



(11) **EP 1 266 207 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention
of the grant of the patent:
27.10.2010 Bulletin 2010/43

(51) Int Cl.:
G01N 21/77 (2006.01) **G01N 21/47** (2006.01)
G01N 33/543 (2006.01)

(21) Application number: **01914906.1**

(86) International application number:
PCT/CA2001/000367

(22) Date of filing: **22.03.2001**

(87) International publication number:
WO 2001/071322 (27.09.2001 Gazette 2001/39)

(54) **METHOD AND APPARATUS FOR MULTIPLE-ANALYTE ASSAY**

VERFAHREN UND VORRICHTUNG ZUR BESTIMMUNG MEHRERER ANALYTEN

PROCEDE ET APPAREIL POUR UN DOSAGE DESTINE AUX ANALYTES MULTIPLES

(84) Designated Contracting States:
**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE TR**

(30) Priority: **22.03.2000 US 191344 P**

(43) Date of publication of application:
18.12.2002 Bulletin 2002/51

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a method and apparatus for detecting multiple analytes in a medium, and more particularly the present invention relates to a method of assaying based on light diffraction which appears or changes upon the binding of analytes to their specific receptors laid out in patterns on a substrate.

BACKGROUND OF THE INVENTION

[0002] In many instances, it is desirable to determine the presence and the amount of a specific material in solution (the 'medium'). Surface-based assays rely on the interaction of the material to be assayed (the 'analyte') with a surface that results in a detectable change in any measurable property. For the purpose of this patent application, the term 'analyte' refers to the material to be assayed. Examples of analytes include: an ion; a small molecule; a large molecule or a collection of large molecules such as a protein or DNA; a cell or a collection of cells; an organism such as a bacterium or virus. 'Analyte-specific receptor, or 'recognition element' refers to that complementary element that will preferentially bind its partner analyte. This could include: a molecule or collection of molecules; a biomolecule or collection of biomolecules, such as a protein or DNA; a groove on the substrate that has the complementary geometry and/or interaction. In general, in order to assay for a specific analyte, the surface is modified so as to offer the appropriate chemical interaction. In immunoassays, for example, one takes advantage of the specificity of the antibody-antigen interaction: A surface can be coated with an antigen in order to assay for the presence of its corresponding antibody in the solution. Similarly, a strand of deoxyribonucleic acid (DNA) can be attached to a substrate and used to detect the presence of its complementary strand in solution. In any of these cases, the occurrence of binding of the analyte to its recognition element on the surface, which thus identifies the presence of the specific analyte in solution, is accompanied by a detectable change. For example, the binding can produce a change in the index of refraction at the interfacial layer; this can be detected by ellipsometry or surface plasmon resonance. Alternatively, the bound analyte molecules may emit light; this emission can be collected and detected, as is the case for fluorescence-based sensors. Non-optical signals may also be used, as in the case of radio immunoassays and acoustic wave sensing devices.

[0003] Diffraction is a phenomenon that occurs due to the wave nature of light. When light hits an edge or passes through a small aperture, it is scattered in different directions. But light waves can interfere to add (constructively) and subtract (destructively) from each other, so that if light hits a non-random pattern of obstacles, the subsequent constructive and destructive interference will result

in a clear and distinct diffraction pattern. A specific example is that of a diffraction grating, which is of uniformly spaced lines, typically prepared by ruling straight, parallel grooves on a surface. Light incident on such a surface produces a pattern of evenly spaced spots of high light intensity. This is called Bragg scattering, and the distance between spots (or 'Bragg scattering peaks') is a unique function of the diffraction pattern and the wavelength of the light source. There is a unique correspondence between a pattern and its diffraction image, although in practice, diffraction is best illustrated by using periodic patterns, because these yield easily recognized diffraction images of clearly defined regions of high and low light intensity.

[0004] Diffraction techniques are commonly used in studies of molecular structure; specifically, X-ray diffraction is used in the identification of chemical compounds and in the determination of protein structures. However, the principle of diffraction, especially in the optical domain, has rarely been invoked for use in assays.

[0005] United States Patent No. 4,647,544 (Immunoassay using optical interference detection) describes a light optical apparatus and method, in which a ligand, or an antibody, is arranged in a predetermined pattern, preferably stripes, on a substrate, and the binding between ligand and antiligand, or between an antibody and an antigen, is detected by an optical detector set at the Bragg scattering angle, which is expected to arise due to optical interference. The pattern of ligand or antibody is created by first laying out a uniform layer of antibody on a substrate, then deactivating sections of this coverage.

[0006] U.S. Patent No. 4,537,861 issued to Elings et al. discloses an apparatus and method for homogeneous assay of binding reactions between a ligand and an antiligand using a spatial pattern formed on a substrate. The assay technique is based on detecting fluorescence from fluorescent labeled molecules.

[0007] U.S. Patent No. 4,931,384 issued to Layton et al. discloses an optical assay technique which uses a preformed textured surface which involves producing a textured surface, and coating the bottoms of the troughs with analyte specific receptors. Changes in the optical properties of the combination are observed after exposure to samples containing analytes for the specific receptors on the surface.

[0008] U.S. Patent No. 5,986,762 issued to Challener discloses an optical sensor with an optimized surface profile for detecting analytes using Surface Plasmon Resonance (SPR).

[0009] United States Patent No. 4,876,208 to Gustafson et al. (Diffraction Immunoassay apparatus and method) describes the apparatus and reagents for an immunoassay based on a silicon or polysilicon substrate with a pattern of evenly spaced lines of a biological probe (a 'biological diffraction grating') to which binding can take place. The pattern is created by first coating the substrate with an even layer of antibodies, then deacti-

vating regions by the use of a mask and of ultraviolet (UV) lights. This idea is extended to the assay of DNA in United States Patent No. 5,089,387 (DNA probe diffraction assay and reagents), which describes a biological diffraction grating, and a process for its manufacture by first immobilizing a uniform layer of hybridizing agent on a smooth surface, and then exposing this surface to UV radiation through a mask with diffraction grating lines. The UV exposure deactivates the hybridizing agent, leaving a pattern of lines of active hybridizing agents.

[0010] The above patents on assays by diffraction are necessarily restricted to the case of a single analyte. In United States Patent Nos. 4,876,208 and 5,089,387, the described techniques are extended to the case of multiple analytes by making biogratings with identical patterns of different analyte-specific receptors on different areas of a substrate and then measuring the diffraction due to each pattern measured independently of the others.

[0011] United States Patent No. 5,922,550 to Everhart et al. (Biosensing devices which produce diffraction images) describes a device and method for detecting and quantifying analytes in a medium based on having a predetermined pattern of self-assembling monolayer with receptors on a polymer film coated with metal. The size of the analytes are of the same order as the wavelength of transmitted light, thereby its binding results in a diffraction pattern that is visible. This patent also describes a method of producing the patterned surface by microcontact printing of the self-assembled monolayer of receptors on a metal-coated polymer. This is extended to the case of a predetermined pattern of receptors (not necessarily self-assembling) in United States Patent No. 6,060,256 (Optical Diffraction Biosensor). The technique of microcontact printing of self-assembled monolayers on a metal substrate is described in United States Patent No. 5,512,131 (Formation of microstamped patterns on surfaces and derivative articles).

[0012] Microcontact printing is a technique of forming patterns of micrometer dimensions on a surface using an elastomeric stamp; the material to be patterned serves as the "ink" and is transferred by contacting the stamp to the surface. Microcontact printing of proteins on silicon, silicon dioxide, polystyrene, glass and silanized glass is reported in Bernard, A.; Delamarche, E.; Schmid, H.; Michel, B.; Bosshard, H.R.; Biebuyck, H.; "Printing Patterns Of Proteins" *Langmuir* (1998), 14, 2225-2229.

[0013] To utilize diffraction techniques in surface-based assays, it is important to be able to produce a material patterned with receptors, and the five patents discussed above have outlined their ways of doing so. In addition, other techniques that exist in the literature may be adaptable for patterning. For example, using photolithographic techniques, oligonucleotides have been immobilized on a substrate in arrays such that each array is a distinct species. United States Patent Nos. 5,831,070 and 5,599,695 show how this is done through the use of deprotection agents in the gas phase. This approach has not been used in the creation of patterns for diffraction

assays, but can be adapted for such with the design of an appropriate mask.

[0014] It would be very advantageous to provide a method of simultaneously assaying for multiple analytes using diffraction of light.

SUMMARY OF THE INVENTION

[0015] An objective of the present invention is to provide a method and apparatus for the simultaneous assay of multiple analytes using diffraction of light as defined by independent claims 1 and 21. The method involves the laying down of analyte-specific receptors on the surface of a solid substrate, such that each type of receptor defines a distinct pattern. Exposure of the substrate to a medium containing one or more analytes will result in binding events between each analyte and its analyte-specific receptor. These binding events will result in a diffraction image from which can be derived the presence of the analyte(s).

[0016] The sensing element substrate may be transparent and have two opposed surfaces upon which analyte-specific receptors are patterned. The assay is performed by contacting both faces of the substrate with the medium, for example, by dipping.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The invention will now be described, by way of example only, reference being had to the accompanying drawings, in which;

Figure 1 a is a top view of a sensing element for a diffraction assay for detecting two or more analytes having three patterns of analyte-specific receptors with the three patterns interleaved in the same area on the substrate surface;

Figure 1b is a top view of a sensing element for a diffraction assay for detecting two or more analytes having three patterns of analyte-specific receptors with the three patterns spaced from each other on the substrate surface;

Figure 2a shows a diagrammatic illustration of an apparatus for performing an assay in accordance with the present invention using a transmission configuration;

Figure 2b shows a diagrammatic illustration of an apparatus for performing an assay using a reflection configuration;

Figure 2c shows a diagrammatic illustration of an apparatus for performing an assay using a configuration with a rotating mirror to direct the signal to a detector;

Figure 3a is a perspective view of a cell for performing an assay in the static mode;

Figure 3b is a cross-sectional view showing an embodiment of a flow cell constructed for performing the present assay;

Figure 3c is a perspective view of an alternative embodiment of a flow cell constructed in accordance with the present invention;

Figure 3d is a cross-sectional view of a flow cell using total internal reflection;

Figure 4 shows a glass substrate patterned with goat immunoglobulin G (IgG) by microcontact printing, visualized by atomic force microscopy;

Figure 5 shows a glass substrate patterned with goat IgG and rabbit IgG produced by microcontact printing using a stamp for both having the same pattern but rotated $\sim 90^\circ$ with respect to each other, the images being obtained by atomic force microscopy.

Figure 6 shows a glass substrate patterned with mouse IgG and rabbit IgG produced by microcontact printing using a stamp for both having the same pattern but rotated $\sim 30^\circ$ with respect to each other, the images being obtained by atomic force microscopy; Figure 7 shows effect of treating a rabbit and mouse IgG cross-stamped substrate sequentially with the indicated solutions;

Figure 8 shows effect of treating a biotin and fluorescein (both as bovin serum albumin (BSA) conjugates) cross-stamped substrate sequentially with the indicated solutions;

Figure 9 shows the use of an avidin stamped substrate for the detection of single-stranded DNA by the sequential treatment with the indicated solutions; Figure 10 shows the titration of a substrate patterned with rabbit IgG with increasing concentrations of anti-rabbit IgG; and

Figure 11 shows the change in signal over time resulting from the treatment of a biotin-BSA patterned substrate with streptavidin solution.

DETAILED DESCRIPTION OF THE INVENTION

[0018] The present invention provides a method for the assay of multiple analytes on the same general region of a substrate using light diffraction. The method takes advantage of the unique correspondence between a given pattern and its diffraction pattern, in order to assess the presence or absence of specific analytes. Analyte-specific receptors are laid out on the surface of a solid substrate, either directly or through an intervening layer, such that each type of receptor defines a unique pattern. For the purpose of this patent, two patterns are considered 'distinct' or 'unique' if they correspond to diffraction patterns distinguishable from each other. The solid substrate may be transparent, partially transparent, or reflecting at the wavelength of the incident illumination. In the case of a transparent substrate, analyte-specific receptors may be patterned on one or both surfaces of the substrate.

[0019] Figures 1a and 1b depict general representations of two possible layouts of patterns of recognition elements on a substrate. Referring to Figure 1a, a sensing element shown generally at 10 comprises a substrate

12 that holds multiple recognition elements, in this example there are three different recognition elements 14, 16 and 18, with each recognition element laid out in a unique pattern on the surface of the substrate. In this embodiment the patterns 14, 16 and 18 interpenetrate each other in a preselected area of the substrate 12. Under illumination, defined by the circle 13, portions of the different patterns within circle 13 are simultaneously illuminated. Figure 1b shows another sensing element 20 having a substrate 12' having three different analyte-specific receptors laid out in three different unique patterns 21, 23 and 25 distinct from each other but in this case the patterns do not interpenetrate each other.

[0020] Once the recognition element that is capable of specific binding (e.g., protein, oligonucleotide, antibody, etc.) is laid out on the surface in a preselected pattern, the medium to be assayed is contacted with the substrate, allowing analytes present in the medium to bind to their complementary recognition element. When a particular analyte is present in the medium, the subsequent binding event between analyte and its complementary recognition element is accompanied by a change in the local thickness of the layer on the substrate and/or in the local index of refraction. Both the change in thickness and the change in index of refraction will alter the optical properties at the interface between the substrate and medium in regions where the binding has taken place. Since the recognition elements are present on the substrate in a predetermined pattern, light incident on the substrate will not be scattered uniformly, but rather will be diffracted. In one embodiment of this invention, the patterned substrate is non-diffracting, and the binding events result in an observable diffraction image. In another embodiment, the patterned substrate itself produces an observable diffraction image, but the binding events alter the intensities of the diffracted signal.

[0021] The pattern of the diffracted light (the 'diffraction image') corresponds to a unique pattern on the substrate. The assay works in the following manner: The substrate is patterned with a multiplicity of analyte-specific receptors, say RA, RB, RC, such that each type of receptor defines a distinct pattern, PA, PB, PC, respectively. (Patterns are considered distinct if they individually correspond to distinguishable diffraction images, say DA, DB, DC respectively). In the case of only one type of analyte present, say AA which is complementary to receptor RA, said analyte will bind to its partner and the pattern corresponding to that of receptor RA will thus be highlighted by a change in refractive index and/or height above the substrate due to this binding event. If the patterned substrate is initially non-diffracting, the binding event will cause the appearance of a diffraction image that looks like DA. Thus, observing a diffraction image that looks like DA immediately identifies the presence of analyte AA bound to receptor RA, and hence the presence of AA in the original medium. The signal intensities at the bright regions (for example, the Bragg peaks if the pattern were a grating) reflect the amount of binding, and can be cal-

ibrated in order to effect quantification of bound analytes, and thus makes for a quantitative assay. If there are a multiplicity of analytes present, say AA, AB, AC, complementary partners to RA, RB, RC respectively, the binding events will produce a diffraction image that is a non-additive composite of DA, DB and DC. That is, patterns DA, DB and DC will be present in the observed diffraction image, but additional features will also be present. In this case, the assay can be effected in either of following manner. (1) The full diffraction image can be stored on a computer, and with the use of image processing and computational tools, the image is deconvoluted into the individual patterns. (2) In a preferred embodiment of this invention, the appearance or change in signal at specific regions of the diffraction image signify the presence of specific analytes. For example, the appearance of a bright region characteristic of DA but not DB or DC is a good marker for the presence of AA. Similar regions can be located for AB and AC, and when electronic detection is employed, their signal intensities can be calibrated (as in the case of only one analyte) in order to effect a quantitative assay. The more analytes and analyte-specific receptor patterns present, the more complex the observed diffraction image will be. It is thus important to choose patterns that are as distinct from each other as possible to enable ease of assay. As well, in simple cases, visual inspection may suffice to indicate distinctness of patterns; that is, one can clearly see that the diffraction image corresponds to DA and not DB. However, as complexity increases, a preferred embodiment of this invention uses an imaging device that will enable a more effective comparison. In one embodiment, the detector obtains the diffraction image as an electronic signal that is stored in a computer, and image processing is utilized. In another embodiment, information is already stored in the computer that will facilitate such interpretation. For example, changes in intensities at specific pixels of the image signify a particular binding event. In this latter case; this information may either be programmed in the computer or encoded in the substrate itself and be read by the apparatus during the assay.

[0022] Referring to Figure 2a, an apparatus for performing an assay in accordance with the present invention is shown generally at 30. Apparatus 30 is configured for transmission and comprises a source of illumination 32, substrate 10 with the patterned recognition elements located on a surface thereof, and a detector 34 for detecting the light after it has been transmitted through the substrate. Figure 2b illustrates another embodiment of an apparatus at 40 constructed in accordance with the present invention that is configured for operating in reflection mode. Figure 2c illustrates another embodiment of an apparatus 50 for use in the transmission mode including a rotating mirror 11 to direct the signal transmitted through substrate 10 to detector 34. A similar design may be used in another embodiment of a reflection configuration.

[0023] Light source 32 may produce a monochromatic

beam, typically light with a wavelength in the range from the ultraviolet to the infrared, but preferably a coherent and collimated light beam, such as would come from a laser (e.g. diode, He-Ne, Nd:YVO₄, Argon-ion). This may be a low power, continuous wave laser. The substrate 10 may either be an optically transmitting or partially transmitting substrate with respect to the wavelength of light used in Figure 2a or it may be reflecting or partially reflecting as shown in Figures 2b and 2c. In one embodiment of this invention, the incident illumination is delivered to the substrate by an optical fibre. In another embodiment of the invention, the incident illumination is scanned (rastered) over the substrate, illuminating one or more recognition elements at a time. Since each pattern is distinct and it is known *a priori* which analyte binds with that pattern, a detection of a change in diffraction image associated with that pattern immediately identifies the presence of that analyte.

[0024] The substrate is preferably flat or smooth enough so that impinging light will not be scattered to such an extent that it obscures or degrades the diffraction signal. Non-limiting examples of substrates that may be used are glass, mica, polished silicon, silicon dioxide, various smooth polymer materials, gold and other metals with reflecting surfaces, either as sheet or as thin films on a support. The substrate may be of any size, but the area of the active region, that which contains the patterns of analyte-specific receptors or recognition elements, should be at least the cross sectional size of the incident beam as it intercepts the surface of the substrate, and preferably of comparable size (indicated by the circles 13 in Figures 1 a and 1 b). In this way each analyte-specific receptor pattern is simultaneously illuminated so that the resulting diffraction image simultaneously gives information about the presence or absence of two or more analytes depending on the number of analyte-specific receptor patterns in the illuminated portion of the substrate.

[0025] In applications in which moisture may be problematic, the substrate may be placed in a cell that is partially evacuated in order to reduce moisture. This is advantageous where it is desirable to reduce the signal strength that may arise due to water condensation. However, in the case where the analytes but not their partner receptors are favoured by water, the presence of water condensation (also called 'condensation figures') can be utilized to enhance the diffracted signal. In another embodiment of the invention, the assay may also be performed *in situ* by placing the substrate into a chamber into which the medium can be introduced. Figure 3a shows a cell 50 with a substrate 52 immersed in a liquid being tested for the presence of one or more of the analytes in a static configuration with no flow-through. Analyte-specific receptors are patterned on one or both surfaces of substrate 52.

[0026] Figure 3b shows a flow configuration comprising a cell 56 comprising spaced parallel walls 58 and 60 with analyte-specific receptor patterns formed on the in-

sides of each of the walls. The liquid is continuously flowed through the cell during operation and the reflection or transmission mode may be used as indicated by the arrows. Figure 3c shows another embodiment of a flow cell 66 comprising spaced parallel walls 68 and 70 with wall 70 having an inlet port 72 and an outlet port 74. The analyte specific receptor pattern 76 is formed on the inner surface of wall 68 and an O-ring 78 is used to seal the flow chamber. In each of these embodiments the chamber should have at least one window transparent to the incident illumination. The substrate within the chamber is located in direct line of illumination, and the assay is performed either in reflection or transmission, as described previously. In another embodiment, the fluid chamber may comprise the patterned substrate as one or more of its windows. In these embodiments, the time dependence of the binding events may be monitored simultaneously for all analytes. This may be useful for measurement of relative binding affinities.

[0027] Detector 34 must be sensitive to the illumination of choice. The detector 34 may be a position sensitive photodiode, a photomultiplier tube (PMT), a photodiode (PD), an avalanche photodiode (APD), a charged-coupled device (CCD) array, the unaided eye, a camera, a photographic plate, or any other imaging device. In one embodiment of this invention, the transmitted or reflected signal is collected by an imaging optical fibre and directed to an imaging detector. Detector 34 is attached to the appropriate accessories to provide power and enable signal collection and data processing. If a position sensitive photodiode is used it is first calibrated; the intensity of the signal reflects the position of the pattern impinging on the detector.

[0028] The photodiode, photomultiplier tube or avalanche photodiode is mounted on a translation stage. By moving the detector on the stage, the pattern of high and low light levels are mapped out. Alternatively, the PMT or (APD) may be held in a stationary position. A mirror is positioned to direct the light from the substrate to the PMT, PD or APD. This mirror is mounted on a rotation stage, and by rotating the stage, the pattern of low and high light levels can be mapped out on the PMT, PD or APD as shown in Figure 2c.

[0029] When a CCD array or other imaging device is used, it is positioned to collect either the full diffraction image, or a part thereof. In the latter case, the imaging device is mounted on a translation stage to enable inspection of selected regions of the diffraction image; changes in the intensities signify the binding event(s).

[0030] In certain cases, as will be described in the examples hereinafter, the diffracted signal will be strong enough to be visible to the unaided eye under proper lighting conditions. In this case, all that is needed is the observer's eye, or for a more permanent record, any camera, or similar imaging device. For quantification of low intensity signals, a sensitive CCD array detector or a PMT may be used. For further signal enhancement, lock-in detection as well as amplification schemes known to

those skilled in the art may be employed. As discussed previously, the image, or a part thereof, obtained as an electronic signal from the detector is stored on a computer and image analysis software is then used to identify the patterns on the substrate that gave rise to the observed diffraction image thus identifying which analytes are present in the medium. A code may be written on the substrate itself that identifies which analyte-specific receptors are present. The presence of signals at specific locations relative to a standard encoded location within the diffraction image corresponds to the presence of specific analytes. Quantification of signals at defined locations enables quantification of the amount of different analytes.

[0031] In operation, the recognition elements that are capable of specific binding (e.g., protein, oligonucleotide, antibody, etc.) are laid out on a surface in preselected patterns. The medium to be assayed is contacted with the substrate, allowing analytes present in the medium to bind to their complementary recognition element. It should be noted that the recognition element could be a structural or topographical feature such as grooves formed in the top surface of the substrate having dimensions to trap the target of interest such as a bacterium. In one embodiment of this invention, the substrate is rinsed and dried, and placed in one of the devices previously described such that the substrate with the bound analytes is placed in direct line of the light beam from the light source 32. The substrate may be a dipstick.

[0032] While it is simplest to utilize a clear medium, such as an aqueous solution, this method can also be used for assay of analytes present in other media. The medium may generally be a fluid including gas or liquid and the analytes can include various biological pathogens, environmental toxins or chemical warfare agents dispersed in air. In one embodiment of this invention, analytes present in complex media such as urine, blood, serum, plasma or other turbid media are assayed. If the medium is not completely transparent to the incident illumination, the assay is best performed under reflection configuration. The assay of analytes in complex media may be complicated by degradation of signal-to-noise due to scattering and/or absorption of the incident illumination by the medium. Thus, in one embodiment of the invention the apparatus used to perform the assay uses total internal reflection of the incident light from the substrate-medium interface. Referring to Figure 3d, a substrate 84 having analyte-specific receptor patterns 86 is in contact on one side thereof with the medium 82 being tested, which is contained within a chamber 80. Light is totally reflected from the interface between substrate 84 and medium 82. The cell operates as a flow cell when fluid is pumped through tube 90 into chamber 80 and out of tube 92. In another embodiment of this invention, the incident illumination is chosen so that the complex medium is transparent at the wavelength of the light, for example, the use of near-infrared laser wavelengths for the assay of fluids such as blood and the like.

[0033] The significant advantage of the present method is that by using a multiplicity of patterns, such that each type of recognition element defines a unique pattern, multiple analytes may be assayed for simultaneously using detection of light diffracted by the patterns with the preselected analytes bound thereto using light from a simple source impinging on the substrate either in reflection or transmission mode.

[0034] An exemplary, non-limiting list of analyte-specific receptors or recognition elements that may be used may be from one member of any specific binding pair, such as either member of the following pairs: antibody-antigen, enzyme-inhibitor, complementary strands of nucleic acids or oligonucleotides, receptor-hormone, receptor-effector, enzyme-substrate, enzyme-cofactor, lectin-carbohydrate, binding protein-substrate, antibody-hapten, protein-ligand, protein-nucleic acid, protein-small molecule, protein-ion, cell-antibody to cell, small molecule-antibody to small molecule, chelators to metal ions and air-born pathogens to associated air-born pathogen receptors to mention just a few. The analyte that is assayed for is thus the complementary member of the specific binding pair. Analytes may be present in a medium after processing, such as purification, isolation, amplification, for example. Alternatively, the analytes may be in fluids such as blood, serum, plasma, urine, or other body fluids.

[0035] Similarly, depending on the application and analytes that need to be identified, recognition elements may comprise small molecules that participate in non-specific but preferential binding events, as for example, a hydrogen-bonding compound, that can interact with hydrogen-bonding species over non-hydrogen bonding species, a charged species that will preferentially recognize its opposite charge. The important consideration in this case is that within a substrate with multiple recognition elements, these recognition elements can provide the desired distinction between species. For example, on the substrate there may be located one recognition element that provides a hydrogen-bonding interaction, and another that provides a hydrophobic interaction.

[0036] Each specific recognition element is arranged on the substrate to form a distinct pattern, such that the different recognition elements form different patterns on the same active region of the substrate surface that is illuminated. The presence of these patterns are preferably invisible or near-invisible to the source (that is, transmission or reflection of the source by the substrate is unaffected or minimally affected by the presence of this pattern; i.e. the pattern is non-diffracting). However, the visibility of this pattern may be adjusted by appropriate adjustment of the intensity of the source of illumination (e.g. through the use of filters), or of the detector signal (e.g. electronic filters or by software), and does not limit the scope of the invention.

[0037] In the present invention, we utilize patterns that correspond to diffraction patterns that are different from each other. This is not a fundamental issue, but simply

one of ease of detection. That is, given a perfect detector, which can capture the full diffraction image to infinite resolution, this image can be deconvoluted into the set of surface patterns that gave rise to it; in practice, one should choose surface patterns that can be easily differentiated, as well as can be made with reasonable ease. The following are non-limiting examples of simple distinct patterns: (1) they may consist of different geometric elements (lines, circles, etc.); (2) they may be of the same geometric elements but arranged with different periodicities; (3) they may be of the same geometric elements with the same periodicity but rotated with respect to each other, provided the patterns do not have rotational symmetry; (4) they may be a mixture of any of the above. The size and shape of the elements in a pattern, and their periodicities determine the resulting diffraction image, as is discussed in many textbooks in optics (for example: E. Hecht, "Optics", 2nd edition, Addison-Wesley, 1987) and known to those skilled in the art.

[0038] The patterned layer itself may be invisible to the source for several reasons, including that the layer of recognition elements is very thin and its refractive index is closely matched to that of the substrate. If the layer of recognition elements is not very thin with regards to the original substrate, an inert material can be added, such that this inert material covers the rest of the substrate, and reduces the effective thickness of the patterned layer. In this case, the refractive index of the patterned layer and of the inert material should be closely matched. Another reason the patterned layer may not be visible to the source is that the layer of recognition elements is very thin and the refractive indices of the substrate, the thin layer and medium are very similar.

[0039] If the conditions above are not met, the patterned layer may produce a weak diffraction signal prior to addition of the analyte. In this case, a binding event is accompanied by an enhancement in diffraction signal, and detection of the analyte is accomplished by observing the changes in the signal intensities of selected parts of the diffraction image. Alternatively, the light source can be reduced in intensity, either by controlling its input power, or by the use of optical filters, so as to null this background diffraction pattern that arises from the recognition elements. The enhanced signal due to binding will thus cause a positive signal on the detector.

[0040] It may be very useful to detect light diffracted from the substrate surface prior to exposure of the substrate surface to the medium being screened for the purpose of producing a baseline diffraction image due to the substrate and analyte-specific receptor patterns in the absence of analytes. This baseline diffraction image is then stored and compared in the appropriate way to the diffraction image obtained after exposure of the substrate to the medium.

[0041] Alternatively, the initial patterned substrate may produce a diffracted image, and the analyte may interact with the recognition elements on the substrate that would result in the decrease of the diffracted signal. One exam-

ple is the case where the recognition elements are probe molecules that are degraded by the analyte. Another example is the case where the recognition elements are grooves or other types of surface relief patterns or topographical features on the substrate, which are filled in by the binding of the analytes. Such interaction would then be detectable by the disappearance or decrease in brightness of specific regions within the diffraction image.

[0042] The device can quantitatively determine the amount of analyte in the original solution by measurement of intensities at the appropriate parts of the diffraction image. Each type of analyte, when bound to its partner receptor, defines a specific diffraction pattern, and thus gives rise to certain characteristic parts of the resulting diffraction image. Different analytes can thus be quantified by examination of the intensity of the appropriate parts of the diffraction image. The way to effect quantification is by calibration with standard analyte samples of known concentration. The utilization of calibration curves for quantification purposes is typical of immunoassay methods.

[0043] The diffracted signal strength may be enhanced by the addition of one or more secondary species selected to localize on the already immobilized analytes. The secondary species may contain a substance that will enhance the change in index of refraction (such as a chromophore, a metal colloid with a plasmon band, resonant with the source wavelength, or an enzyme that can cause a precipitate to form when appropriate reagents are added), or enhance the change in height above the substrate (such as a large particle, a metal colloid, a polymer colloid, a quantum dot, a protein), or both.

[0044] Alternatively, the analytes may be pre-treated so as to be first coupled to a material that will enhance the signal obtained upon binding, either through a change in refractive index, or in height, or both. This material may be a polymer colloid, a large molecule, a chromophore or a metal colloid. The chromophore or metal colloid should preferably absorb radiation at the wavelength of the source illumination.

[0045] The patterns of recognition elements on the surface may be created in any of several ways, depending on the specific analyte to be assayed. Example methods include microlithography and its variations, microcontact printing, ink-jet writing, robotics spotting, dip pen nanolithography, nanolithography by atomic force microscopy, near-field optical scanning lithography. These various techniques are described in more detail hereinafter.

[0046] Microlithographic techniques are well known to those skilled in the art. For example, masking strategies and reactions developed for the creation of DNA arrays, as described in United States Patent Nos. 5,599,695; 5,753,788; 5,831,070; 4,867,208 and 5,089,387 may also be employed here. The main difference is that in these previous patents, different types of oligonucleotides are placed on different spatial regions on the substrate by using a mask that exposes one region of interest at a time. In the current invention, masks corresponding to

various patterns are used to prepare a multiplicity of oligonucleotide patterns on the same total area.

[0047] Microlithography can also be used to create patterns on self-assembled monolayers (SAM) of thiol on gold. Using the appropriate mask, SAMs of thiol on gold can be exposed to UV light. Areas that are not covered by the mask undergo a reaction and the thiols are desorbed and can be washed off to leave a bare gold surface. A different thiol can then be adsorbed on these exposed gold regions. These thiols may already contain the receptor elements or can be derivatized subsequently by common methods. Thus, iterative processing using different masks and different thiols result in multiple patterns in the same area.

[0048] Microcontact printing is a stamping technique, in which the ink is transferred from an elastomeric stamp, such as polydimethylsiloxane (PDMS), to the desired substrate. The stamp is prepared by casting the precursor polymer on a master, and subsequent curing to harden it. The master is typically a hard material which has topographic features corresponding to the desired pattern.

[0049] The use of self-assembled monolayers as the ink to form a patterned monolayer on metals such as gold by microstamping or microcontact printing is described in United States Patent No. 5,512,131. Patterning of polymer substrates by self-assembled monolayers is feasible through the use of a thin metal film that is deposited on the polymer; this is described in United States Patent No. 6,020,047. In particular, the stamping technique has been used to create protein patterns on silicon, polystyrene and silanized glass, as described in Bernard, A.; Delamarche, E.; Schmid, H.; Michel, B.; Bosshard, H.R.; Biebuyck, H.; "Printing Patterns Of Proteins" *Langmuir* (1998), 14, 2225-2229.

[0050] In order to create multiple recognition elements on the same substrate, different stamps are used for each element. The stamps vary in the geometric structure they contain (lines, circles, etc.) and/or the periodicity of the patterns. Alternatively, in the case of patterns lacking in-plane rotational symmetry (such as lines), the same exact same pattern may be used, but different recognition elements are stamped at different angles with respect to each other.

[0051] Patterns may be 'written' on a substrate using current technology of inkjet printers, or by the use of computer-controlled robot arm, or by an analog plotter with fine point. In any of these cases, the substance to be patterned, either the recognition element or its precursor, is in a liquid medium and is deposited by dropping the solution at the desired locations. The solution is allowed to dry, so that the recognition elements are adsorbed onto the substrate, and excess material is rinsed off. Alternatively, a chemical or photochemical reaction is used to covalently bind the recognition elements at the appropriate location, subsequent to writing the pattern. In one embodiment of this process, the substrate surface is first activated by being coated with a reactive layer. This

method is suitable for creating patterns whose elements are of the order of tens of microns in their smallest dimension.

[0052] When it is preferred to use smaller patterns, such as to increase the number of patterns in a given area, advances in scanning probe microscopy approaches are utilized. Dip pen nanolithography is based on the strong preferential adsorption of certain molecules to form self-assembled monolayers, such as thiols, bound to metals such as gold. Thus, a pen dipped in a dilute solution of thiols can pick up some molecules. By contacting such 'ink' to a gold surface, a monolayer of thiols is strongly immobilized at the point of contact. By using a small point, such as the probe tip of an atomic force microscope, structures (consisting of a monolayer of materials) that are tens of nanometer in size can be 'written' on a metal substrate. The technique of dip pen nanolithography is described in Piner, R. D.; Zhu, J.; Xu, F.; Hong, S. H.; Mirkin, C. A. *Science* 1999, 283, 661-663. In particular, a derivative of biotin that has a dithiol linkage can be patterned in this manner. By using the known avidin-biotin interaction, other materials can be immobilized in a pattern dictated by the initial biotin layer.

[0053] Atomic force microscopy (AFM) can be used to pattern proteins on surfaces by the simple procedure of allowing protein adsorption, then using the AFM probe tip to scratch off regions so as to produce the desired pattern. This sample is then backfilled by contacting with a solution of another recognition element. A description of this approach in the case of thiols and carboxylic acids is given in United States Patent No. 5,922,214, and extended to proteins in Wadu-Mesthrige, K.; Xu, S.; Amro, N. A.; Liu, G. Y.; Langmuir 1999, 15, 8580-8583.

[0054] In one embodiment of pattern formation, the recognition elements are laid out directly on the substrate by any of the techniques described above or by other means. In another embodiment of pattern formation, an intervening layer is used that will assist in the patterning. One example is the use of the known biotin-avidin affinity as follows. A pattern of biotin is 'written' on the substrate. This is then contacted with a solution of streptavidin, which binds selectively to the biotin layer. After washing off excess protein, this sample, which now has a patterned layer of streptavidin-biotin, is then contacted with a solution of a biotinylated recognition element, which binds to the patterned streptavidin, creating a patterned recognition element. The process is then iterated to produce the second pattern of a second recognition element, and so on.

[0055] The patterning of the initial biotin layer can be produced in many of the ways describe above. A preferred embodiment is the use of either microcontact printing or dip pen nanolithography using a dithiol compound on a metal or metal film as substrate. Another relies on the use of photobiotin, which is a light-activated form, in conjunction with lithographic techniques, see Hengsakul, M.; Cass, A. E. G.; *Bioconjugate Chemistry*, 1996, 7, 249-254.

[0056] Another embodiment is the use of microcontact printing of an activated form of biotin on a substrate with which it can interact, and preferably react. An example of this substrate is glass coated with an aminosilane layer.

[0057] In another embodiment of the invention, the pattern of recognition elements that is overlaid on a substrate that is also topographically patterned with crevices. The substrate is preferably a polymer that has several different topographical patterns; the topographic patterns may be produced by micromachining or by microlithography and etching. On each pattern there is immobilized one recognition element. The polymer substrate is chosen such that its index of refraction matches that of the solution of analytes. Alternatively, the medium's refractive index is adjusted to match that of the patterned substrate. In either case, the assay is performed in the following manner. The patterned substrate is placed in a cell with flat windows, which is illuminated by the source. The medium containing the analytes to be assayed is then introduced. At the initial time, no diffraction image is observed because of refractive index matching between the substrate and the medium. As the binding event takes place, a diffraction pattern emerges, which is characteristic of the pattern to which the appropriate analyte binds.

[0058] The invention may be utilized as an indicator of presence or absence of a specific analyte. In one embodiment of the invention, the amount of analyte is determined by measurement of the intensities of the light in the portion of the diffraction image that corresponds to the specific analyte. This is preferably done by first producing a calibration curve. In another embodiment this signal intensity is monitored as a function of time after introduction of the analyte; from this can be obtained information about kinetics of the binding. The binding of two or more analytes to their analyte-specific receptors can be compared within the same substrate. In this embodiment of the invention, the time dependence of the intensities of portions of the diffraction pattern that can be ascribed to specific analytes are compared.

[0059] The apparatus and method described herein is applicable to assay various combinations of analytes. Substrates patterned with different sets of analyte-specific receptors can thus be prepared and used within the same apparatus. In one embodiment of this invention, the substrate is encoded with markings that identifies which type of receptors are patterned within it, and hence which analytes it can be used to assay. In another embodiment of this invention, the substrate is encoded with information regarding which specific locations within the diffraction image relative to a standard location should be used to assay for specific analytes. The diffraction image thus recorded can be analyzed with this prior information already available to the instrument.

[0060] The method of detecting multiple analytes disclosed herein is advantageous for several reasons. It is possible to perform an assay for a multitude of analytes

using a very small sample depending on the resolution of the pattern printing methodology. For example, the active area of the substrate may be as small as, or smaller than, 1 mm on a side. The sample amount required will then be as small as, or smaller than, 1 mm x 1 mm x thickness of the pattern. The method is advantageous because of increased reliability due to repetition of elements within a pattern and the method is quite inexpensive. The sensing elements 10 may be produced in bulk with the analyte-specific receptors being dependent on the analyte the user requires.

[0061] The method disclosed herein may be utilized for numerous applications. It may be used as an alternative or complement to a DNA array. A plurality of patterns, each one containing a specific sequence of oligonucleotide or nucleic acid, is laid out on a small region (typically a millimeter, or less.) The method may be used for rapid medical diagnostic applications, for example rapid analysis of body fluids, such that several different tests can be performed with the same (small) sample and at the same time.

[0062] This method is of great benefit when diagnosing a specific syndrome that has multiple markers. For example, red tide outbreak is marked by the presence of any of several toxins. It is very useful for differential assays, that is, in cases where a comparison between the amount of A, B, C etc. are needed in the same sample. It may be used for binding assays of multiple analytes. In one embodiment of this invention, one of the analyte-specific receptor may be a marker for an analyte that serves as a standard that identifies the material, or that serves to calibrate the instrument. The present method may also be adapted so that time dependence of the binding events can be monitored. The following non-limiting examples are intended to illustrate the present invention and in no way are to be considered limitations on the scope of the present invention.

Example 1

Preparation of patterned substrate by microcontact printing

[0063] The substrates were patterned by microcontact printing following the procedure described in Bernard, A.; Delamarche, E.; Schmid, H.; Michel, B.; Bosshard, H.R.; Biebuyck, H.; "Printing Patterns Of Proteins" Langmuir (1998), 14, 2225-2229. The poly(dimethylsiloxane) (PDMS) stamps were fabricated by using as molds acrylic diffractive optic masters (G1007A and G1008A, Thor Labs) using typically 10% crosslinking (Sylgard 184 Silicone elastomer kit, Dow Corning Corporation purchased from Paisley Products, Ontario Canada) and curing at 50-60° C for 14-18 h. The PDMS stamps prepared in this manner have a diffractive surface of -50 mm². The PDMS stamp was cleaned by sonication in a 2:1 solution of distilled and deionized water (ddH₂O)/ethanol for 5-10 min, followed by drying under a stream of nitrogen gas (N₂)

and applying a fresh piece of adhesive tape to the stamp surface. The tape was removed from the stamp surface after a few minutes, 150-200 μL of protein at 50-100 μg/mL in phosphate buffered saline (PBS) was immediately applied to the stamp surface and allowed to stand at room temperature. After 30 min, the solution of protein was removed and the inked stamp surface was washed with PBS (2x2mL), ddH₂O (2x2mL) and, finally, dried under a stream of N₂. The stamp was then applied under light pressure to a substrate, previously cleaned by sonication in 2:1 ddH₂O/EtOH and dried under a stream of N₂, and left in place for several seconds. The stamped substrate was then washed with PBS (2mL), ddH₂O (2mL) and dried under a stream of N₂. A substrate prepared in this manner is shown in Figure 4, where the deposited material is visualized using atomic force microscopy.

[0064] Subsequent patterns were produced on the same substrate by using additional PDMS stamps cleaned, inked and stamped in the same manner as above, but cross-stamped onto the substrate at angles offset from the existing patterns. Figure 5 shows an example of a substrate prepared with two analytes stamped on the same region using the same stamp pattern but rotated with respect to each other, as visualized by atomic force microscopy.

Example 2

Signal Measurement

[0065] The substrate was illuminated with either a Nd:YVO₄ laser (λ = 532 nm) or a red diode laser (λ = 650 nm). The diffraction image of crossed-stamped substrates resulting from illumination by either laser can be visually observed in transmission or reflection mode prior to addition of analyte. For visual and photographic signal detection, the intensity of the diffracted light was reduced to the point when the diffraction image was no longer discernible by eye using a neutral density filter before the addition of analyte. For electronic signal detection, the intensity was reduced with a neutral density filter to a small, but measurable value to maximize the signal range of the detection device before the addition of analyte.

Example 3

"Dry" Measurement

[0066] In the "dry" measurement scheme, the substrate was immersed in a solution containing the analyte for the specified period of time. The substrate was then removed from the analyte solution, washed with PBS (2 mL) and ddH₂O (2mL), and dried under a stream of N₂. The substrate was illuminated with a laser and a visible diffraction image could be discerned by eye and the intensity measured using a CCD linear array or CCD area array detector hooked up to a computer. Alternatively, a

photomultiplier tube mounted on an x-y translation stage was used to measure the signal intensity of a specific spot on the diffraction image by moving it across the spot while recording the intensity on an oscilloscope.

Example 4

In Situ Measurement

[0067] In situ measurements were done in either a low volume (10-20 μL) or high volume (100-200 μL) arrangement. The low volume configuration consisted of a 10mm x 10mm substrate held in place with two pieces of double-sided adhesive tape against a microscope slide with the stamped substrate surface facing the microscope slide. A channel of 1 mm x 5 mm x 10 mm was formed by the two pieces of double-sided sticky tape through which an analyte solution can be wicked into contact with the stamped surface of the substrate. In the high volume configuration, the substrate was separated from a plastic backing with a rubber O-ring such as shown in Figure 3c. Two holes were drilled into the plastic backing through which analyte solution could be added and removed. The total volume of this cell is $\sim$ 100-200 μL . In both these configurations, the diffraction signal is measured after illumination of the substrate by the lasers in reflection mode.

[0068] The intensity of the diffraction image is reduced when the substrate is immersed in an aqueous solution compared to when the substrate is dry and in air. As measured by a CCD linear array coupled to an oscilloscope, a 900 mV signal in air drops to 580 mV upon addition of 1X PBS solution to the cell.

Example 5

Goat and Rabbit IgG Stamped Substrate Tested with Anti-goat and Anti-rabbit Gold Conjugates

[0069] Goat and rabbit IgG were cross-stamped onto a glass substrate as described above. See Figure 5 for an AFM image of the cross-stamped substrate. The resulting cross-stamped slide was immersed in anti-goat IgG gold conjugate solution for 30-60 min and then removed from the solution of anti-goat IgG gold conjugate and washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried under a stream of N₂. The development of the diffraction images observed in both the transmitted and reflected modes corresponding to goat IgG on the substrate was monitored visually (data not shown). The stamp was then immersed in an anti-rabbit IgG gold conjugate solution for 30-60 min and then removed from the solution of anti-rabbit IgG gold conjugate and washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried under a stream of N₂. The development of the diffraction images observed in both the transmitted and reflected modes corresponding to rabbit IgG on the substrate was monitored visually (data not shown).

Example 6

Goat and Rabbit IgG Stamped Substrate Tested with Anti-goat and Anti-rabbit IgG

[0070] Goat and rabbit IgG were cross-stamped onto a substrate as described above. The resulting cross-stamped slide was immersed in anti-goat IgG solution for 30-60 min and then removed from the solution of anti-goat IgG and washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried under a stream of N₂. The development of diffraction images from both transmission and reflection mode measurements corresponding to goat IgG on the substrate was observed visually (data not shown). The stamp was then immersed in an anti-rabbit IgG solution for 30-60 min and then removed from the solution of anti-rabbit IgG and washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried under a stream of N₂. The development of diffraction images from both transmission and reflection mode measurements corresponding to rabbit IgG on the substrate was observed visually (data not shown).

Example 7

Rabbit and Mouse IgG Stamped Substrate Tested with Anti-rabbit and Anti-mouse IgG

[0071] Rabbit and mouse IgG were cross-stamped onto a substrate as described above. Figure 6 is an AFM image of the cross-stamped substrate. The resulting cross-stamped slide was immersed in a solution of goat anti-rabbit IgG for 60 min and then washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried under a stream of N₂. The substrate was then immersed in a solution of goat anti-mouse IgG for 60 min and then washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried under a stream of N₂. Finally, the substrate was immersed in a solution of rabbit anti-goat IgG for 60 min and then washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried under a stream of N₂. The anti-goat IgG treatment was used to enhance the existing signals through a "sandwich" assay. The intensity of a characteristic spot in the diffraction image was measured after each incubation/wash cycle.

[0072] Figure 7 shows effect of treating a rabbit and mouse IgG cross-stamped substrate sequentially with the indicated solutions. The diffraction image consists of two bright rows of dots perpendicular to each other (other periodic patterns of dots can be seen, but they are much weaker in intensity). One row of dots is characteristic of the rabbit IgG pattern, while the other is due to the mouse IgG. The intensities at two locations in this diffraction image, one of the bright dots corresponding to rabbit and one corresponding to mouse IgG, were measured with a linear CCD array detector attached to an oscilloscope. Prior to introduction of the analytes, the substrate gives a low intensity reading for both spots. Addition of goat

anti-rabbit IgG results in an increase in the signal arising from the stamped rabbit IgG, while little change is observed in the signal that derives from mouse IgG. Treatment of the substrate with goat anti-mouse IgG then results in the increase in signal that arises from stamped mouse IgG, while the signal for rabbit IgG remains constant from the previous treatment. Finally, the addition of anti-goat IgG to the previously treated substrate results in the further increase of both signals, confirming that the goat-raised antibodies used in the first two treatments are present. Additionally, this also demonstrates the use of a secondary species, the anti-goat antibody, for enhancing the signal for analyte detection.

Example 8

BSA and BSA-biotin Conjugate Stamped Substrate Tested with Avidin Gold Conjugate

[0073] BSA and BSA-biotin conjugate were cross-stamped onto a substrate as described above. The resulting cross-stamped slide was immersed in a solution of avidin gold conjugate for 30-60 min and then washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried under a stream of N₂. The development of diffraction images in both transmission and reflection mode measurements corresponding to BSA-biotin on the substrate was observed visually (data not shown). No diffraction pattern attributable to BSA was observed.

Example 9

BSA-fluorescein and BSA-biotin Conjugate Stamped Substrate Tested with Anti-fluorescein and Avidin

[0074] BSA-fluorescein and BSA-biotin conjugate were cross-stamped onto a substrate as described above. The resulting cross-stamped slide was immersed in BSA (100 µg/mL in PBS) for 60 min and then washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried under a stream of N₂. The substrate was then immersed in a solution of anti-fluorescein antibody (10% solution of A-889 from Molecular Probes in PBS) for 60 min and then washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried under a stream of N₂. The substrate was then immersed in an avidin solution (-30 µg/mL in PBS) for 60 min and then washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried under a stream of N₂. The intensities of characteristic spots in the diffraction image were measured after each incubation/wash cycle using a linear CCD array detector attached to an oscilloscope. Figure 8 shows the results. The patterned substrate shows low intensity diffraction signals initially (prior to the introduction of the analyte). Treatment with BSA partially fills in the areas of exposed glass not already covered by stamped BSA-conjugates, reducing the signals further. Addition of a solution of anti-fluorescein antibody results in a dramatic

increase in the diffraction signal arising from the stamped fluorescein-BSA conjugate, while little change is observed in the signal that derives from the patterned biotin-BSA conjugate. Finally, addition of a solution of avidin results in the increase in the diffraction signal that arises from stamped biotin-BSA conjugate, while the signal for fluorescein-BSA conjugate is unchanged.

Example 10

DNA Hybridization

[0075] A glass slide was stamped with avidin as described above. The resulting patterned slide was immersed in a solution of BSA (50 µg/mL in PBS) for 60 min and then washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried under a stream of N₂. The substrate was then immersed in a 10 µM aqueous solution of biotinylated oligonucleotide 2590BT (5'CAGTCAGTCAGTCAGTCAGT-biotin-3') for 60 min at room temperature. After washing with PBS (2x2ml) and ddH₂O (2x2ml) and drying under a stream of N₂, the substrate was immersed for 60 min at room temperature in a 10 µM aqueous solution of the colloidal gold-labelled complementary oligonucleotide strand 2593T (5'ACTGACTGACTGACTGACTG-S-gold-3'). The sample was again washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried under a stream of N₂, before a final 60 min. incubation in 1.0M NaCl. A control experiment using biotinylated oligo-dG (5'-G₂₀-biotin-3') instead of 2590BT as the first strand was also performed. Figure 9 shows the results. The intensity of a characteristic spot in the diffraction image corresponding to the patterned avidin layer was monitored after each incubation/wash cycle with a linear CCD array detector attached to an oscilloscope. The avidin-patterned substrate was initially treated with biotinylated oligonucleotide 2590BT; a small signal at the characteristic spot was observed. Addition of the complementary oligonucleotide 2593T (gold-conjugate) results in an increase in the signal. Further treatment of the substrate with 1.0 M NaCl wash results in a further increase in signal. Finally, as a control, a substrate patterned with avidin was treated initially with a biotinylated poly-dG oligonucleotide instead of 2590BT; the same sequence of treatments did not result in a corresponding increase in signal intensity.

Example 11

Titration of Rabbit IgG Stamped Substrate with Anti-rabbit IgG

[0076] The substrate was stamped with rabbit IgG as described above. The resulting patterned slide was treated sequentially by incubating with increasing concentrations of anti-rabbit IgG solution for 15 min at room temperature. After each incubation, the substrate was washed with PBS (2x2ml) and ddH₂O (2x2ml) and dried

under a stream of N₂. The intensities of two characteristic spots from the resulting diffraction image were measured and averaged after each treatment. Figure 10 shows the results.

Example 12

Time Dependence of Streptavidin Binding to Biotin-BSA substrate

[0077] A glass slide was stamped with biotin-BSA as described above. The resulting patterned slide was placed in a liquid flow cell as shown in Figure 3c. A solution of streptavidin (500 µL, 200 µg/mL in PBS) was added to the flow cell and the intensity of a characteristic spot from the resulting diffraction image was measured at varying time intervals. Figure 11 shows the change in signal over time resulting from the treatment of a biotin-BSA patterned substrate with streptavidin solution.

[0078] The foregoing description of the preferred embodiments of the invention has been presented to illustrate the principles of the invention and not to limit the invention to the particular embodiment illustrated. It is intended that the scope of the invention be defined by all of the embodiments encompassed within the following claims and their equivalents.

Claims

1. A method for detecting simultaneously at least two analytes in a medium (82) using light diffraction, comprising providing a substrate (12, 12') including a surface and on said surface a first pre-selected pattern of first analyte-specific receptors and at least a second pre-selected pattern including second analyte-specific receptors, the method **characterized in that** each of said pre-selected patterns (14, 16, 18, 21, 23, 25) on said surface are geometrically distinct patterns and, when bound to an analyte, gives rise to a pre-selected diffraction pattern distinct from diffraction patterns formed from all other pre-selected patterns on the surface; contacting said surface of said substrate (12, 12') with said medium (82) for a sufficient time to permit analytes present in said medium to bind to their associated analyte-specific receptors; and illuminating said substrate (12, 12') and detecting, at a position spaced from the substrate surface, a full image of diffracted light from said substrate surface and analysing the image of diffracted light for the presence or absence of each of said pre-selected diffraction patterns (12, 16, 18, 21, 23, 25) representative of binding of said analytes to their associated analyte-specific receptors, said analyzing step comprising deconvoluting said full image into individual patterns, and identifying from the full image of said

diffracted light the presence or absence of said analytes in said medium.

2. The method according to claim 1 wherein illuminating said substrate (12, 12') includes illuminating a sufficient area of said substrate to illuminate at least a part of each pre-selected pattern present on said substrate (12, 12').
3. The method according to claim 1 wherein illuminating said substrate (12, 12') includes illuminating the pre-selected patterns one at a time.
4. The method according to claim 2 wherein analysing the image of diffracted light for the presence or absence of said pre-selected diffraction patterns representative of binding of one or more analytes to their analyte-specific receptors includes storing the image of diffracted light from the illuminated area.
5. The method according to claim 2 or 4 including detecting an image of diffracted light from the substrate surface (12, 12') prior to exposure of the substrate surface (12, 12') to the medium for producing a baseline diffraction image due to said substrate (12, 12') and analyte-specific receptor patterns in the absence of analytes, including storing said baseline diffraction image.
6. The method according to claim 5 wherein analysing the image of diffracted light for the presence or absence of said pre-selected diffraction patterns (14, 16, 18, 21, 23, 25) representative of binding of one or more analytes with their analyte-specific receptors includes comparing the image of diffracted light with the baseline diffraction image.
7. The method according to claim 2 wherein illuminating said substrate (12, 12') includes illuminating with a substantially coherent, monochromatic laser beam.
8. The method according to claim 7 wherein said laser beam emits light in the infrared, visible or ultraviolet.
9. The method according to any one of claims 1 to 8 wherein said substrate is substantially transparent and said surface is illuminated from one side of said substrate (12, 12'), and wherein the image of diffracted light from said substrate is detected on the opposite side of said substrate.
10. The method according to any one of claims 1 to 8 wherein said substrate (12, 12') is partially reflecting and said surface is illuminated from one side thereof, and wherein the image of diffracted light is detected on the same side of said substrate (12, 12').

11. The method according to any one of claims 1 to 8 wherein said substrate (12, 12') is reflecting, and said surface is illuminated from one side thereof, and wherein the image of diffracted light is detected on the same side of said substrate (12, 12'). 5
12. The method according to any one of claims 1 to 11 wherein, after contacting said surface of the substrate (12, 12') with a medium being screened for preselected analytes, said substrate (12, 12') is rinsed and dried prior to being illuminated. 10
13. The method according to any one of claims 1 to 10 wherein contacting said surface of the substrate (12, 12') with the medium (82) includes placing said substrate in a cell (50) containing said medium being screened for analytes, said cell (50) having at least one optical window for light to pass therethrough for detecting for analytes in said medium in situ. 15
14. The method according to claim 13 wherein intensities of selected regions of the resulting image of diffracted light are monitored as a function of time. 20
15. The method according to any one of claims 1 to 8 wherein the light illuminating said substrate (12, 12') is directed toward said substrate (12, 12') at an effective angle such that it undergoes total internal reflection from a substrate/medium interface. 25
16. The method according to any one of claims 1 to 10 wherein said analyte-specific receptors are one of a member of a binding pair selected from the group consisting of antibody-antigen, enzyme-inhibitor, complementary strands of nucleic acids or oligonucleotides, receptor-hormone, receptor-effector, enzyme-substrate, enzyme-cofactor, glycoprotein-carbohydrate, binding protein-substrate, antibody-hapten, protein-ligand, protein-nucleic acid, protein-small molecule, protein-ion, cell-antibody to cell, small molecule-antibody to said small molecule, chelators to metal ions and air-born pathogens to associated air-born pathogen receptors. 30
17. The method according to any one of claims 1 to 8 wherein said substrate is selected from the group consisting of glass, mica, polished silicon, silicon dioxide, polymeric materials, substantially transparent polymeric materials, partially or fully reflective substrates including metals, and metal coated substrates. 35
18. The method according to any one of claims 1 to 8 including contacting said surface of the substrate (12, 12') with a medium (82) containing a standard material that binds to the bound analytes after contacting said surface of the substrate (12, 12') with the medium (82) and prior to illuminating a selected 40
19. The method according to claim 18 wherein said standard material is selected from the group consisting of proteins, metal colloids, polymer colloids, colloidal silica, quantum dots, and combinations thereof. 45
20. The method according to claim 1 wherein the medium (82) is selected from the group consisting of blood, serum, plasma and urine. 50
21. The method according to claim 1 wherein the at least two patterns interpenetrate each other. 55
22. The method of claim 1 including quantitatively determining an amount of the analytes present by measuring intensities at appropriate parts of the diffraction image.
23. The method according to claim 5 wherein the step of analyzing the image of diffracted light includes analysing for differences in intensity between the image of diffracted light and the baseline diffraction image.
24. The method according to claim 1 wherein said first pre-selected pattern of first analyte-specific receptors and said at least a second pre-selected pattern including second analyte-specific receptors are laid out on said surface so that they interpenetrate each other.
25. The method according to claim 1 wherein said step of analysing the image of diffracted light includes computationally deconvoluting the image of diffracted light.>
26. An apparatus (30, 40, 50) for detection of analytes in a medium (82) using diffraction of light, comprising:
 - a source of illumination (32);
 - a sensing element (10, 20) including a substrate (12, 12') having a surface and the apparatus **characterized in that** it includes on said surface a first pre-selected pattern of first analyte-specific receptors and at least a second pre-selected pattern including second analyte-specific receptors, wherein each of said pre-selected patterns (14, 16, 18, 21, 23, 25) on said surface are geometrically distinct patterns and, when bound to an analyte, gives rise to a pre-selected diffraction pattern distinct from diffraction patterns formed from all other pre-selected patterns on the surface, said source of illumination being positioned so as to illuminate said substrate surface;
 - detection means (34) spaced from the substrate

- surface to detect a full image of light diffracted from said illuminated surface; and processing means for analysing the full image of said diffracted light for the presence or absence of each of said pre-selected diffraction patterns (14, 16, 18, 21, 23, 25) representative of binding of said analytes to their associated analyte-specific receptors and identifying from the full image of said diffracted light the presence or absence of said analytes in said medium, said processing means including image analysis means for deconvoluting said full image into individual patterns.
27. The apparatus according to claim 26 wherein said processing means is connected to said detection means (34) and includes storage means for storing signals that are output from said detection means (34) corresponding to said diffracted light.
28. The apparatus according to claim 27 wherein said processing means includes signal processing means for calculating kinetics of interaction of said analytes binding with their analyte-specific receptors from said diffracted light stored as a function of time.
29. The apparatus according to claim 26 wherein the source of illumination produces a coherent and monochromatic collimated beam of light.
30. The apparatus according to claim 26 wherein said source of illumination is a laser with emission at UV, visible, near-infrared or infrared wavelengths.
31. The apparatus according to claim 26 wherein said light illuminating said substrate surface is delivered through an optical fiber.
32. The apparatus according to any one of claims 26 to 30 including a cell (50, 56, 66) enclosing a chamber to contain therein said medium (82) being screened for analytes, said cell being adapted to receive said substrate with said selected area of said substrate in contact with said medium (82), said cell (50, 56, 66) having at least one optical window for light to pass therethrough for detecting for analytes in said medium *in situ*.
33. The apparatus according to any one of claims 26 to 32 wherein the light used to illuminate said surface of said substrate undergoes total internal reflection from a substrate/medium interface.
34. The apparatus according to claim 32 or 33 wherein said cell (66) includes a fluid inlet (72) and a fluid outlet (74) for continuous flow of said medium (82) through said cell.
35. The apparatus according to claim 26 wherein the substrate is selected from the group consisting of glass, silanized glass, silicon, silicon dioxide, polymer, metal, metal oxide, metal film, metal oxide film, partially or fully reflective substrates including metals, and metal coated substrates.
36. The apparatus according to claim 26 wherein said detection means (34) is an imaging device.
37. The apparatus according to claim 36 wherein said imaging device is an electronic imaging device.
38. The apparatus according to claim 36 wherein said imaging device is a camera.
39. The apparatus according to claim 26 wherein said detection means (34) includes one of a photodiode detector, a photomultiplier tube, an avalanche photodiode and a position-sensitive photodiode.
40. The apparatus according to claim 37 wherein said imaging device is a matrix array detector.
41. The apparatus according to claim 40 wherein said matrix array detector is a CCD detector array.
42. The apparatus according to claim 26 wherein said analyte specific receptors are one of a member of a binding pair selected from the group consisting of antibody-antigen, enzyme-inhibitor, complementary strands of nucleic acids or oligonucleotides, receptor-hormone, receptor-effector, enzyme-substrate, enzyme-cofactor, glycoprotein-carbohydrate, binding protein-substrate, antibody-hapten, protein-ligand, protein-nucleic acid, protein-small molecule, protein-ion, cell-antibody to cell, and small molecule-antibody to said small molecule, chelators to metal ions and air-born pathogens to associated air-born pathogen receptors.
43. The apparatus according to claim 26 wherein one of the analyte-specific receptors assays for a known analyte that is present in a medium (82) to be screened for said analytes.
44. The apparatus according to claims 26 wherein said analyte-specific receptors are laid out in said patterns directly on the substrate (12, 12').
45. The apparatus according to claim 26 including an intervening layer formed directly on the surface of said substrate (12, 12'), and wherein said analyte-specific receptor patterns are laid out on said intervening layer.
46. The apparatus according to claim 45 wherein said intervening layer is a layer of avidin in a pattern, and

wherein said analyte-specific receptors are biotinylated analyte-specific receptors to bind with the patterned avidin layer.

47. The apparatus according to claim 26 including means for rastering said source of illumination across the surface of said substrate (12, 12').
48. The apparatus according to claim 26 wherein said first pre-selected pattern of first analyte-specific receptors and said at least a second pre-selected pattern including second analyte-specific receptors are laid out on said surface so that they interpenetrate each other.

Patentansprüche

1. Ein Verfahren zum gleichzeitigen Erfassen von zumindest zwei Analyten in einem Medium (82) unter Verwendung von Lichtbeugung, aufweisend das Bereitstellen eines Substrates (12, 12') mit einer Oberfläche und auf dieser Oberfläche einem ersten vorgegebenen Muster erster analytspezifischer Rezeptoren und zumindest einem zweiten vorgegebenen Muster enthaltend zweite analytspezifische Rezeptoren, wobei das Verfahren **dadurch gekennzeichnet ist, dass** alle vorgegebenen Muster (14, 16, 18, 21, 23, 25) auf der Oberfläche geometrisch verschiedene Muster sind und jeweils bei Bindung mit einem Analyten ein vorgegebenes Beugungsmuster hervorrufen, das von den Beugungsmustern, die von allen anderen vorgegebenen Mustern auf der Oberfläche hervorgerufen werden verschieden ist; in Kontakt Bringen der Oberfläche des Substrates (12, 12') mit dem Medium (82) für eine ausreichende Zeit, um es im Medium vorhandenen Analyten zu ermöglichen, an ihre zugeordneten analytspezifischen Rezeptoren zu binden; und Beleuchten des Substrates (12, 12') und Erfassen eines Vollbildes des von der Substratoberfläche gebeugten Lichtes an einer von der Substratoberfläche beabstandeten Position, und Analysieren des Bildes des gebeugten Lichtes hinsichtlich der An- oder Abwesenheit jedes der vorgegebenen Beugungsmuster (12, 16, 18, 21, 23, 25), die ein Binden der Analyten an ihre zugeordneten analytspezifischen Rezeptoren repräsentieren, wobei der Analyseschritt eine Dekonvolution des Vollbildes in Einzelmuster aufweist, und Identifizieren der An- oder Abwesenheit der Analyten in dem Medium aus dem Vollbild des gebeugten Lichtes.
2. Das Verfahren gemäß Anspruch 1, wobei das Beleuchten des Substrates (12, 12') ein Beleuchten eines ausreichenden Bereichs des Substrates enthält, um zumindest einen Teil jedes auf dem Substrat (12,

12') vorhandenen vorgegebenen Mustern zu beleuchten.

3. Das Verfahren gemäß Anspruch 1, wobei das Beleuchten des Substrates (12, 12') das Beleuchten der vorgegebenen Muster eines nach dem anderen enthält.
4. Das Verfahren gemäß Anspruch 2, wobei das Analysieren des Bildes des gebeugten Lichtes hinsichtlich der An- oder Abwesenheit der vorgegebenen Beugungsmuster, die ein Binden von ein oder mehreren Analyten an ihre analytspezifischen Rezeptoren repräsentieren, das Speichern des Bildes des gebeugten Lichtes von dem beleuchteten Bereich enthält.
5. Das Verfahren gemäß Anspruch 2 oder 4 enthaltend, das Erfassen eines Bildes des gebeugten Lichtes von der Substratoberfläche (12, 12'), bevor die Substratoberfläche (12, 12') dem Medium ausgesetzt wird, um ein Basisbeugungsbild bedingt durch das Substrat (12, 12') und analytspezifische Rezeptormuster in Abwesenheit von Analyten zu erzeugen, enthaltend das Speichern des Basisbeugungsbildes.
6. Das Verfahren gemäß Anspruch 5, wobei das Analysieren des Bildes des gebeugten Lichtes hinsichtlich der An- oder Abwesenheit der vorgegebenen Beugungsmuster (14, 16, 18, 21, 23, 25), die ein Binden von ein oder mehreren Analyten an ihre analytspezifischen Rezeptoren repräsentieren, das Vergleichen des Bildes des gebeugten Lichtes mit dem Basisbeugungsbild enthält.
7. Das Verfahren gemäß Anspruch 2, wobei das Beleuchten des Substrates (12, 12') das Beleuchten mit einem im Wesentlichen kohärenten, monochromatischen Laserstrahl enthält.
8. Das Verfahren gemäß Anspruch 7, wobei der Laserstrahl Licht im Infrarot-, sichtbaren oder ultravioletten Bereich ausstrahlt.
9. Das Verfahren gemäß einem der Ansprüche 1 bis 8, wobei das Substrat im Wesentlichen transparent ist und die Oberfläche von einer Seite des Substrates (12, 12') beleuchtet wird, und wobei das Bild des gebeugten Lichtes von dem Substrat auf der gegenüberliegenden Seite des Substrates erfasst wird.
10. Das Verfahren gemäß einem der Ansprüche 1 bis 8, wobei das Substrat (12, 12') teilweise reflektierend ist und die Oberfläche von einer Seite desselben beleuchtet wird, und wobei das Bild des gebeugten Lichtes auf der gleichen Seite des Substrates (12, 12') erfasst wird.

11. Das Verfahren gemäß einem der Ansprüche 1 bis 8, wobei das Substrat (12, 12') reflektierend ist und die Oberfläche von einer Seite desselben beleuchtet wird, und wobei das Bild des gebeugten Lichtes auf der gleichen Seite des Substrates (12, 12') erfasst wird. 5
12. Das Verfahren gemäß einem der Ansprüche 1 bis 11, wobei nach dem in Kontakt Bringen der Oberfläche des Substrates (12, 12') mit einem Medium, das hinsichtlich vorgegebener Analyten untersucht wird, das Substrat (12, 12') gespült und getrocknet wird, bevor es beleuchtet wird. 10
13. Das Verfahren gemäß einem der Ansprüche 1 bis 10, wobei das in Kontakt Bringen der Oberfläche des Substrates (12, 12') mit dem Medium (82) ein Platzieren des Substrates in einer Zelle (50) enthält, die das Medium enthält, das hinsichtlich Analyten untersucht wird, wobei die Zelle (50) zumindest ein optisches Fenster zum Durchlassen von Licht aufweist, um Analyten in dem Medium in situ zu erfassen. 15
14. Das Verfahren gemäß Anspruch 13, wobei Intensitäten ausgewählter Regionen des sich ergebenden Bildes des gebeugten Lichtes in Abhängigkeit von der Zeit überwacht werden. 20
15. Das Verfahren gemäß einem der Ansprüche 1 bis 8, wobei das Licht, das das Substrat (12, 12') beleuchtet, so in einem effektiven Winkel auf das Substrat (12, 12') gerichtet wird, dass es einer inneren Totalreflexion an einer Substrat/Medium-Grenzfläche unterliegt. 25
16. Das Verfahren gemäß einem der Ansprüche 1 bis 10, wobei die analytspezifischen Rezeptoren eines von einem Element eines Bindungspaares sind, das aus der Gruppe ausgewählt ist, bestehend aus Antikörper-Antigen, Enzym-Inhibitor, komplementären Stränge von Nukleinsäuren oder Oligonukleotiden, Rezeptor-Hormon, Rezeptor-Effektor, Enzym-Substrat, Enzym-Cofaktor, Glykoprotein-Kohlenhydrat, Bindungsprotein-Substrat, Antikörper-Hapten, Protein-Ligand, Protein-Nukleinsäure, Protein-Kleinmolekül (small molecule), Protein-Ion, Zelle-Antikörper gegen die Zelle, Kleinmolekül-Antikörper gegen das Kleinmolekül, Chelatbildner mit Metallionen und in der Luft befindliche Pathogene mit zugeordneten Luftpathogenrezeptoren. 30
17. Das Verfahren gemäß einem der Ansprüche 1 bis 8, wobei das Substrat aus der Gruppe ausgewählt ist, bestehend aus Glas, Glimmer, poliertes Silizium, Siliziumdioxid, Polymermaterialien, im Wesentlichen transparente Polymermaterialien, teilweise oder vollständig reflektierende Substrate einschließlich Metalle und metallbeschichtete Substrate. 35
18. Das Verfahren gemäß einem der Ansprüche 1 bis 8, enthaltend ein in Kontakt Bringen der Oberfläche des Substrates (12, 12') mit einem Medium (82), das ein Standardmaterial enthält, das an die gebundenen Analyten bindet, nachdem die Oberfläche des Substrates (12, 12') mit dem Medium (82) in Kontakt gebracht wurde und bevor ein ausgewählter Bereich der Oberfläche beleuchtet wird. 40
19. Das Verfahren gemäß Anspruch 18, wobei das Standardmaterial aus der Gruppe ausgewählt ist, bestehend aus Proteinen, Metallkolloiden, Polymerkolloiden, kolloidales Silikamaterial, Quantenpunkten und Kombinationen hiervon. 45
20. Das Verfahren gemäß Anspruch 1, wobei das Medium (82) aus der Gruppe ausgewählt ist, bestehend aus Blut, Serum, Plasma und Urin. 50
21. Das Verfahren gemäß Anspruch 1, wobei die zumindest zwei Muster sich gegenseitig durchdringen.
22. Das Verfahren gemäß Anspruch 1, enthaltend das quantitative Bestimmen einer Menge der vorhandenen Analyten durch Messen von Intensitäten in geeigneten Bereichen des Beugungsbildes.
23. Das Verfahren gemäß Anspruch 5, wobei der Schritt des Analysierens des Bildes des gebeugten Lichtes ein Analysieren nach Intensitätsunterschieden zwischen dem Bild des gebeugten Lichtes und dem Basisbeugungsbild enthält.
24. Das Verfahren gemäß Anspruch 1, wobei das erste vorgegebene Muster erster analytspezifischer Rezeptoren und das zumindest eine zweite vorgegebene Muster enthaltend zweite analytspezifische Rezeptoren so an der Oberfläche angeordnet sind, dass sie sich gegenseitig durchdringen.
25. Das Verfahren gemäß Anspruch 1, wobei der Schritt des Analysierens des Bildes des gebeugten Lichtes ein rechnerisches Entfalten (Dekonvolieren) des Bildes des gebeugten Lichtes enthält.
26. Eine Vorrichtung (30, 40, 50) zum Erfassen von Analyten in einem Medium (82) unter Verwendung von Lichtbeugung, aufweisend:
- eine Beleuchtungsquelle (32);
ein Erkennungselement (10, 20), das ein Substrat (12, 12') mit einer Oberfläche enthält, und wobei die Vorrichtung **dadurch gekennzeichnet ist, dass** sie enthält:
- auf der Oberfläche ein erstes vorgegebe-

- nes Muster erster analytspezifischer Rezeptoren und zumindest ein zweites vorgegebenes Muster enthaltend zweite analytspezifische Rezeptoren, wobei alle vorgegebenen Muster (14, 16, 18, 21, 23, 25) auf der Oberfläche geometrisch verschiedene Muster sind und jeweils bei Bindung mit einem Analyten ein vorgegebenes Beugungsmuster hervorrufen, das von den Beugungsmustern verschieden ist, die von allen anderen vorgegebenen Mustern auf der Oberfläche hervorgerufen werden, wobei die Beleuchtungsquelle so positioniert ist, dass sie die Substratoberfläche beleuchtet;
- Erfassungsmittel (34), die von der Substratoberfläche beabstandet sind, um ein Vollbild von Licht zu erfassen, das von der beleuchteten Oberfläche gebeugt wird; und Verarbeitungsmittel zum Analysieren des Vollbildes des gebeugten Lichtes hinsichtlich der An- oder Abwesenheit jedes der vorgegebenen Beugungsmuster (14, 16, 18, 21, 23, 25), die ein Binden der Analyten an ihre zugeordneten analytspezifischen Rezeptoren repräsentieren, und Identifizieren der An- oder Abwesenheit der Analyten in dem Medium aus dem Vollbild des gebeugten Lichtes, wobei die Verarbeitungsmittel eine Bildanalyseeinrichtung zum Entfalten (Dekonvolvieren) des Vollbildes in Einzelmuster enthalten.
27. Die Vorrichtung gemäß Anspruch 26, wobei die Verarbeitungsmittel mit den Erfassungsmitteln (34) verbunden sind und Speichermittel zum Speichern von Signalen enthalten, die von den Erfassungsmitteln (34) entsprechend dem gebeugten Licht ausgegeben werden.
28. Die Vorrichtung gemäß Anspruch 27, wobei die Verarbeitungsmittel Signalverarbeitungsmittel zum Berechnen von Wechselwirkungskinetiken der Analyten, die an ihre analytspezifischen Rezeptoren binden, aus dem gebeugten Licht, das in Abhängigkeit von der Zeit gespeichert ist, enthalten.
29. Die Vorrichtung gemäß Anspruch 26, wobei die Beleuchtungsquelle einen kohärenten und monochromatischen, kollimierten Lichtstrahl erzeugt.
30. Die Vorrichtung gemäß Anspruch 26, wobei die Beleuchtungsquelle ein Laser mit Emission im UV-, sichtbaren, Nah-Infrarot- oder Infrarotwellenlängenbereich ist.
31. Die Vorrichtung gemäß Anspruch 26, wobei das Licht, das die Substratoberfläche beleuchtet, durch eine optische Faser geliefert wird.
32. Die Vorrichtung gemäß einem der Ansprüche 26 bis 30, enthaltend eine Zelle (50, 56, 66), die eine Kammer einschließt, um darin das Medium (82) zu enthalten, das hinsichtlich Analyten untersucht wird, wobei die Zelle angepasst ist, um das Substrat mit dem ausgewählten Bereich des Substrats in Kontakt mit dem Medium (82) aufzunehmen, wobei die Zelle (50, 56, 66) zumindest ein optisches Fenster zum Durchlassen von Licht aufweist, um Analyten in dem Medium *in situ* zu erfassen.
33. Die Vorrichtung gemäß einem der Ansprüche 26 bis 32, wobei das Licht, das verwendet wird, um die Oberfläche des Substrates zu beleuchten, innerer Totalreflexion an einer Substrat/Medium-Grenzfläche unterliegt.
34. Die Vorrichtung gemäß Anspruch 32 oder 33, wobei die Zelle (66) einen Fluideinlass (72) und einen Fluidauslass (74) für einen kontinuierlichen Fluss des Mediums (82) durch die Zelle enthält.
35. Die Vorrichtung gemäß Anspruch 26, wobei das Substrat aus der Gruppe ausgewählt ist, bestehend aus Glas, silanisiertes Glas, Silizium, Siliziumdioxid, Polymer, Metall, Metalloxid, Metallfilm, Metalloxidfilm, teilweise oder vollständig reflektierende Substrate einschließlich Metalle und metallbeschichtete Substrate.
36. Die Vorrichtung gemäß Anspruch 26, wobei die Erfassungsmittel (34) eine Bilderfassungsvorrichtung sind.
37. Die Vorrichtung gemäß Anspruch 36, wobei die Bilderfassungsvorrichtung eine elektronische Bilderfassungsvorrichtung ist.
38. Die Vorrichtung gemäß Anspruch 36, wobei die Bilderfassungsvorrichtung eine Kamera ist.
39. Die Vorrichtung gemäß Anspruch 26, wobei die Erfassungsmittel (34) einen Photodiodendetektor, eine Photovervielfacherröhre, eine Lawinenphotodiode oder eine lageempfindlichen Photodiode enthalten.
40. Die Vorrichtung gemäß Anspruch 37, wobei die Bilderfassungsvorrichtung ein Matrix-Array-Detektor ist.
41. Die Vorrichtung gemäß Anspruch 40, wobei der Matrix-Array-Detektor ein CCD-Detektorarray ist.
42. Die Vorrichtung gemäß Anspruch 26, wobei die analytspezifischen Rezeptoren eines von einem Ele-

ment eines Bindungspaares sind, das aus der Gruppe ausgewählt ist, bestehend aus Antikörper-Antigen, Enzym-Inhibitor, komplementären Stränge von Nukleinsäuren oder Oligonukleotiden, Rezeptor-Hormon, Rezeptor-Effektor, Enzym-Substrat, Enzym-Cofaktor, Glykoprotein-Kohlenhydrat, Bindungsprotein-Substrat, Antikörper-Hapten, Protein-Ligand, Protein-Nukleinsäure, Protein-Kleinmolekül (small molecule), Protein-Ion, Zelle-Antikörper gegen die Zelle und Kleinmolekül-Antikörper gegen das Kleinmolekül, Chelatbildner mit Metallionen und in der Luft befindliche Pathogene mit zugeordneten Luftpathogenrezeptoren.

43. Die Vorrichtung gemäß Anspruch 26, wobei einer der analytspezifischen Rezeptoren hinsichtlich eines bekannten Analyten untersucht, der in einem Medium (82) vorliegt, das hinsichtlich der Analyten zu untersuchen ist.

44. Die Vorrichtung gemäß Anspruch 26, wobei die analytspezifischen Rezeptoren in den Mustern direkt auf dem Substrat (12, 12') angeordnet sind.

45. Die Vorrichtung gemäß Anspruch 26, enthaltend eine Zwischenschicht, die direkt an der Oberfläche des Substrates (12, 12') gebildet ist, und wobei die analytspezifischen Rezeptormuster auf der Zwischenschicht angeordnet sind.

46. Die Vorrichtung gemäß Anspruch 45, wobei die Zwischenschicht eine Schicht aus Avidin in einem Muster ist, und wobei die analytspezifischen Rezeptoren biotinylierte analytspezifische Rezeptoren sind, um an die mit einem Muster versehene Avidinschicht zu binden.

47. Die Vorrichtung gemäß Anspruch 26, enthaltend eine Einrichtung zum Rastern der Beleuchtungsquelle über die Oberfläche des Substrates (12, 12').

48. Die Vorrichtung gemäß Anspruch 26, wobei das erste vorgegebene Muster erster analytspezifischer Rezeptoren und das zumindest eine zweite vorgegebene Muster enthaltend zweite analytspezifische Rezeptoren so auf der Oberfläche angeordnet sind, dass sie sich gegenseitig durchdringen.

Revendications

1. Procédé pour détecter simultanément au moins deux analytes dans un milieu (82) en utilisant la diffraction de la lumière, renfermant les étapes consistant à se procurer un substrat (12, 12') comportant une surface, et sur cette surface, un premier réseau pré sélectionné de premiers récepteurs spécifiques à un analyte et au moins un second réseau pré sé-

lectionné comportant des seconds récepteurs spécifiques à un analyte, ce procédé étant **caractérisé en ce que** chacun des réseaux pré sélectionnés (14, 16, 18, 21, 23, 25) de la surface est un réseau géométriquement distinct et, lorsqu'il est lié à un analyte crée un réseau de diffraction pré sélectionné distinct des réseaux de diffraction formés à partir de tous les autres réseaux pré sélectionnés de la surface, mettre en contact la surface du substrat (12, 12') avec le milieu (82) pendant un temps suffisant pour permettre aux analytes présents dans ce milieu de se lier à leur récepteur spécifique associé, et éclairer le substrat (12, 12') détecter, dans une position située à distance de la surface du substrat, une image complète de la lumière diffractée à partir de cette surface, et analyser l'image de la lumière diffractée pour détecter la présence ou l'absence de chacun des réseaux de diffraction pré sélectionnés (12, 16, 18, 21, 23, 25) représentatifs de la liaison des analytes et de leur récepteur spécifique associé, cette étape d'analyse renfermant une étape de déconvolution de cette image complète en des réseaux individuels et d'identification à partir de l'image complète de la lumière diffractée de la présence ou de l'absence des analytes dans le milieu.

2. Procédé conforme à la revendication 1, selon lequel l'étape d'éclairage du substrat (12, 12') renferme une étape d'éclairage d'une surface suffisante du substrat pour éclairer au moins une partie de chacun des réseaux pré sélectionnés présents sur le substrat (12, 12').

3. Procédé conforme à la revendication 1, selon lequel l'étape d'éclairage du substrat (12, 12') renferme une étape d'éclairage des réseaux pré sélectionnés un par un.

4. Procédé conforme à la revendication 2, selon lequel l'étape d'analyse de l'image de la lumière diffractée pour détecter la présence ou l'absence des réseaux de diffraction présélectionnés représentatifs de la liaison d'au moins un analyte à son récepteur spécifique renferme une étape de mise en mémoire de l'image de la lumière diffractée provenant de la surface éclairée.

5. Procédé conforme à la revendication 2 ou à la revendication 4, renfermant une étape consistant à détecter une image de la lumière diffractée à partir de la surface du substrat (12, 12') avant d'exposer la surface du substrat (12, 12') au milieu pour obtenir une image de diffraction de base correspondant à ce substrat (12, 12') et aux réseaux de récepteurs spécifiques à un analyte en l'absence d'analyte, et à mettre en mémoire cette image de diffraction de base.

6. Procédé conforme à la revendication 5, selon lequel l'étape d'analyse de l'image de la lumière diffractée pour détecter la présence ou l'absence des réseaux de diffraction présélectionnés (14, 16, 18, 21, 23, 25) représentatifs de la liaison d'au moins un analyte avec son récepteur spécifique renferme une étape de comparaison de l'image de la lumière diffractée avec l'image de diffraction de base.
7. Procédé conforme à la revendication 2, selon lequel l'étape d'éclairage du substrat (12, 12') renferme une étape consistant à éclairer le substrat avec un faisceau laser monochromatique essentiellement cohérent.
8. Procédé conforme à la revendication 7, selon lequel le faisceau laser émet de la lumière dans le domaine infrarouge visible ou ultraviolet.
9. Procédé conforme à l'une quelconque des revendications 1 à 8, selon lequel le substrat est essentiellement transparent, la surface est éclairée sur un côté du substrat (12, 12'), et l'image de la lumière diffractée à partir du substrat est détectée sur le côté opposé du substrat.
10. Procédé conforme à l'une quelconque des revendications 1 à 8, selon lequel le substrat (12, 12') est partiellement réfléchissant, la surface est éclairée sur un côté du substrat, et l'image de la lumière diffractée est détectée sur le même côté du substrat (12, 12').
11. Procédé conforme à l'une quelconque des revendications 1 à 8, selon lequel le substrat (12, 12') est réfléchissant, la surface est éclairée sur un côté du substrat, et l'image de la lumière diffractée est détectée sur le même côté du substrat (12, 12').
12. Procédé conforme à l'une quelconque des revendications 1 à 11, selon lequel après avoir mis en contact la surface du substrat (12, 12') avec un milieu ayant été criblé pour des analytes pré sélectionnés, le substrat (12, 12') est rincé et séché avant d'être éclairé.
13. Procédé conforme à l'une quelconque des revendications 1 à 10, selon lequel l'étape de mise en contact de la surface du substrat (12, 12') avec le milieu (82) renferme une étape consistant à placer ce substrat dans une cellule (50) contenant ce milieu ayant été criblée pour les analytes, cette cellule (50) ayant au moins une fenêtre optique permettant à la lumière de passer au travers pour détecter les analytes dans le milieu in situ.
14. Procédé conforme à la revendication 13, selon lequel les intensités des régions sélectionnées de l'image résultant de la lumière diffractée sont contrôlées en fonction du temps.
15. Procédé conforme à l'une quelconque des revendications 1 à 8, selon lequel la lumière éclairant le substrat (12, 12') est dirigée vers ce substrat (12, 12') selon un angle efficace pour subir une réflexion interne totale sur une interface substrat/milieu.
16. Procédé conforme à l'une quelconque des revendications 1 à 10, selon lequel les récepteurs spécifiques à un analyte sont l'un des membres d'un couple d'agents de liaison choisi dans le groupe formé par les anticorps-antigène, enzyme-inhibiteur, brins complémentaires d'acides nucléiques ou d'oligonucléotides, récepteur-hormone, récepteur-effecteur, enzyme-substrat, enzyme-cofacteur, glycoprotéine-hydrate de carbone, protéine de liaison-substrat, anticorps-haptène, protéine-ligand, protéine-acide nucléique, protéine-petite molécule, protéine-ion, cellule-anticorps de cette cellule, petite molécule-anticorps de cette petite molécule, agent de chélation d'ions métalliques et agents pathogènes en suspension dans l'air et récepteurs associés.
17. Procédé conforme à l'une quelconque des revendications 1 à 8, selon lequel le substrat est choisi dans le groupe formé par le verre, le mica, le silicium poli, le dioxyde de silicium, les matériaux polymères, les matériaux polymères essentiellement transparents, les substrats partiellement ou totalement réfléchissants y compris les métaux et les substrats revêtus de métal.
18. Procédé conforme à l'une quelconque des revendications 1 à 8, renfermant une étape consistant à mettre en contact la surface du substrat (12, 12') avec un milieu (82) contenant un matériau standard qui se lie aux analytes liés après la mise en contact de cette surface du substrat (12, 12') avec le milieu (82) et avant l'éclairage d'une surface prédéfinie de cette surface.
19. Procédé conforme à la revendication 18, selon lequel le matériau standard est choisi dans le groupe formé par les protéines, les colloïdes métalliques, les colloïdes polymères, la silice colloïdale, les points quantum et leurs combinaisons.
20. Procédé conforme à la revendication 1, selon lequel le milieu (82) est choisi dans le groupe formé par le sang, le sérum, le plasma et l'urine.
21. Procédé conforme à la revendication 1, selon lequel les réseaux au moins au nombre de deux pénètrent l'un dans l'autre.
22. Procédé conforme à la revendication 1, renfermant

une étape de détermination quantitative de la quantité d'analytes présents par mesure d'intensités dans des parties appropriées de l'image de diffraction.

23. Procédé conforme à la revendication 5, selon lequel l'étape consistant à analyser l'image de la lumière diffractée renferme une étape d'analyse des différences d'intensité entre l'image de la lumière diffractée et l'image de diffraction de base.

24. Procédé conforme à la revendication 1, selon lequel le premier réseau pré sélectionné de premiers récepteurs spécifiques à un analyte et le ou les second(s) réseau(x) pré sélectionné(s) renfermant des seconds récepteurs spécifiques à un analyte sont appliqués sur la surface de sorte qu'ils pénètrent les uns dans les autres.

25. Procédé conforme à la revendication 1, selon lequel l'étape consistant à analyser l'image de la lumière diffractée renferme une étape de déconvolution par ordinateur de l'image de la lumière diffractée.

26. Appareil (30, 40, 50) de détection d'analytes dans un milieu (82) en utilisant la diffraction de la lumière renfermant :

- une source d'éclairage (32),
- un élément de détection (10, 20) renfermant un substrat (12, 12') ayant une surface,
- cet appareil étant **caractérisé en ce qu'il** comporte :

sur cette surface, un premier réseau pré sélectionné de premiers récepteurs spécifiques à un analyte et au moins un second réseau pré sélectionné renfermant des seconds récepteurs spécifiques à un analyte, chacun des réseaux pré sélectionnés (14, 16, 18, 21, 23, 25) de la surface étant un réseau géométriquement distinct, et, lorsqu'il est lié à un analyte, créant un réseau de diffraction pré sélectionné distinct des réseaux de diffraction formés à partir de tous les autres réseaux pré sélectionnés de la surface, la source d'éclairage étant placée de façon à éclairer la surface du substrat,

- des moyens de détection (34) situés à distance de la surface du substrat de façon à détecter une image complète de la lumière diffractée à partir de la surface éclairée et,
- des moyens de traitement pour analyser l'image complète de la lumière diffractée pour détecter la présence ou l'absence de chacun des réseaux de diffraction pré sélectionnés (14, 16, 18, 21, 23, 25) représentatifs de la liaison des analytes et de leur récepteur spécifique associé,

et identifier à partir de l'image complète de la lumière diffractée la présence ou l'absence des analytes dans ce milieu, ces moyens de traitement renfermant des moyens d'analyse d'images pour effectuer la déconvolution de l'image complète en des réseaux individuels.

27. Appareil conforme à la revendication 26, selon lequel les moyens de traitement sont reliés aux moyens de détection (34) et renferment des moyens de stockage pour mettre en mémoire des signaux de sortie des moyens de détection (34) correspondant à la lumière diffractée.

28. Appareil conforme à la revendication 27, dans lequel les moyens de traitement renferment des moyens de traitement de signal pour calculer les cinétiques d'interaction des analytes se liant à leur récepteur spécifique à partir de la lumière diffractée, mise en mémoire en tant que fonction du temps.

29. Appareil conforme à la revendication 26, dans lequel la source d'éclairage produit un faisceau de lumière collimatée cohérente et mono chromatique.

30. Appareil conforme à la revendication 26, dans lequel la source d'éclairage est un laser émettant à des longueurs d'ondes situées dans l'UV, le visible, le proche infrarouge ou l'infrarouge.

31. Appareil conforme à la revendication 26, dans lequel la lumière éclairant la surface du substrat est fournie par une fibre optique.

32. Appareil conforme à l'une quelconque des revendications 26 à 30, comportant une cellule (50, 56, 66) renfermant une chambre destinée à contenir un milieu (82) ayant été criblé pour les analytes, cette cellule étant adaptée pour recevoir le substrat, de sorte que la surface prédéfinie de celui-ci soit en contact avec le milieu (82) et ayant au moins une fenêtre optique permettant à la lumière de passer au travers pour détecter les analytes dans le milieu in situ.

33. Appareil conforme à l'une quelconque des revendications 26 à 32, dans lequel la lumière utilisée pour éclairer la surface du substrat est soumise à une réflexion interne totale sur une interface substrat/milieu.

34. Appareil conforme à la revendication 32 ou 33, dans lequel la cellule (66) comporte une entrée de fluide (72) et une sortie de fluide (74) pour permettre un écoulement continu du milieu (82) au travers de cette cellule.

35. Appareil conforme à la revendication 26, dans lequel le substrat est choisi dans le groupe formé par le

- verre, le verre silanisé, le silicium, le dioxyde de silicium, les polymères, les métaux, les oxydes métalliques, les films métalliques, les films d'oxyde métallique, les substrats partiellement ou totalement réfléchissants y compris les métaux et les substrats revêtus de métal. 5
36. Appareil conforme à la revendication 26, dans lequel les moyens de détection (34) sont un dispositif d'imagerie. 10
37. Appareil conforme à la revendication 36, dans lequel le dispositif d'imagerie est un dispositif d'imagerie électronique. 15
38. Appareil conforme à la revendication 36, dans lequel le dispositif d'imagerie est une caméra.
39. Appareil conforme à la revendication 26, dans lequel les moyens de détection (34) renferment une photodiode ou un détecteur ou un tube photomultiplicateur ou une photodiode à avalanche ou une photodiode sensible à la position. 20
40. Appareil conforme à la revendication 37, dans lequel le dispositif d'imagerie est un détecteur à réseau de matriciel. 25
41. Appareil conforme à la revendication 40, dans lequel le détecteur est un détecteur à couplage de charge. 30
42. Appareil conforme à la revendication 26, dans lequel les récepteurs spécifiques à un analyte sont l'un des membres d'un couple d'agents de liaison choisi dans le groupe formé par les anticorps-antigène, enzyme-inhibiteur, brins complémentaires d'acides nucléiques ou d'oligonucléotides, récepteur-hormone, récepteur-effecteur, enzyme-substrat, enzyme-cofacteur, glycoprotéine-hydrate de carbone, protéine de liaison- substrat, anticorps-haptène, protéine-ligand, protéine-acide nucléique, protéine-petite molécule, protéine-ion, cellule-anticorps de cette cellule, petite molécule-anticorps de cette petite molécule, agents de chélation d'ions métalliques et agents pathogènes en suspension dans l'air et récepteurs associés. 35 40 45
43. Appareil conforme à la revendication 26, dans lequel l'un des récepteurs spécifiques à un analyte teste un analyte connu qui est présent dans un milieu (82) destiné à être criblé pour les analytes. 50
44. Appareil conforme à la revendication 26, dans lequel les récepteurs spécifiques à un analyte sont appliqués dans les réseaux, directement sur le substrat (12, 12'). 55
45. Appareil conforme à la revendication 26, renfermant
- une couche intermédiaire formée directement sur la surface du substrat (12, 12') et dans lequel les réseaux de récepteurs spécifiques à un analyte sont appliqués sur cette couche intermédiaire.
46. Appareil conforme à la revendication 45, dans lequel la couche intermédiaire est une couche d'avidine en réseau, et les récepteurs spécifiques à un analyte sont des récepteurs spécifiques à un analyte biotinylisés pour pouvoir se lier avec la couche d'avidine en réseau.
47. Appareil conforme à la revendication 26, renfermant des moyens pour tramer la source d'éclairage au travers de la surface du substrat (12, 12').
48. Appareil conforme à la revendication 26, dans lequel le premier réseau pré sélectionné de premiers récepteurs spécifiques à un analyte et le ou les second(s) réseau(x) pré sélectionné(s) renfermant des seconds récepteurs spécifiques à un analyte sont appliqués sur la surface de façon à pénétrer les uns dans les autres.

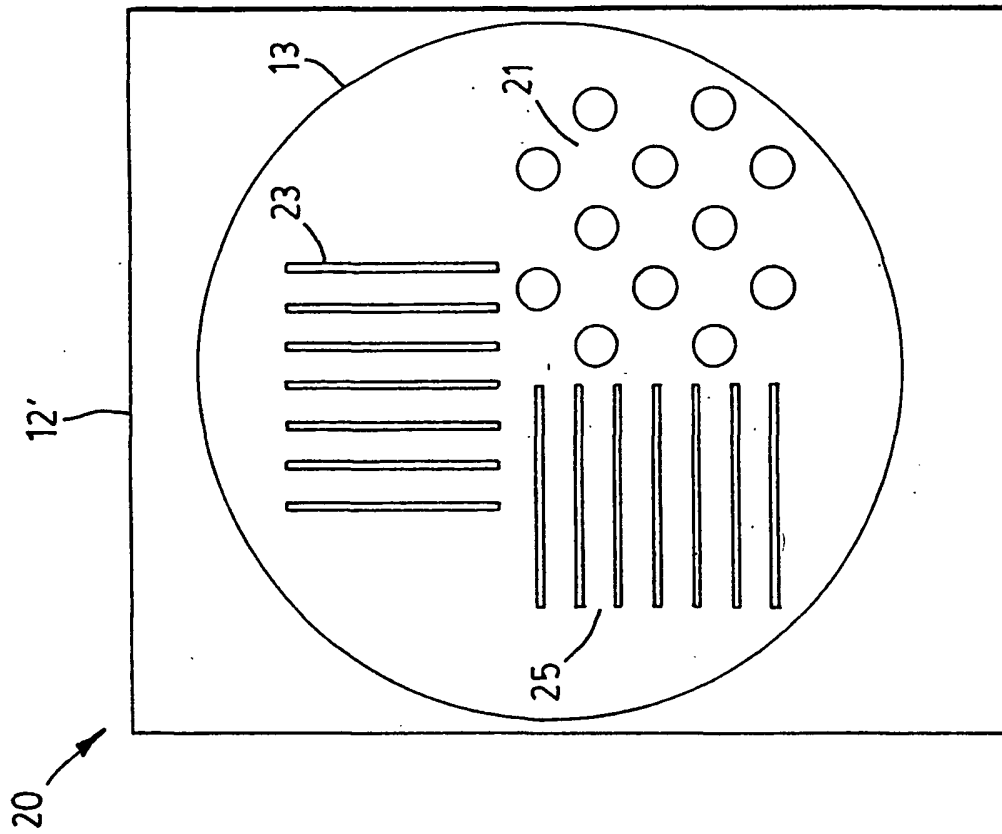


FIG. 1a

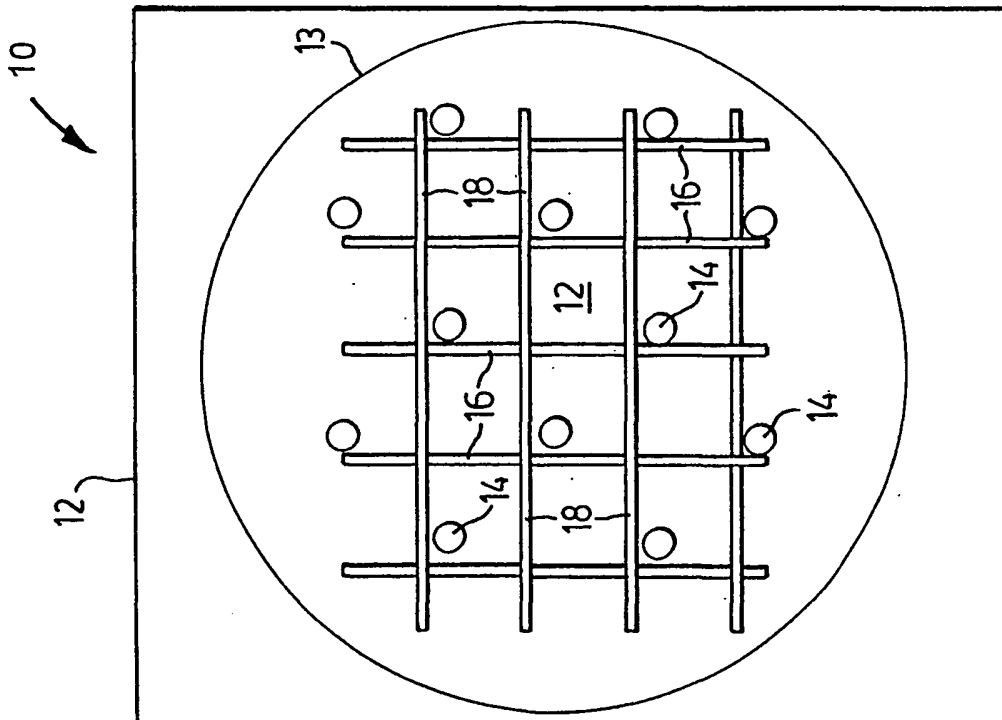


FIG. 1b

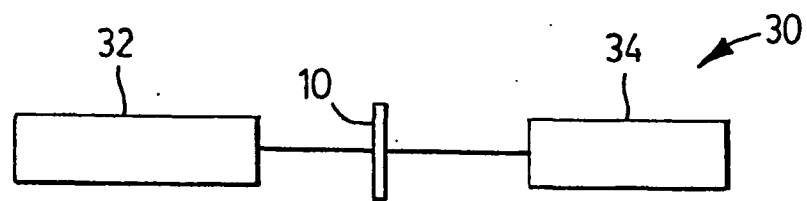


FIG. 2a

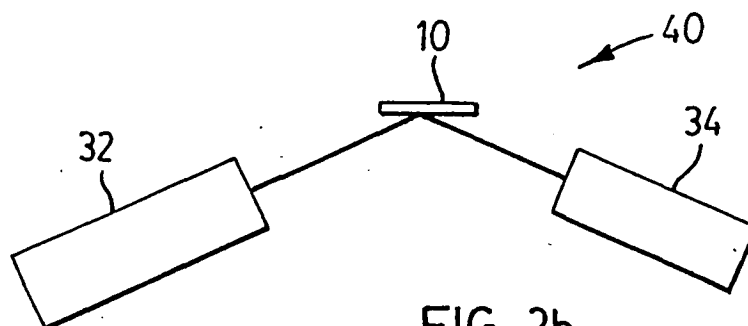


FIG. 2b

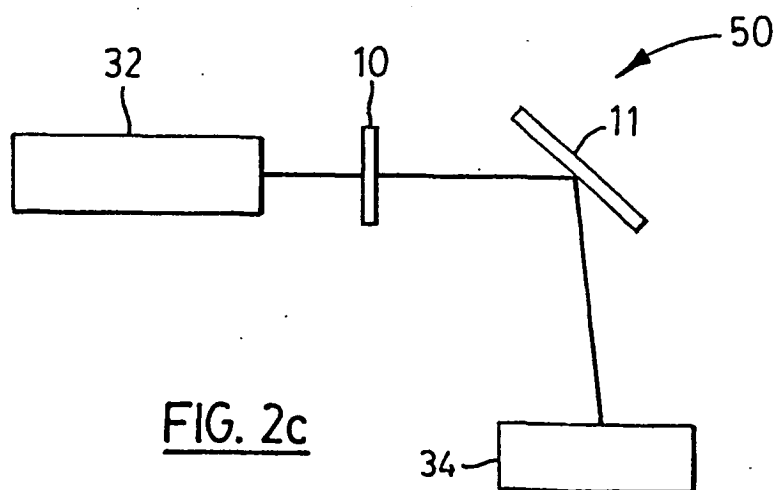
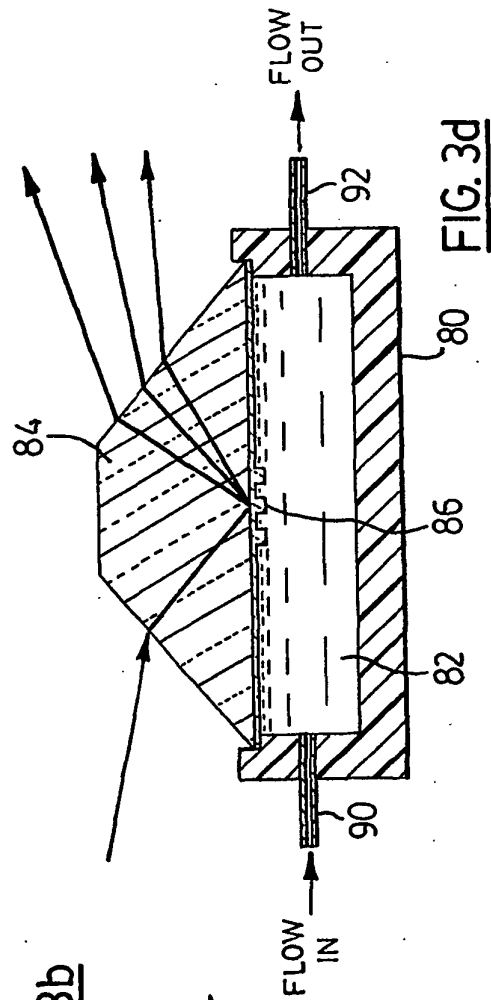
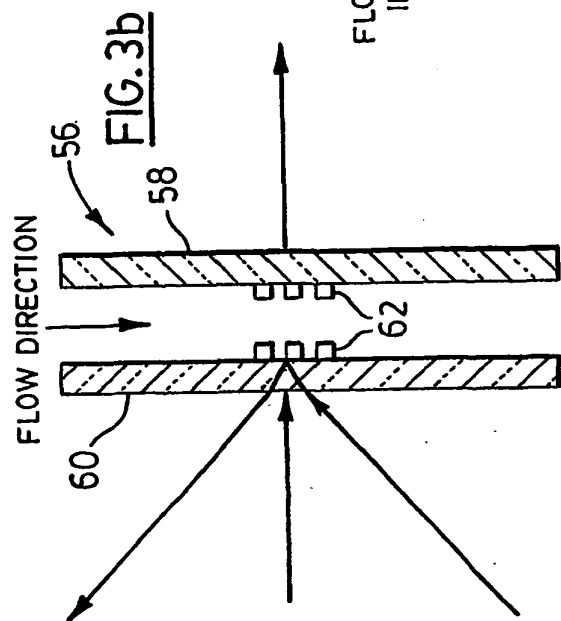
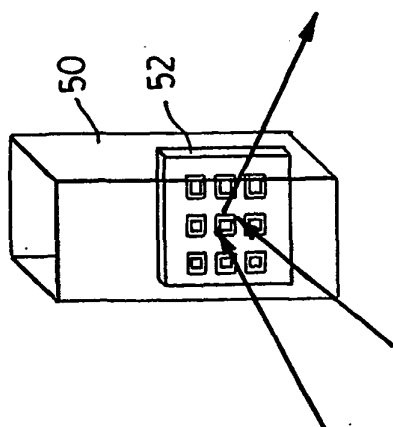
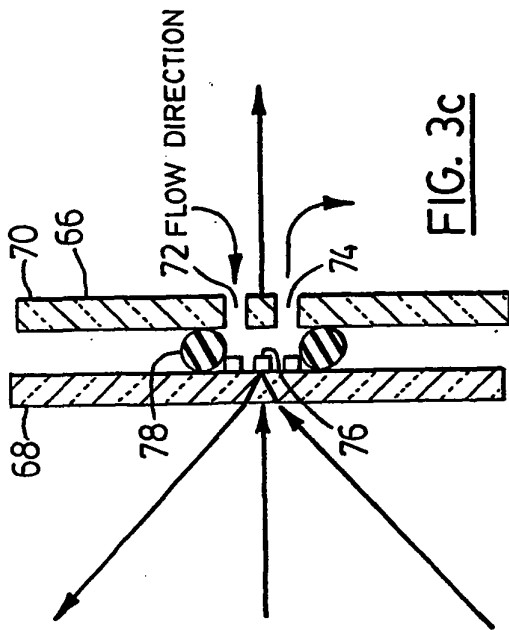


FIG. 2c



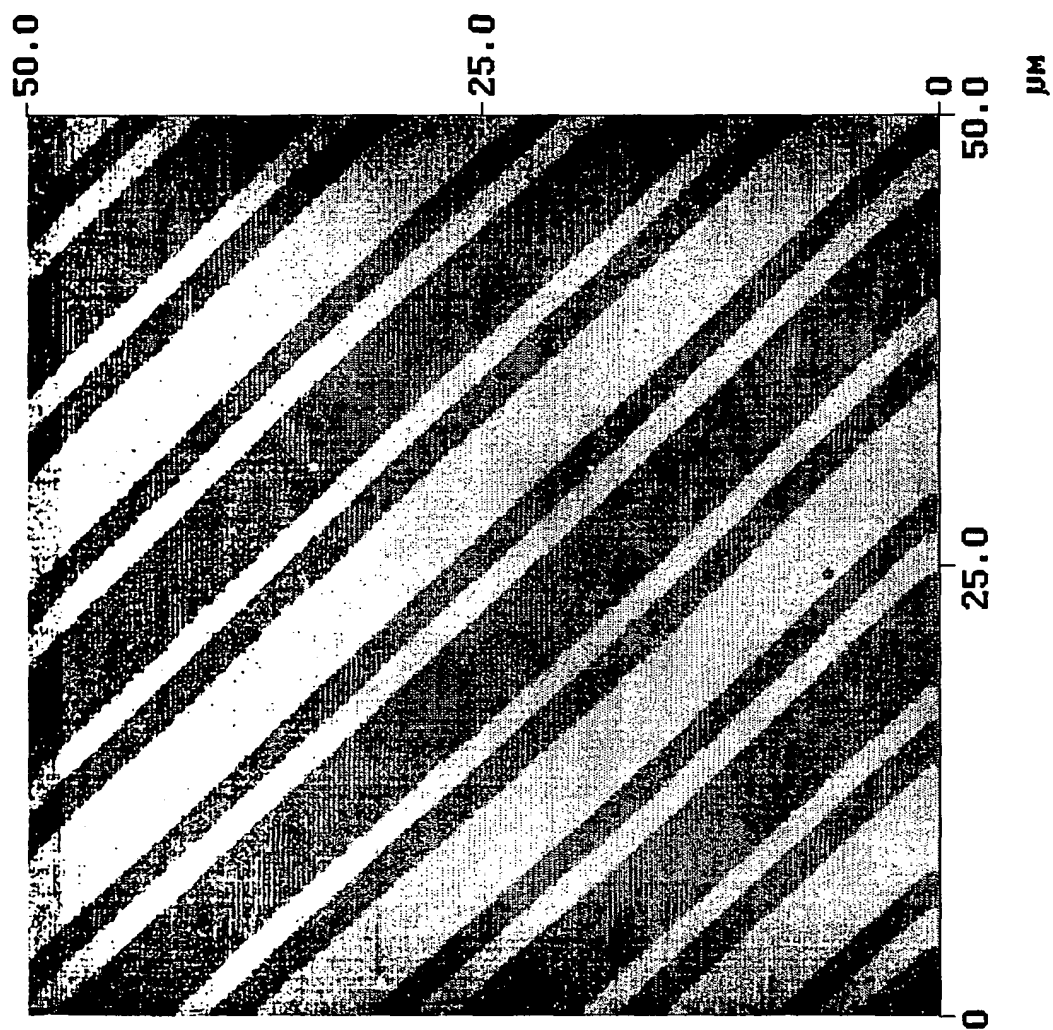
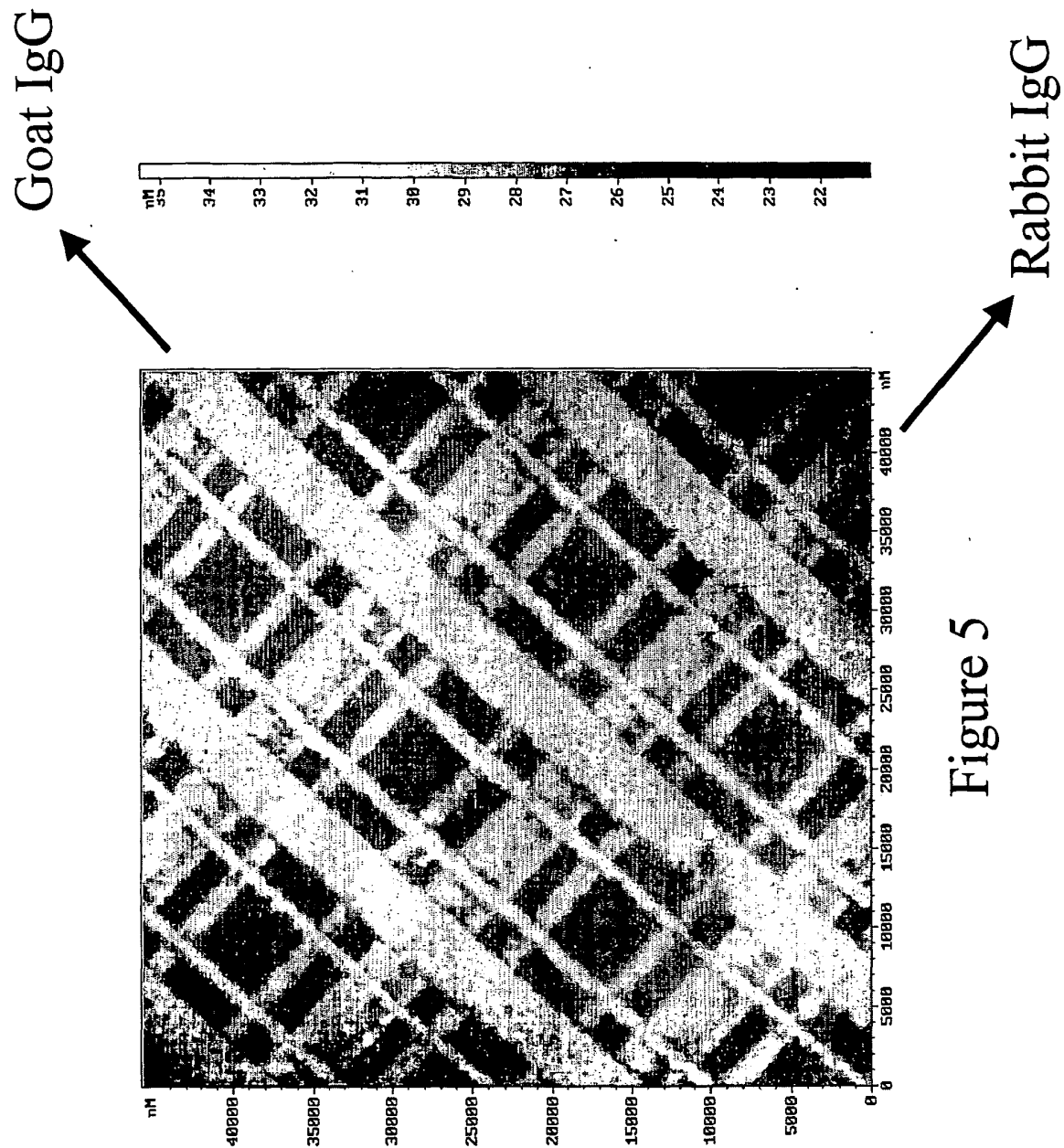


Figure 4



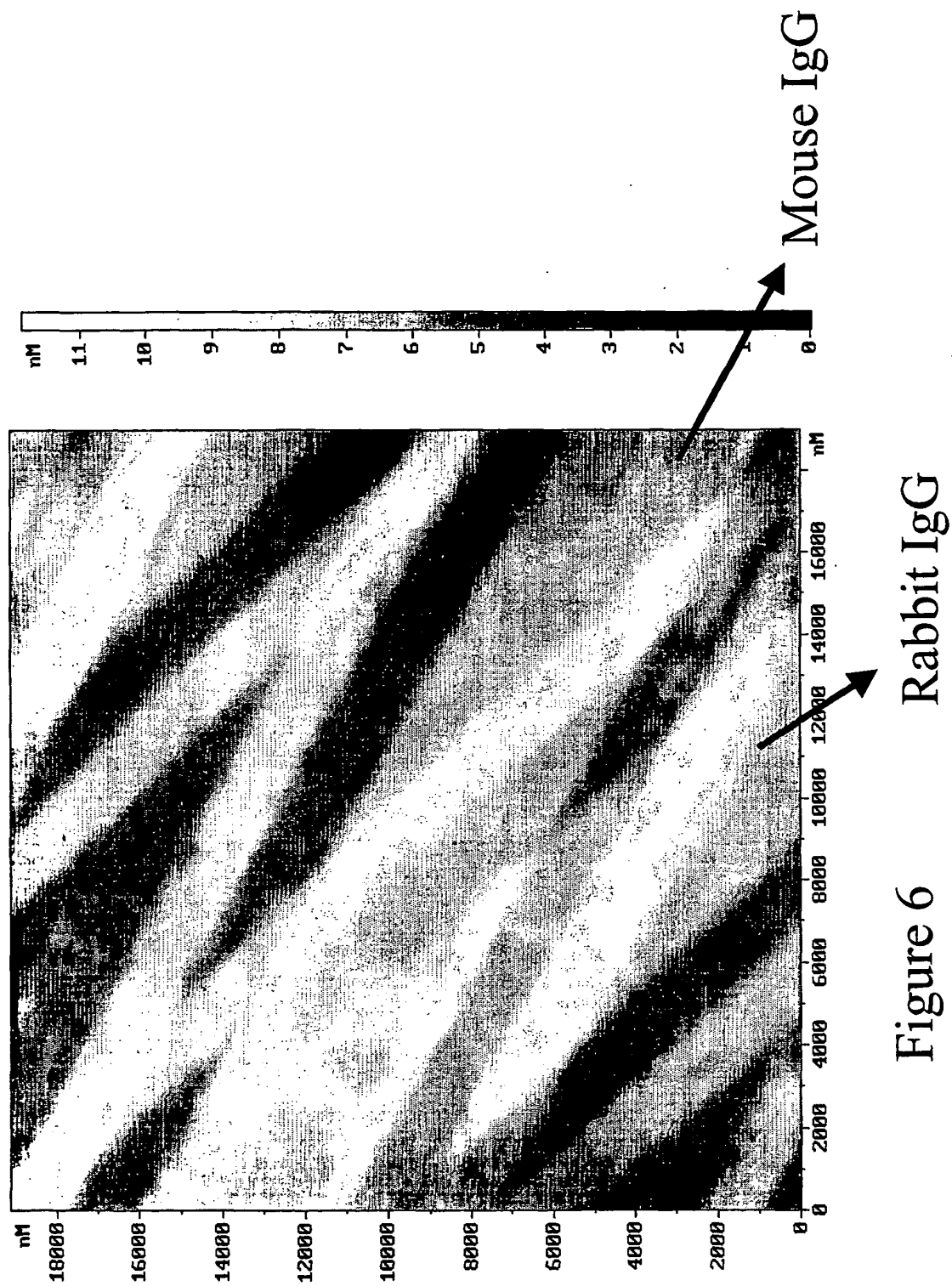


Figure 6 Rabbit IgG

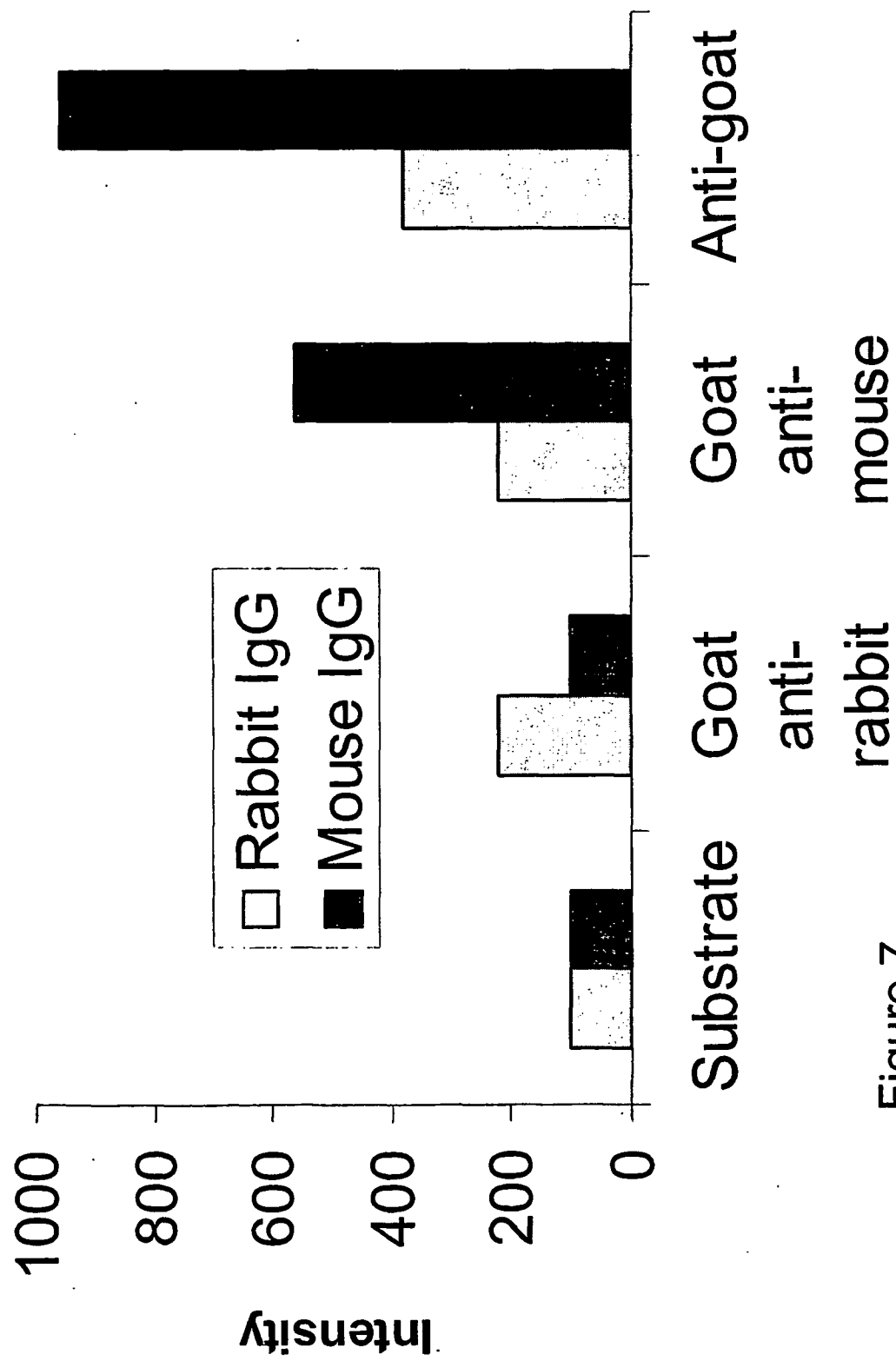


Figure 7

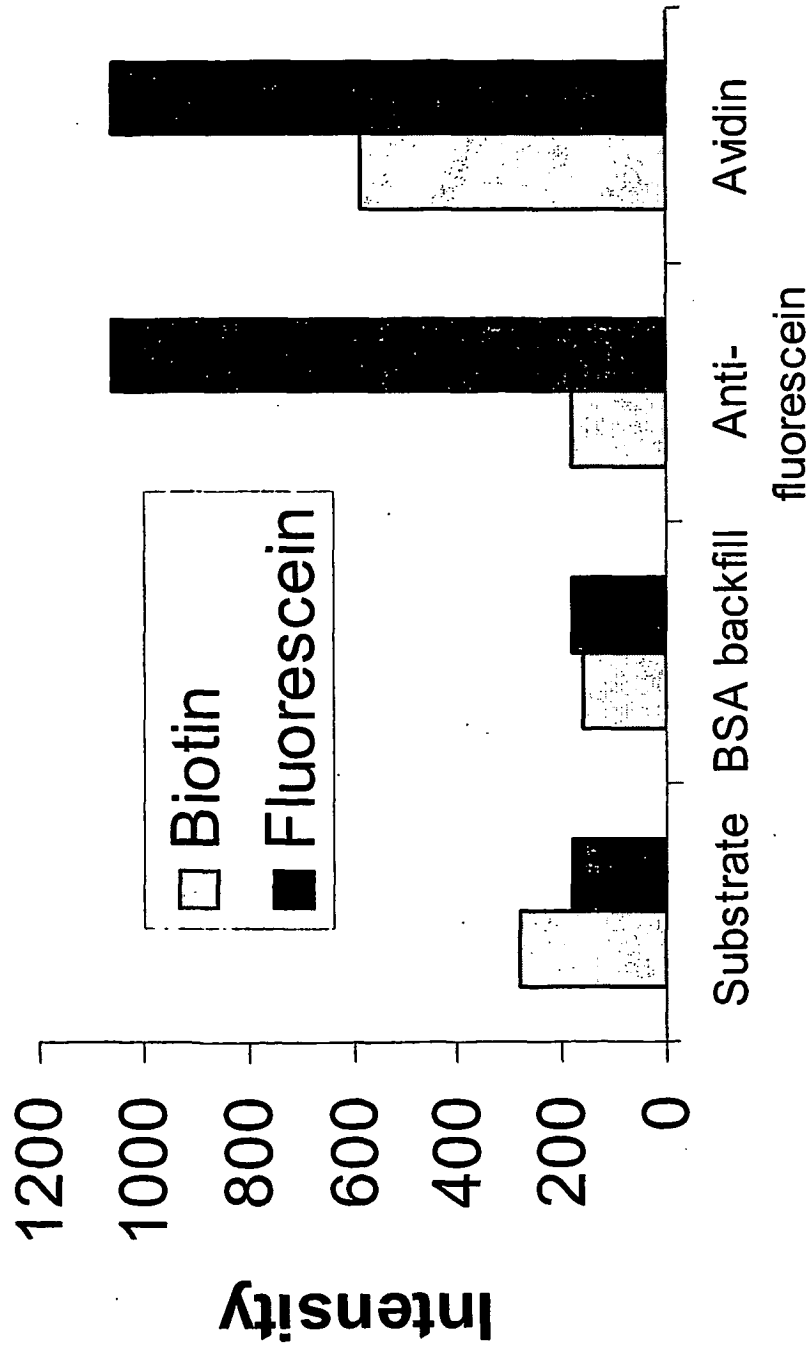


Figure 8

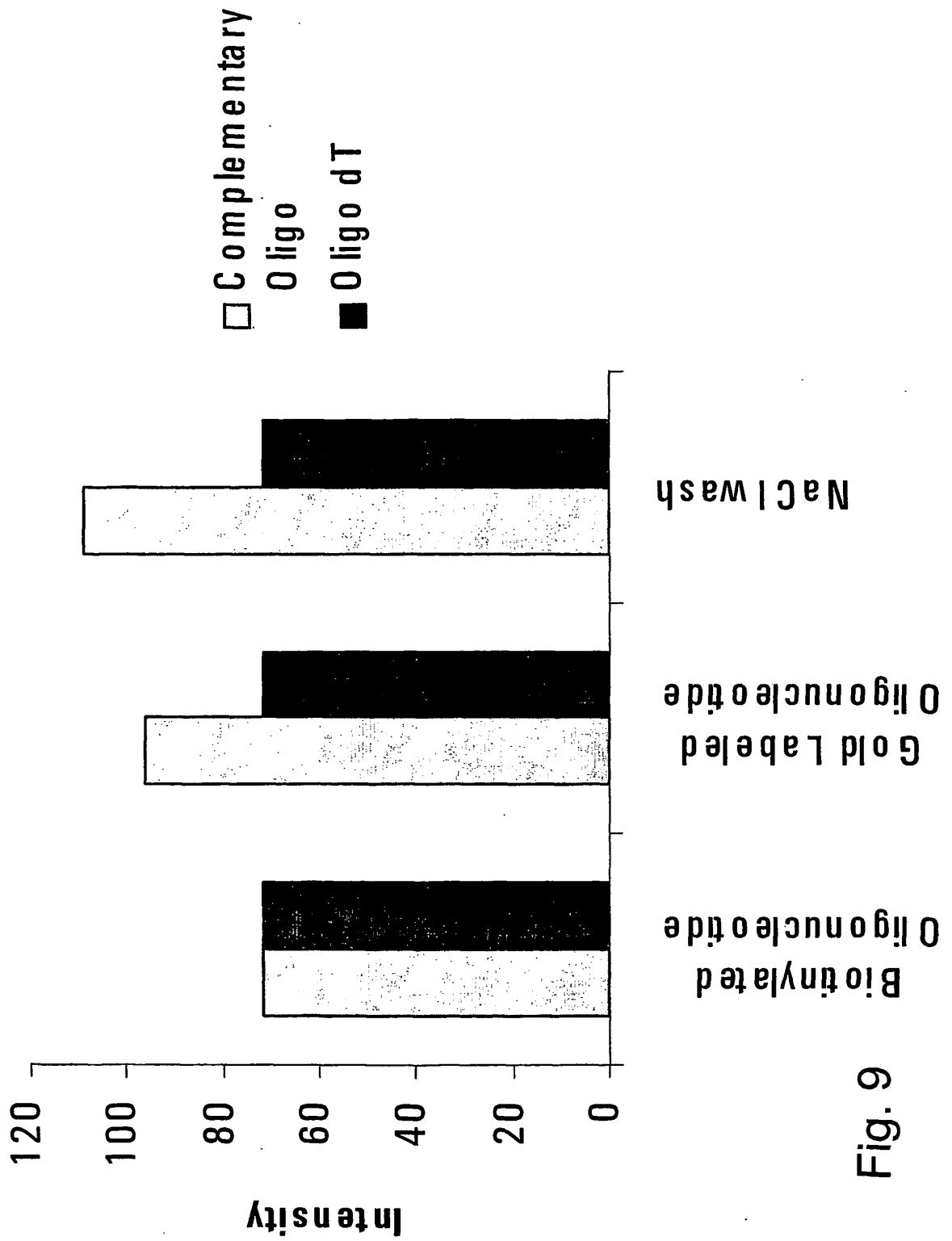


Fig. 9

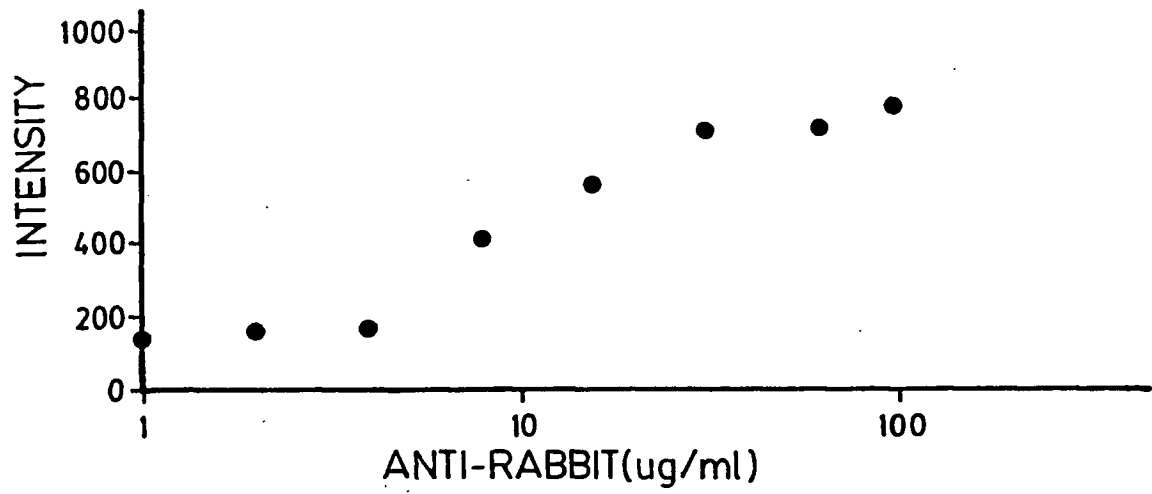


FIG. 10

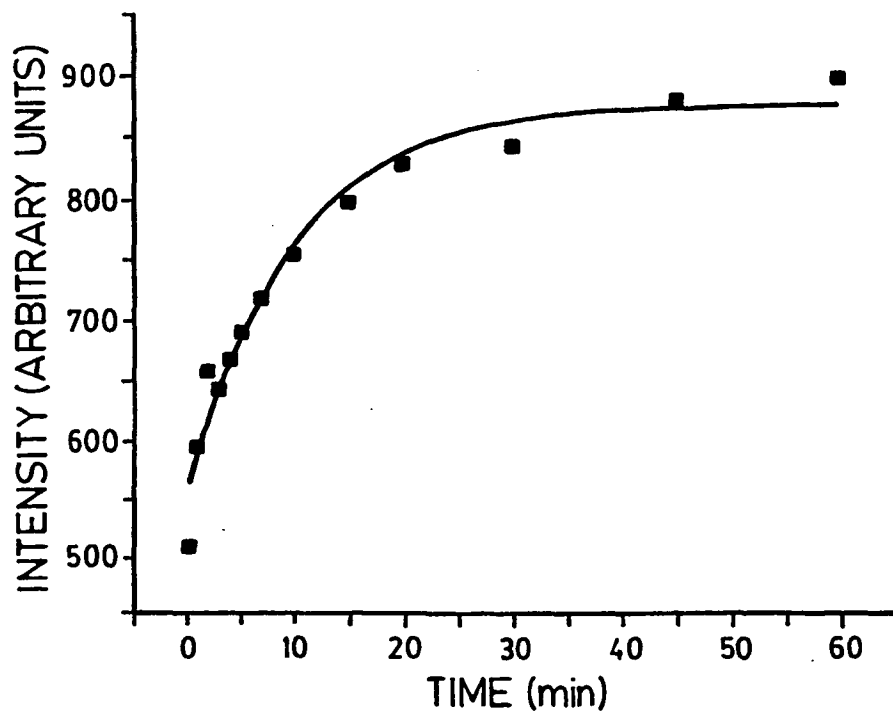


FIG. 11

REFERENCES CITED IN THE DESCRIPTION

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专利名称(译)	用于多分析物测定的方法和设备		
公开(公告)号	EP1266207B1	公开(公告)日	2010-10-27
申请号	EP2001914906	申请日	2001-03-22
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IPC分类号	G01N21/77 G01N21/47 G01N33/543 G01N33/53 G01N33/566 G01N37/00		
CPC分类号	G01N33/54373 B01J2219/00659 B01L2300/0636 B01L2300/0819 B82Y30/00 C12Q1/6837 C12Q2565/513 G01N21/4788 G01N21/77 G01N33/543 G01N2035/00158 G01N2035/0429 Y10S435/808 Y10S436/805 Y10T436/13		
代理机构(译)	ELSY , DAVID		
优先权	60/191344 2000-03-22 US		
其他公开文献	EP1266207A2		
外部链接	Espacenet		

摘要(译)

用于测定多种分析物的方法和设备。该方法使用包括基板 (12) 的传感元件, 在基板 (12) 上布置有多个识别元件 (14,16,18), 使得每个元件以预定图案布置。每种图案都是独特的, 因为它可以在测定中产生特征性衍射图案。图案可以或可以不在基板表面上互穿。检测多种分析物的方法包括使分析物介质与图案化基底接触, 通过光源照射基底, 并检测任何合成的衍射图像。衍射图案和衍射信号的强度提供了有关特定分析物的存在及其量化的信息。