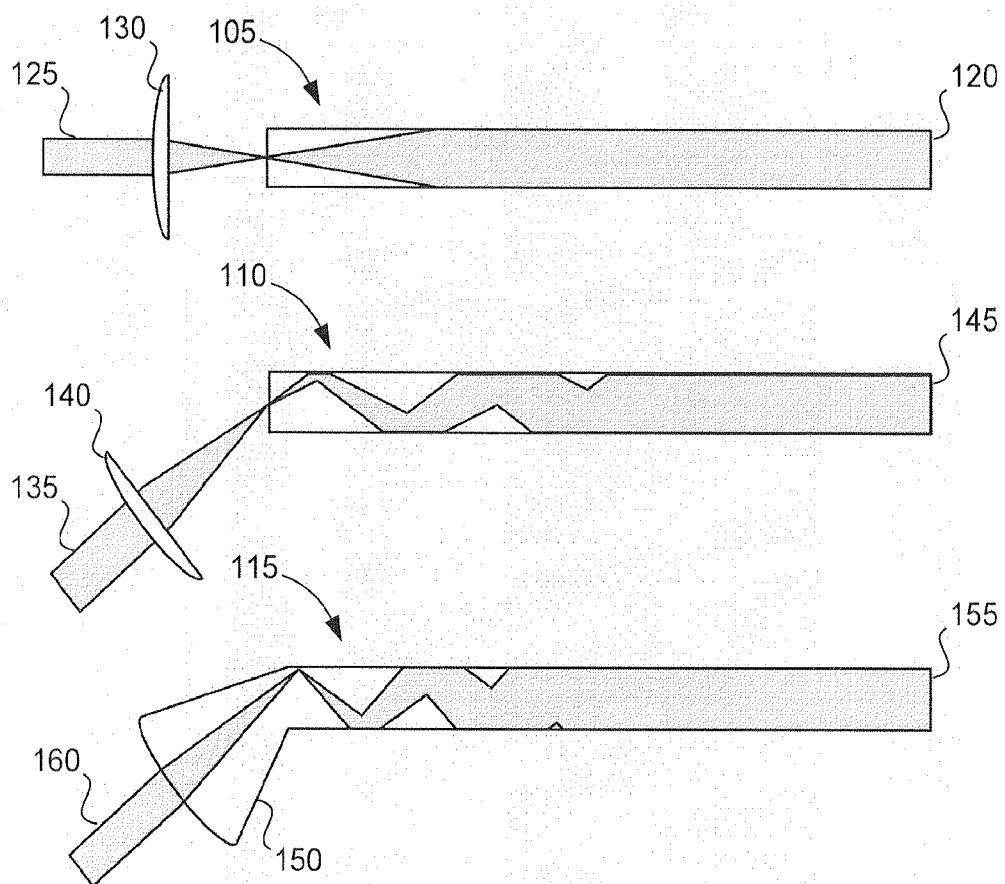


FIGURE 1 (PRIOR ART)

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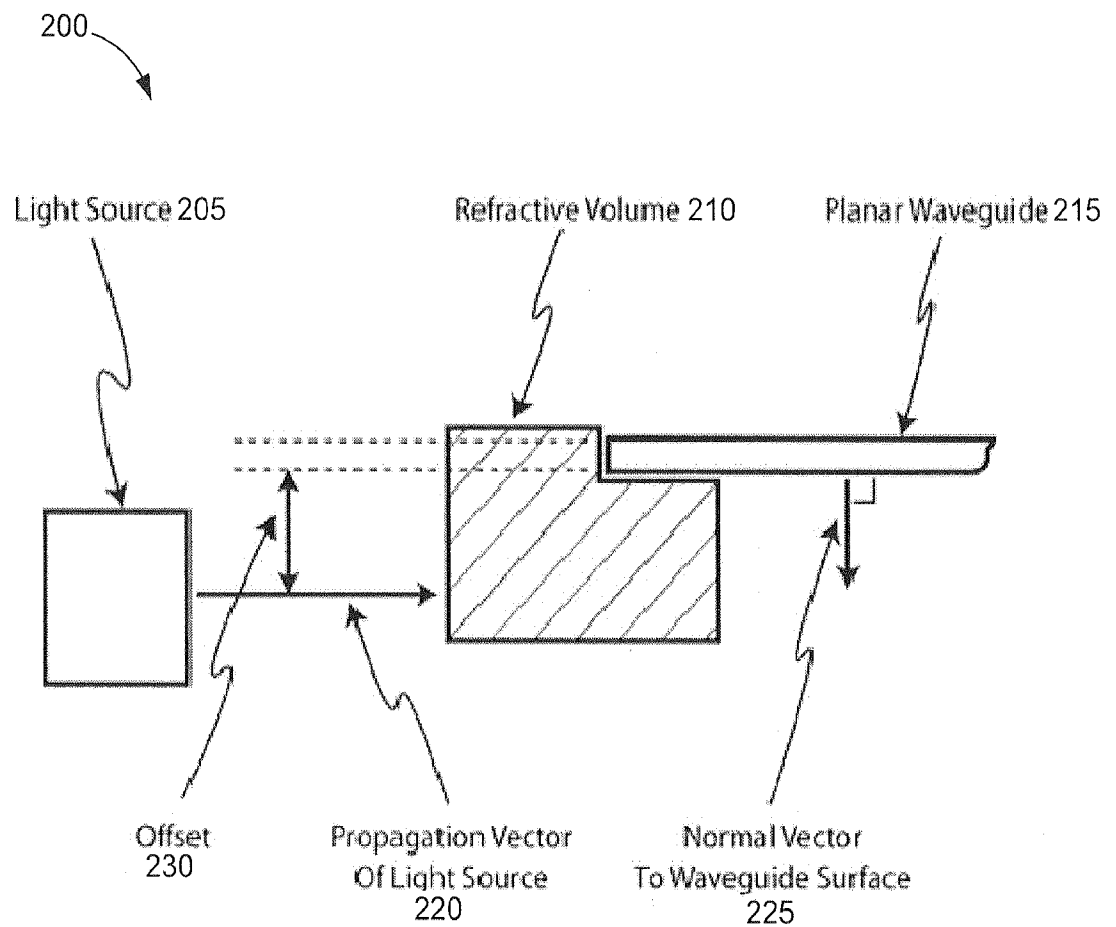


FIGURE 2

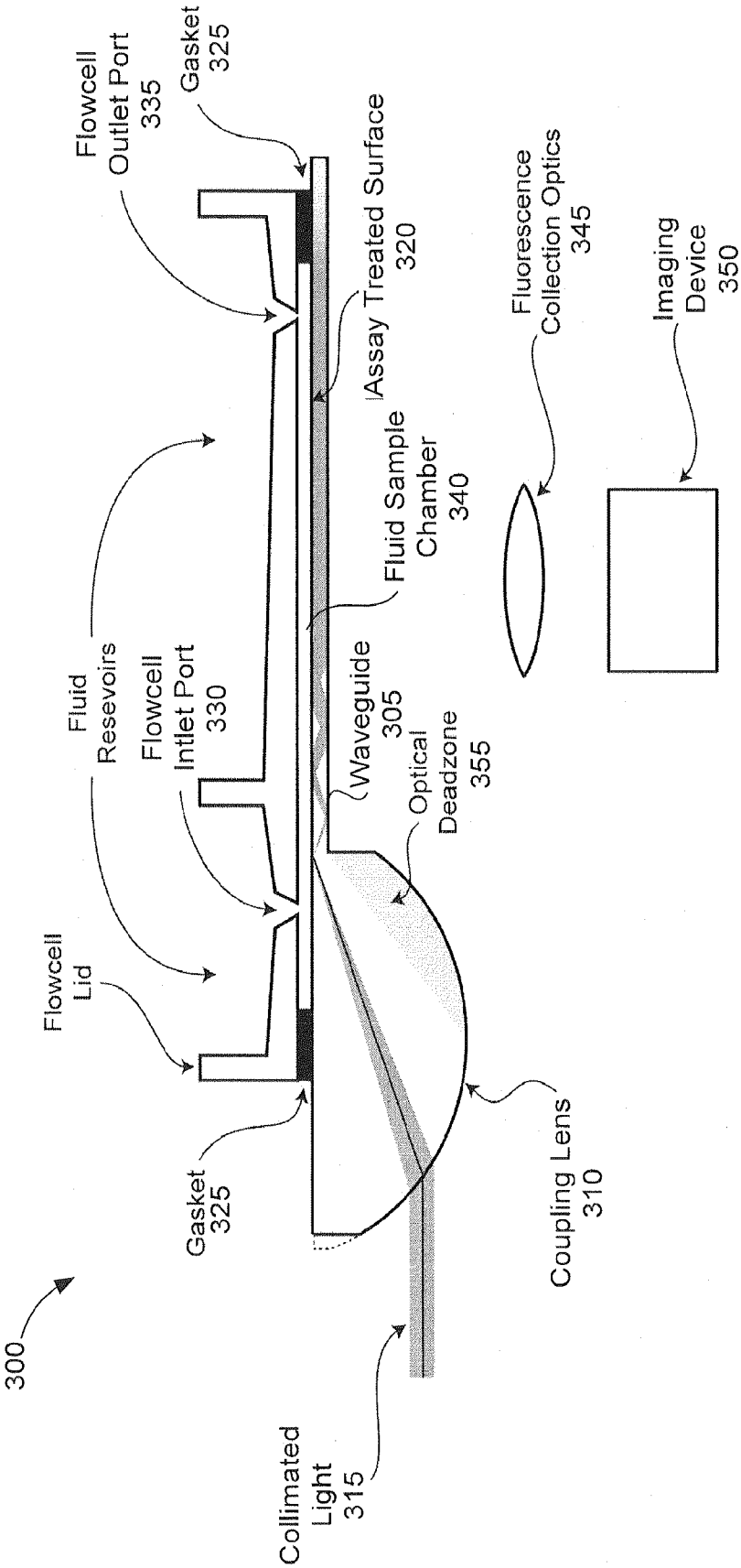


FIGURE 3

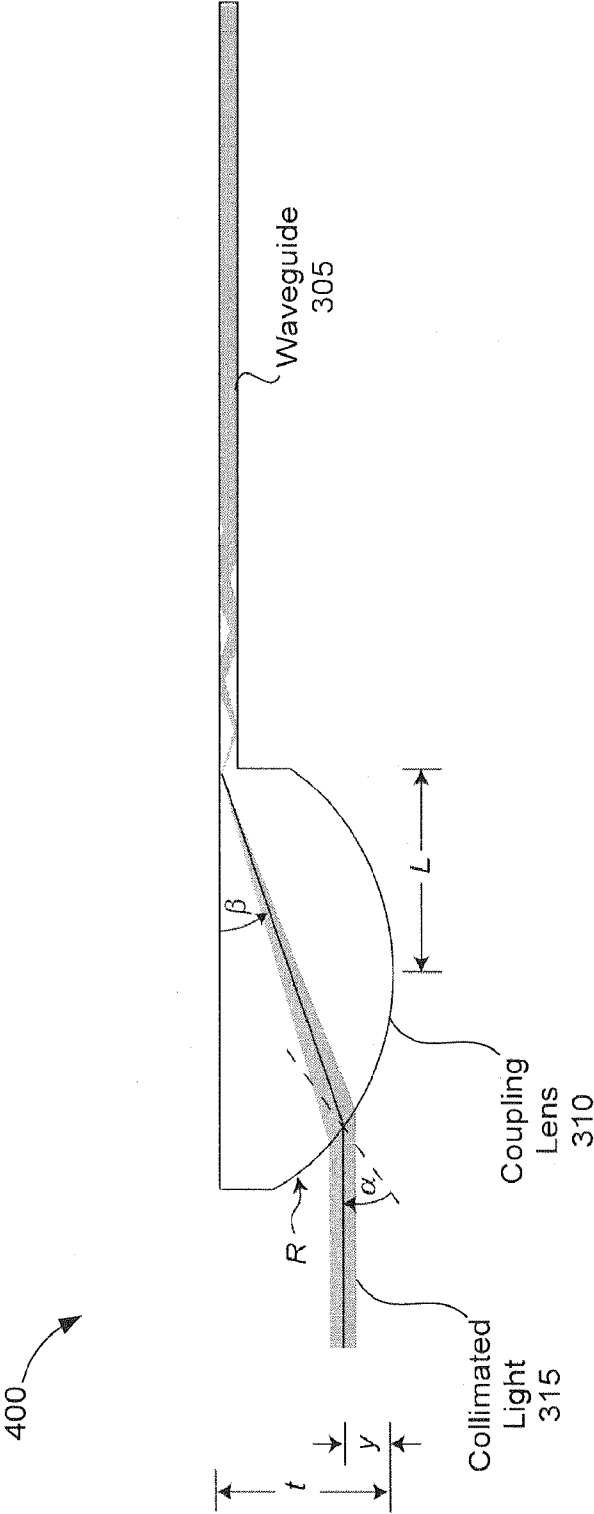


FIGURE 4

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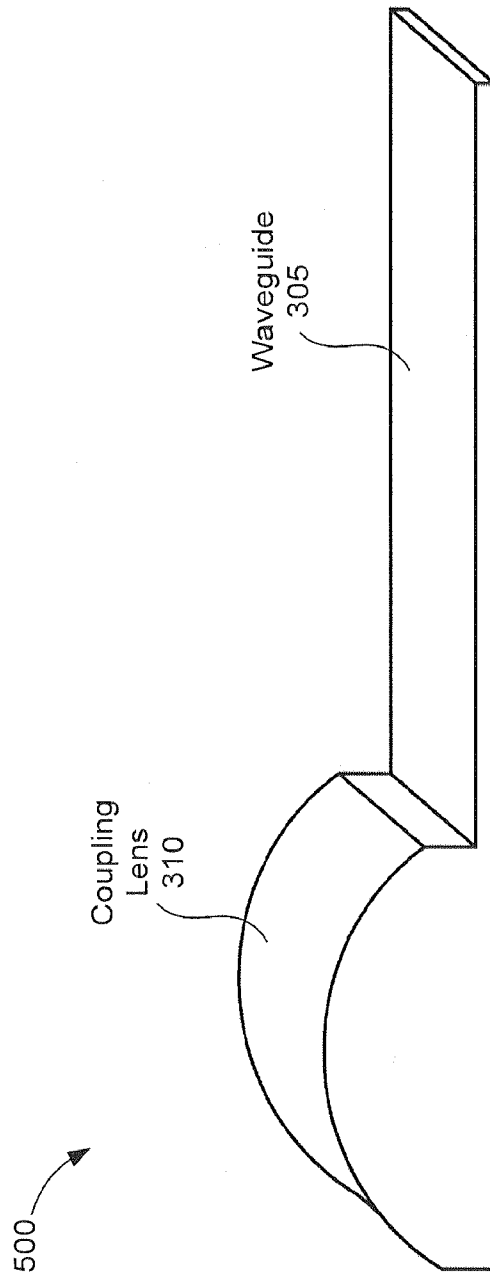


FIGURE 5

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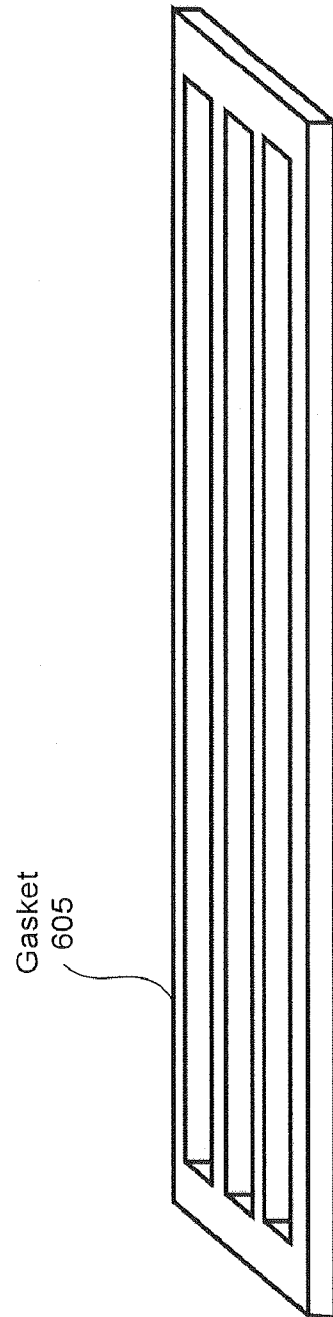


FIGURE 6

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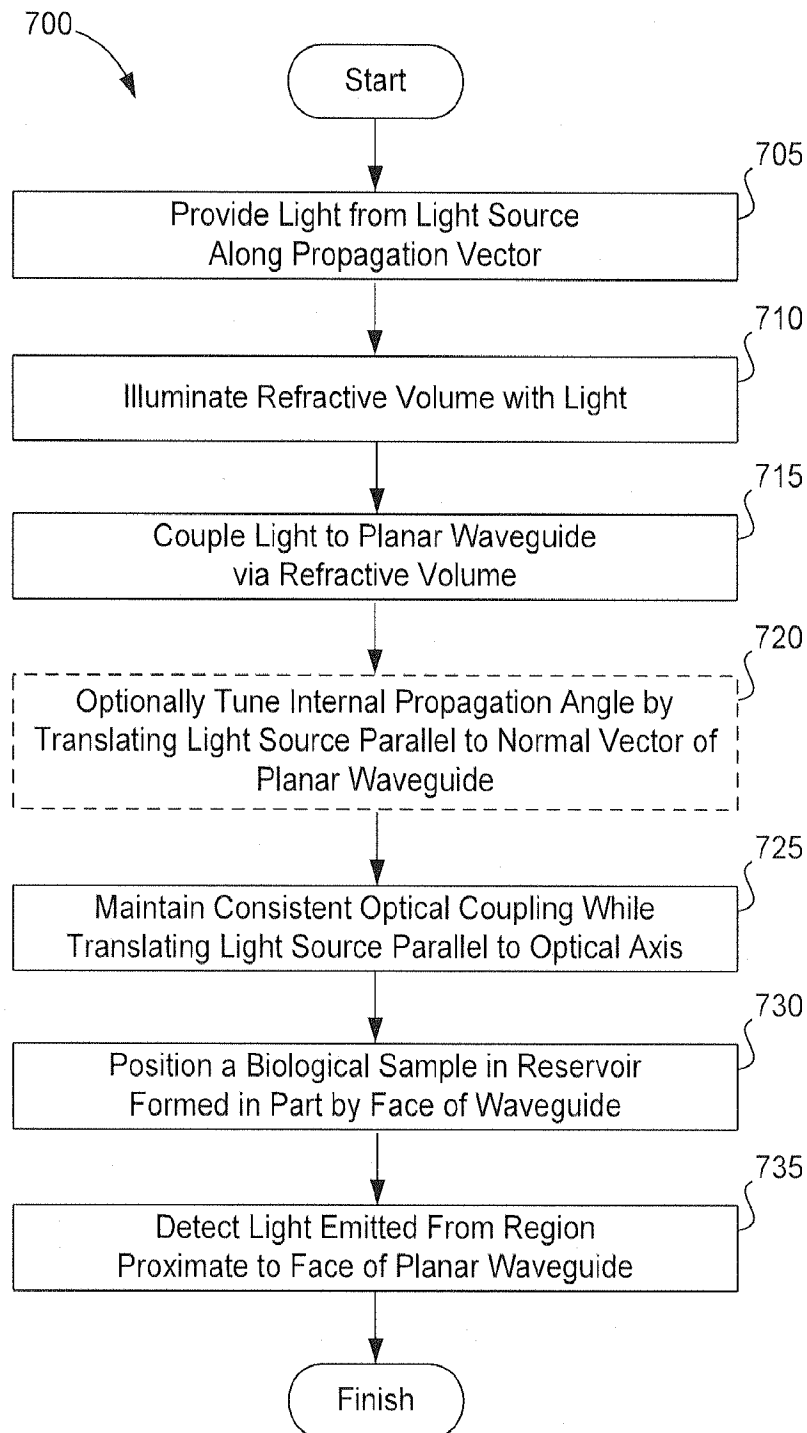


FIGURE 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 10/25172

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G02B 6/10; G02B 6/32

USPC - 385/33, 129

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

USPC:385/33, 129

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 385/31, 33, 129; 362/610, 611 / IPC: G02B 6/10; G02B 6/32 (see search terms below)

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

PubWest (PGPB, USPT, USOC, EPAB, JPAB), Google Scholar, USPTO

Search Terms: waveguide, lens, integrate, propagate, capture, molecules, offset, align, biological, fluid, cell, illuminate, planer, between, biochemical assays, plano convex,

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	US 6,954,580 B2 (Soskind et al.) 11 October 2005 (11.10.2005) entire document especially Fig. 9, col 7, ln 62 to col 8, ln 2, col 5, ln 65 to col 6, ln 14, and col 6, ln 36 to col 7, ln 7.	1, 2, 6, 8, and 15 ----- 3-5, 7, 9-14, and 16-20
Y	US 6,611,634 B2 (Herron et al.) 26 August 2003 (26.08.2003) entire document especially col 9, ln 50-67, Fig. 8, col 10, ln 18-34, col 9, ln 39-49, col 7, ln 59-65, col 4, ln 60 to col 5, ln 30, col 5, ln 46-49, and col 9, ln 11-37.	3-5, 7, 9-14, and 16-20
A	US 2010/00220318 (Moll et al.) 02 September 2010 (02.09.2010) entire document.	1-20

☐ Further documents are listed in the continuation of Box C.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search

25 October 2010 (25.10.2010)

Date of mailing of the international search report

08 NOV 2010

Name and mailing address of the ISA/US

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