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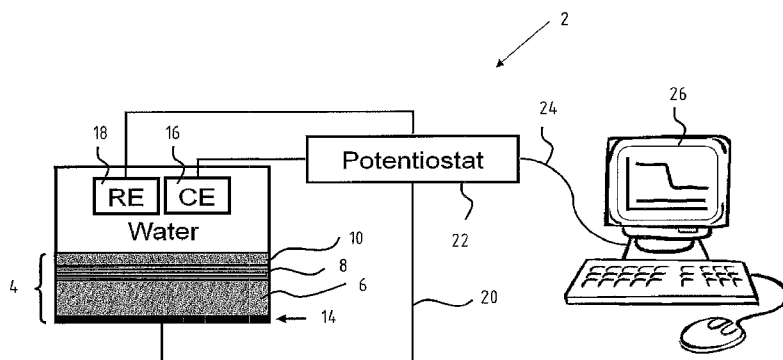


FIG. 1

(57) **Abstract:** The invention relates to an electrode, and a sensor- system for capacitively and/or photovoltaic sensing contaminants in a fluid. The invention also relates to a micro-reactor comprising such sensor- system and methods for measuring and producing. The capacitance electrode comprises: - a transducing element (6),- an affinity layer (10) that in use is in contact with a fluid to be measured, wherein the affinity layer comprises a multi-array surface; and - an organic Monolayer insulating layer (8) separating the transducing element and the affinity layer, wherein the electrode is arranged such that in use contaminants in the fluid may interact with the affinity layer.

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CAPACITANCE ELECTRODE AND SENSOR-SYSTEM CAPABLE OF SENSING
CONTAMINANTS AND METHOD THEREFOR

5 The present invention relates to a capacitance
electrode for use in a sensor-system. The electrode is
capable of capacitively sensing contaminants in a fluid. An
example of a fluid is water and the electrode can for
example be used in the production of high-quality drinking
10 water and industrial water.

Existing sensing techniques include the determination
of the binding of a contamination and a sensor surface using
Surface Plasmon Resonance (SPR) and Mach-Zehnder
Interferometry. Most sensor-systems that are used in
15 practice measure a specific contaminant in a fluid like
water. For example, the presence of nitrite anions in water
can be measured using UV-spectra on a surface of the sensor
that changes in response to bonding of the nitrite anions to
the specific surface layer. Other sensing techniques to
20 measure the presence of specific contaminants include
fluorescence and radiochemical labelling, impedance
measurements.

In order to exclude all safety risks related to ending
up of these contaminations in for example drinking water it
25 would be required to analyse the water on an unacceptably
high number of contaminations using the existing sensing
techniques. As an illustration, the current Water Framework
Directive comprises a list of 33 toxic components with an
EU-Water Quality Specification Directive. This list is about
30 to be extended with more than 100 additional components that
will possibly be included in the water specification in near
future. Furthermore, the number of potentially toxic
components that may end up in the drinking water, like

pharmaceuticals, is continuously increasing. The concentration of all these components will gradually increase in a complete water chain to a steady concentration at which the total amount of toxic components removed through purification equals the amount of toxic components introduced into the water chain. Because of this large number of toxic components and a usually very low concentration in water, the detection of these components in for example surface water or drinking water is expensive, labour intensive and off-line. Another problem relates to determining a concentration of contaminants instead of determining the mere presence of a contamination.

The present invention has for its object to provide a capacitance electrode usable in a sensor-system that is capable of capacitively sensing contaminants in a fluid that is more efficient than existing devices and methods.

This objective is achieved with the electrode according to the invention, the electrode comprising:

- a transducing element;
- an affinity layer that in use is in contact with a fluid to be measured, wherein the affinity layer comprises a multi-array surface; and
- an insulating layer separating the transducing element and the affinity layer,

wherein the electrode is arranged such that in use contaminants in the fluid may interact with the affinity layer.

The basis for the electrode is defined by a transducing element or transducing layer. At least one surface of this transducing element is provided with a skinny affinity layer. The detection principle is based on the interaction of the contaminants with this affinity layer. Contaminations include dissolved components, suspended particles and micro-

organisms. This may include organic and inorganic compounds, such as pharmaceuticals. The transducing element and the affinity layer are separated by an insulating layer. The transducing element can be made of a silicon substrate. On
5 at least one side of this silicon substrate the insulating and affinity layers are provided. Preferably on the back side of this silicon substrate electrical contacts are provided. The set-up of the sensor-system in which the capacitance electrode is used is that of an electrical
10 capacitor in which the two parallel capacitor plates are the silicon substrate and the skinny affinity layer.

A thin insulating layer (of thickness d) contributes to a high capacity C , since $C = (A \times \epsilon_0) / d$, where ϵ_0 is the permittivity of the organic monolayer, and A is the surface
15 area of the plate. Interaction between the skinny affinity layer and contaminants in the sample solution results in a change of charge ΔQ at the affinity layer, which is mirrored in the silicon substrate as a change in charge of $-\Delta Q$. That change of charge or change of charge density, $\Delta\sigma = \Delta Q / A$,
20 changes the electrical field by $\Delta E = \Delta\sigma / \epsilon_0$, which gives rise to a change of electrical potential $\Delta V = (\Delta Q \times d) / (A \times \epsilon_0) = \Delta Q / C$. This chemical sensor is a label-free sensor with electrical read out.

The electric properties of the affinity layer can be
25 very sensitive to contaminations that are present in the fluid. The contaminations interact with the affinity layer, thereby changing the electric properties as mentioned above. The measure of the change in the electric properties is a measure for the type of contaminant in the fluid.
30 Furthermore, the measurement can give a measure for the concentration of this contamination.

The affinity layer can be realised using physisorption and chemisorption. Examples are molecular imprinted polymers, emulsion polymerisation, solvent casting.

Preferably, the multi-array surface of the affinity
5 layer is a 2x2, 4x4, 8x8 or 16x16 multi-array. One possible way of producing the arrays is by photolithography. Preferably the different spots in the array have a diameter between 50 μm to 1 mm. The spots can be made of different materials with each material having its own characteristic
10 behaviour. The electrode according to the present invention is a multi-array, label-free chemical electrode for the detection of contaminants in a fluid. The different materials have different polarities and affinities. These different properties influence the extent of interactions of
15 a specific spot with the contaminants that are present in the fluid. From interactions with one spot or interactions with a combination of different non-selective spots a measure for the presence of a contaminant in the fluid is achieved. This is an indication of the mere presence of a
20 contaminant. In addition, the measure also gives an indication on the concentration of the contaminant. The combination of different non-selective interactions forms a type of fingerprint response of the multi-array sensor.

The multi-array surface preferably comprises different
25 polymers and polymer mixtures. The different materials are provided on the spots of the multi-array surface layer. It is possible to use for example accurel (a micro-porous polypropylene membrane) wherein the pores are filled with specific fluids with characteristic electrical properties.
30 Examples of different polymers and/or polymeric mixtures are the use of cyclo-dextrine modified polymers and plasticizers. The change of the membrane capacity due to the

partition equilibrium between the fluid and the membrane can be measured.

In a preferred embodiment according to the present invention the insulating layer comprises an organic mono-
5 layer.

Known electrodes use a SiO₂ insulating layer. The use of an organic monolayer has the advantage that a Si-C bound mono-layer is more stable. Furthermore, cations that diffuse into the SiO₂ layer, may cause noise in the measurement. By
10 using organic mono-layers this noise is prevented. In addition, organic mono-layers show better insulating properties compared to SiO₂ layers of an equal thickness.

In a preferred embodiment according to the present invention the insulating layer comprises an alkene and/or
15 alkyne that is provided with a functionalised component.

An alkene and/or alkyne of the insulating layer can connect to the transducing layer with Si-H. The alkene and/or alkyne can be functionalised to provide the desired properties for the specific circumstances of the
20 application. Functionalising the mono-layer can be realised directly using a functional group that does not react with Si-H. Also, an indirect approach is possible using a functional group that does not react with Si-H. In a further step the desired molecule is connected. Optionally, this
25 indirect approach can be performed using a functional protected group that is combined with the desired molecule after obviating the protection. Examples of functional groups are COOH and NH₂. Other examples are OH and CN. As OH-COOH- and NH₂-groups may react with Si-H these groups are, in
30 an indirect approach, protected using esters and amides, for example.

In a preferred embodiment according to the present invention the affinity layer substantially comprises

particles smaller than 1 mm, such that the layer substantially acts as a conductor when exposed to a high-frequency alternating current and acts as an insulator when exposed to a direct current.

5 By providing the relatively small particles with a diameter below 1 mm it is possible to manipulate the adsorption characteristic. This adsorption characteristic may be manipulated when applying for example an alternating current between electrodes or between a working electrode
10 and a counter electrode. The manipulation of the adsorption characteristic may improve the sensitivity of a sensor using the electrode according to the present invention.

The invention further relates to a sensor-system for measuring contaminants in a fluid, comprising:

- 15 - a working electrode comprising a capacitance electrode as described above;
- a counter electrode arranged such that in use fluid to be measured separates the working and counter electrode; and
- 20 - a potentiostat capacitively sensing the change in electric properties caused by adsorption of contaminants to the affinity layer.

With the sensor-system comprising a working electrode as mentioned above, the same effects and advantages as those
25 stated to the electrode are provided by the sensor-system. The system uses the specific adsorption of contaminants on the functionalised electrode surface that is part of a condensator in the fluid to be measured. This functionalised electrode is the working electrode of the sensor-system. It
30 is possible to provide more than one working electrode in the sensor-system according to the present invention. A counter electrode is also provided in the fluid. A reference electrode can be used optionally. The counter electrode

comprises a conductive material, like a metal, carbon, active carbon, with a polymer layer on this conductive layer. Preferably, the electrode surface is relatively large, for example above 0.1 mm^2 . Properties of the surface can be characterised using for example impedance spectroscopy. In the array of spots in the affinity layer, every spot has its own specific sensitivity to specific contaminants in the fluid. As mentioned above, both individual measurements and a combination of measurements provide information on the type of contaminants and the concentration thereof in the fluid. This type of measurement can be considered as a fingerprint response measurement of the multi-array sensor-system. Such fingerprint sensor can for example be used to track changes of the water quality to detect an event, like an illegal purge, an accident, heavy rainfall etc. Based upon the measurements quick measures can be taken, such as stopping the intake of water or changing to a different water source. If required additional measurements can be performed to determine more accurately concentration values by measuring offline, using the fingerprint response as a guide. Especially water fingerprinting sensor-systems that provide real-time information and that are sensitive to a specific group of organic/ inorganic compounds, such as pharmaceuticals, will contribute to safeguarding the quality of clean water.

In a preferred embodiment according to the present invention, the affinity layer of the working electrode is arranged in a cylindrical tube.

The multi-array surface of the affinity layer can be considered as a two-dimensional surface area. By providing the surface area in for example a cylindrical tube, through which a fluid is being transported, a three-dimensional surface area is constructed. By studying the measurements

and especially the change in measurements in time additional information is measured. Within the tube a type of chromatography process takes place and the adsorption characteristic of each contaminant in each of the spots in the multi-array surface gives information on the variation in residence time of this contaminant. This involves not only static measurements, but also involves more dynamic measurements. Off course, depending on the dimensions of the two-dimensional surface area, this also applies for this two-dimensional array.

Preferably, flow means are provided to expose the sensor in use to a continuous flow of fluid. This measurement can be performed online. Depending on the dimensions an at-line solution is also possible according to the invention. In this at-line solution, part of the fluid in controlled quantities is transported along the surface area of the sensor. In case of a tube-like configuration, performing the dynamic measurements leads to a sort of four-dimensional measurement.

In a further preferred embodiment according to the present invention, the sensor-system comprises electrical means for providing a potential difference between the working- and counter electrode.

Applying a potential difference between the working electrode and the counter electrode of the sensor-system, manipulates the adsorption characteristics. This changes the sensitivity of the sensor-system, such that the sensor-system can be adapted towards the specific needs like measuring a specific class of contaminants in drinking water for example.

Preferably, the sensor-system further comprises additional electrical means for providing an alternating electrical field between the working and counter electrodes.

Providing an alternating electric field between the electrodes of the sensor-system manipulates the adsorption of contaminants in the fluid. Especially the adsorption characteristics of hydrophilic components and ions can be manipulated. This can be used to improve the sensitivity of the sensor-system in a specific range.

In a further preferred embodiment according to the present invention the counter electrode comprises an affinity layer.

By also providing the counter electrode with a functionalised layer, more specific measurements can be performed. The properties of the affinity layers on both the working- and counter electrodes can be equal or different depending on the specific application for the sensor-system.

The invention further relates to a sensor-system for detecting contaminations in a fluid and/or for treating a fluid, the system comprising:

- a working element comprising an affinity layer that in use is in contact with a fluid to be measured, and wherein the working element is arranged such that in use contaminants in the fluid may interact with the affinity layer; and
- photovoltaic means.

Such sensor-system provides the same effects and advantages as those stated with reference to the electrode and the sensor-system described above. Using the affinity layer as described above in several embodiment for the capacitance electrode and sensor-system a type of photovoltaic sensor-system is achieved. Such photovoltaic sensor-system enables detecting contaminants in a fluid and/or treating a fluid, making use of photovoltaic means, a functionalized surface shaped as an affinity layer, which preferably forms part of the photovoltaic means, or is

arranged thereon, and to which adsorption of the components present in the fluid can take place, at least a source which provides the photovoltaic means with electromagnetic waves, including light, and means for directly or indirectly measuring and/or directly or indirectly utilizing the current produced by the photovoltaic means for electrolysis in and/or disinfection of the fluid. The technology according to the present invention is suitable as sensor for detecting contaminants in water, for the purpose of disinfecting water and for directly or indirectly measuring and influencing the metabolism of micro-organisms in general, and algae and chemoluminescent and/or bioluminescent bacteria in particular.

In the field of water process technology guaranteeing the reliability of delivery and the water quality of drinking water are of particular importance. Owing to the range of toxic components and organisms which may be present in surface water and spring water, rapid analysis of the water quality represents a challenge. A cost-effective method of monitoring the quality of water is to apply "fingerprinting sensors". Such a sensor detects changes in the water quality with relatively simple means and online. If a change is detected, there is then an offline investigation into what type of contaminant(s) is involved and a decision is made as to whether or not to intervene in the process. It is noted that a fingerprinting sensor is preferably based on physical measurement principles, so that no chemicals need be dosed and maintenance of the sensor is limited. It is further noted that the fingerprinting sensor preferably has some selectivity and capacity to distinguish different groups of toxic components present in the water. This latter makes it possible, in the case that the fingerprinting sensor generates an alarm, to already gain an

indication of which group of contaminants it is necessary to look for offline. Finally, it is noted that an array of fingerprinting sensors, each with a specific sensitivity to a group of toxic components, is a particularly cost-effective aid for guaranteeing the quality of water.

The sensor-system according to the present invention enables an effective online fingerprinting sensor which preferably makes use of only physical principles and is preferably applied in array form, wherein each element of the sensor array has a specific sensitivity to one or more groups of toxic components in the water. As will be set forth hereinbelow in this application, the sensor is not only suitable for detecting toxic components in water, but can be widely utilized in the chemical process industry, the pharmaceutical industry, the food industry, in biotechnological processes and in medical applications.

According to a first aspect, the technology consists of photovoltaic means. This is preferably a classical photovoltaic cell (PV cell) consisting of a piece of semiconductor material having a separating surface therein between a p-type and an n-type doping.

According to a second aspect, the present invention consists of a preferably functionalized surface situated in a fluid so that contaminants present in the water adsorb specifically to this surface. The functionalized surface is preferably arranged on the part of the photovoltaic cell which is designed to receive and convert electromagnetic radiation to electrical energy. It is however also possible to place the surface which adsorbs the contaminants in the fluid and the PV cell outside the fluid, wherein the electromagnetic radiation which can be received by the PV cell is guided first through the functionalized surface.

According to a third aspect, the present invention consists of at least an electromagnetic transmitter which preferably emits light which is first guided through the functionalized surface before reaching the PV cell. It is
5 noted that sunlight can serve as electromagnetic transmitter, as well as LEDs including RGB LEDs, UV LEDs, infrared LEDs, electroluminescent foil (EL foil), gas discharge tubes including UV lamps, neon lamps and sodium lamps. It will be apparent to the skilled person that each
10 of these radiation sources has a specific frequency spectrum which, in combination with the present invention, results in a specific sensitivity to different types of contaminants in the fluid. RGB LEDs are particularly interesting in combination with the present invention because they are
15 small, waterproof and inexpensive and can be controlled as light source located in a single point and having an adjustable frequency spectrum. It is further noted that not only light, but also other electromagnetic waves, including radio waves, can be applied in combination with the present
20 invention. It is finally noted that the selectivity and sensitivity of a sensor according to the present invention can be increased by applying modulated electromagnetic waves.

According to a fourth aspect, the present invention
25 consists of means for measuring the electric power generated by the PV cell, for instance by connecting an electrical load to the PV cell and measuring a current through the cell and/or the voltage over the PV cell. It will be apparent to the skilled person that not only the absolute power measured
30 in the stationary situation by the PV cell comprises interesting information concerning components present in the liquid, so too does the dynamic progression of the measured electrical signal and the progression of the amplitude

versus frequency characteristic for different types of input signal of the electromagnetic transmitter. A non-limitative list of input signals which are particularly suitable for application in combination with the present invention is:
5 monochromatic light, modulated light including amplitude-modulated light, pulsed light, light with a wide frequency spectrum in the infrared region, the visible region, the UV region or combinations of one or more of the above stated types of light, radio waves including amplitude-modulated
10 and/or frequency-modulated and/or single sideband-modulated and/or phase-modulated waves.

The invention further relates to a micro-reactor comprising a sensor-system as described above.

The micro-reactor provides the same effects and
15 advantages as those stated with reference to the sensor-system for capacitive and/or photovoltaic sensing. More specific, the micro-reactor is capable to decompose components that adsorb to the functionalised surface area of the electrode or working element. In preferred embodiments
20 for the micro-reactor according to the present invention the surface area of the affinity layer is somewhat smaller than the electrode or working element. Furthermore, preferably a polymer is used that acts as an insulator for direct currents and as a conductor of alternating currents.

25 The invention further relates to a method for measuring contaminants in a fluid, the method comprising the steps of:

- providing a sensor-system as described above; and
- capacitive and/or photovoltaic sensing the change in electric properties of the affinity layer due to
30 adsorption of contaminants of the affinity layer.

Such method provides the same effects and advantages as those stated with reference to the electrode and sensor-system.

The invention further also relates to a method for producing a capacitance electrode, and/or working element, comprising an affinity layer as mentioned above, the method comprising the steps of:

- 5
- etching a silicon surface;
 - hydrosilylating the silicon surface to form a linked organic monolayer; and
 - depositing the affinity layer.

Such method provides the same effects and advantages as those stated with reference to the electrode and the sensor-
10 system. Preferably, the depositing of the affinity layer involves different polymers or polymeric mixtures to form a multi-array affinity layer.

Further advantages, features and details of the invention are elucidated on a basis of preferred embodiments
15 thereof, wherein reference is made to the accompanying drawings in which:

- figure 1 shows an overview of the sensor-system according to the invention;
- 20 - figure 2 illustrates the method to produce the electrode according to the invention;
- figure 3A+B illustrate spots of the multi-array surface;
- figure 4 illustrates the method to produce the surface of figure 3;
- 25 - figure 5 illustrates the method to include particles in the functionalised surface layer; and
- Figure 6 illustrates a sensor-system making use of photovoltaic means.

30 A sensing system 2 (figure 1) comprises working electrode 4. Working electrode 4 comprises a base layer 6 of a silicon substrate. Substrate 6 is covered with an organic monolayer 8 acting as a thin nano-sized insulator between

the substrate 6 and the skinny affinity layer 10. The affinity layer 10 is in contact with the fluid 12. One side of substrate 6 is provided with the mono-layer 8 and affinity layer 10. The other side of substrate 6 is provided with a back contact 14. Sensing system 2 further comprises a counter electrode 16 and a reference electrode 18. The counter electrode 16 is for example made of platinum and the reference electrode is for example made from AgCl/Cl. These electrodes 16, 18 are in the fluid 12. The electrodes 4, 16, 18 are connected through circuit 20 to a Potentiostat 22. Potentiostat 22 is connected by connection or circuit 24 to a computer 26. Computer 26 is used for control of the sensing system 2 and is also be used for monitoring the measurements performed by system 2.

The production 28 (figure 2) of a working electrode 4 starts with the silicon substrate 6. On top of substrate 6 there is provided a thin layer of a silicon oxide 30. By etching 32 this silicon oxide layer 30 is removed and a hydrogen-terminated silicon surface is performed. By hydrosilylating 34, 36 a Si-C linked organic monolayer 8 is formed. On top of monolayer 8 the affinity layer 10 is deposited 38.

Mono-layer 8 is connected to substrate 6 with a double bond (alkenes) or triple bond (alkynes). Mono-layer 8 can be functionalised with functional groups R (figure 2) or R' (not shown) respectively.

Multi-layer surface 40 (figure 3A and B) comprises base material 42 wherein spots 44, 46, 48, 50 are provided. Spots 44, 46, 48, 50 are made of different material, with different electric properties. The spots 44, 46, 48, 50 are provided by process 52 wherein the SiO₂ layer 54 is removed from the base material 42 by etching operation 56. This results in a hydrogen-terminate silicon 58. Surface 58 is

provided with an organic monolayer SiC-linked in step 60. In depositing step 64 affinity layer 66 is added. Molecular imprinted polymers can be used as an affinity layer. These layers are produced by process 68. Base material is provided with polymer material 72 and particles 74. After the depositing step 76 an affinity layer results. Particles 74 exchange with particles 80 in steps 78, 80.

In one of the embodiments the affinity layer is made of a micro-porous polypropylene membrane (accurel). The pores are filled with specific extraction fluids that interact with contaminants in the fluid. Changes in capacitance changes can be measured and indicate the presence of specific components and/or concentrations thereof in the fluid. Alternatively, polymer coatings filled with a solvent can be used as affinity layer. The adsorption properties of the coating can be manipulated by varying the composition of the solvent. A change in properties of such a filled polymer in time can be (automatically) corrected. Furthermore, the stability of polymer coatings during the filling can be manipulated by applying specific cross linking agents and chain transfer agents during the production of the polymer coating.

The electrode according to the invention can be used as a micro-reactor that can be a microbial fuel cell (MFC). By using the electrode as an anode or as a cathode, the fuel cell can be used as a bio toxicity sensor. The coating on the electrodes is selected depending on the specific toxic components for which the fuel cell should be sensitive. Another application of the electrodes according to the present invention is the use as a pro-active scaling sensor. In a supersaturated solution, nucleation is initiated by exposing the solution to ultrasonic vibrations. Using the electrodes according to the present invention enables

measurement of extremely low concentration of agents and scale inhibitors. Using the sensor enables a dosing strategy for the scale inhibitor, thereby improving the efficiency of the process. The same applies in case an electric activator is used in stead of an ultrasonic activator.

The electrodes according to the present invention can also act as a so-called coax sensor wherein water acts as di-electricum between two concentric insulated conductors. These conductors are part of an antenna system and act as electric suction filter. The frequency of this filter changes as a response to a change in electric properties of the water due to contaminants therein. A frequency change can be measured using radio frequent alternating voltage technology. The use of electrodes according to the present invention results in a sensor that is more selective and sensitive. This improved sensitivity is realised by the adsorption characteristics of components in the water in relation to the coating. Furthermore, this selectivity can be manipulated by providing a potential difference between the two concentric insulated conductors.

Next, without hereby imposing any limitation on the scope of the present invention, a number of embodiments of the present invention will now be elucidated of a sensor-system for detecting contaminants making use of photovoltaic means and an "electrode" comprising a functionalized surface. A sensor-system 84 measures contaminations in tube 86 whereon and/or wherein a surface area 88 is provided that is functionalized. Source 90 transmits light 94 through tube 86 towards surface 88 that is (partly) received by receiver 92. This enables measurement of contaminations in a fluid present in tube 86 in a manner described before. Further embodiments, options and/or alternatives will be discussed next.

In a first embodiment a functionalized surface is placed in the light path between a light source and a PV cell. The functionalized surface is transparent to the light produced by the light source. A non-limitative example of such a
5 surface is glass or quartz to which a preferably thin coating is applied. Thin is understood in this case to mean a coating which preferably has a thickness in the range of 0.1 nanometre to 100 micrometres. The properties of the coating are such that it preferably adsorbs components
10 present in the liquid. If components present in the liquid adsorb to the surface, the transmission properties of the surface will change, with the result that the PV cell detects a change in light intensity, this being measurable in the form of a change in the current supplied by the PV
15 cell. The light source and/or the PV cell can be situated outside the liquid as well as in the liquid. The functionalized surface to which adsorption takes place is situated in the liquid.

In a second embodiment a PV cell is applied which is
20 situated in the water. Applied to the PV cell is a coating which prevents corrosion of the PV cell. This coating also serves as surface to which contaminants adsorb.

In a third embodiment a solar cell is applied which is situated in the water and is specially designed for the
25 electrolysis of water. The solar cell is equipped with a very thin coating which prevents corrosion of the solar cell but which guides electrons through the small thickness of the coating. Through the choice of the band gap of the solar cell the potential on the coating can be adjusted. It is
30 hereby possible to apply the solar cell for capacitive deionization. Depending on the potential (the band gap applied) and the composition of the water, different types of contaminant in the water will adsorb to the coating. It

will be apparent to the skilled person that this creates unprecedented possibilities for making the sensor sensitive and specific for detection of a variety of compounds, all the more so because not only the nature of the coating but
5 also the potential can now be used as control parameter to bring about adsorption of components present in the water. It is finally noted that, at a band gap which is sufficiently large, not only does capacitive deionization occur but also electrolysis. This has the result that
10 organic molecules present in the water will decompose as a result of, among others, OH, O and Cl radicals. The decomposition products will or will not adsorb well to the functionalized surface and will or will not absorb light well. It will be apparent to the skilled person that use can
15 be made of these phenomena to control the selectivity of a sensor according to the present invention.

In a fourth embodiment a sensor according to any of the foregoing embodiments is combined with or partially replaced by a sensor which detects light on the basis of a
20 photodiode, phototransistor, light-dependent resistor (LDR), photomultiplier on the basis of vacuum technology, photomultiplier on the basis of solid-state technology, antenna and/or amplifier for radio waves and/or alternating voltages in the range of 0.01 Hz to 1000 GHz, or by a so-
25 called ChemFET (Field Effect Transistor with a Chemically modified gate electrode surface). It is noted that a ChemFET has the drawback relative to the present invention that an electrical circuit, including an external power supply with electrical energy, must be constructed around the FET. In
30 the case a solar cell is applied according to the principle of the present invention, the measuring system can be realized more simply, more cheaply and without electric power supply. It can be advantageous to apply systems

wherein solar cells and FETs and/or ChemFETs are combined. Such systems expressly form part of the present invention.

In a fifth embodiment a sensor according to any of the foregoing embodiments is used to detect the light produced
5 by bioluminescent or chemoluminescent organisms. It is known to the skilled person that the amount of light produced by these organisms can be used as a measure for the presence of toxic components in water. The functionalized surface of the PV cell or of the glass or quartz is preferably chosen such
10 that light-emitting micro-organisms form a biofilm on this surface. A particular application of light-emitting micro-organisms is the arranging of a biofilm with these organisms on a solar cell surface, wherein the activity of the micro-organisms determines the potential of this surface. As a
15 result the micro-organisms will begin to behave differently, this increasing the sensitivity of the sensor. It is noted that a solar cell with a biofilm of light-emitting micro-organisms on the surface forms a new type of microbial fuel cell. Since recent developments in solar cell technology
20 make it possible to produce solar cells with an adjustable small band gap, there are numerous possibilities for optimizing such a fuel cell.

In a sixth embodiment anodophilic and/or cathodophilic bacteria as applied in a microbial fuel cell are arranged on
25 a solar cell which has a configuration as described in any of the above embodiments. We then obtain a new type of microbial fuel cell. When light is now incident on the solar cell, the potential of the surface will change. It will be apparent to the skilled person that the amount of energy
30 which the solar cell produces can in this way be combined with the electrical energy produced by the micro-organisms. In short, this means that water can be decomposed in very efficient manner since a solar cell-assisted microbial

electrolysis cell has been created. Such a system can be applied as sensor, but also to produce hydrogen from wastewater and sunlight. It will be apparent to the skilled person that the system can also be applied to disinfect
5 water.

In a seventh embodiment a sensor according to any of the above embodiments 1 to 6 is used to study and/or inhibit and/or enhance the metabolism of algae. Use can be made for this purpose of the fact that algae dispersed in the water
10 absorb light or that algae can adhere to a surface, whereby this surface absorbs light of a determined frequency spectrum.

In an eighth embodiment the surface of a quartz bottle or a PET bottle or other container is equipped on the inner
15 side with a solar cell, or solar cells are arranged according to any of the above embodiments 1 to 7 in such a container. This provides the option of disinfecting and/or analyzing water in the sun and/or producing hydrogen at low cost and without corroding electrodes.

In a ninth embodiment a sensor according to any of the above embodiments 1 to 7 is applied in the pharmaceutical industry and/or the chemical industry and/or the biochemical industry and/or food industry to characterize intermediate products, end products and to determine quickly by means of
25 fingerprinting whether a product meets the set requirements therefor.

In a tenth embodiment a number of sensors according to any of the above embodiments 1 to 9 is combined so as to thus obtain an array of sensors which together provide more
30 information than the sum of the information provided by each of these sensors separately.

In an eleventh embodiment at least one of the sensors described in embodiments 1 to 10 is combined with an optical

sensor, wherein a measurement is made by means of Mach Zehnder interferometry of whether components have been adsorbed to a surface. It is known to the skilled person that a sensor operating according to the Mach Zehnder
5 interferometry principle is based on a phase difference measurement of light transmitted through a surface to which components have been adsorbed and light which is transmitted through the same surface to which no components have been adsorbed. In the technique according to the present
10 invention a difference measurement is desirable in a number of cases, wherein the energy production of a solar cell, wherein light is incident through a surface to which components have been adsorbed, is compared to the energy production of the same solar cell wherein light is incident
15 through a surface to which no components have been adsorbed. It is however noted that, when the solar cell is applied, use can first be made of light with a frequency which is not absorbed by adsorbed components. This measurement is referred to as the zero measurement. Light is then
20 transmitted through the same solar cell with a frequency at which absorption does occur by components adsorbed to the surface. By determining the quotient of the amplitude of the two signals a relative measure is obtained for the light absorption of the adsorbed components. This procedure can be
25 repeated in automated manner for a wide frequency spectrum, whereby it is possible to map very precisely which substance or combination of substances has been adsorbed to the surface, without a difference measurement with multiple cells being necessary for this purpose. It will be apparent
30 to the skilled person that the band gap of the solar cell determines to a significant extent the width of the frequency spectrum to which the solar cell is sensitive. For this reason a multi-array sensor wherein solar cells are

applied with differing band gaps, in addition to the application with a solar cell, is a powerful aid for fingerprinting of water.

In a twelfth embodiment at least one of the sensors
5 described in embodiments 1 to 11 is combined with a capacitive sensor which measures whether components have been adsorbed to a surface.

In a thirteenth embodiment at least one of the sensors
described in embodiments 1 to 12 is combined with a sensor
10 based on a microbial fuel cell.

In another embodiment an indirect measurement is performed. A water sample is purged with a gas such that the organic contaminations are transferred to the gas phase. The gas phase contacts the sensing layer and contaminations are
15 transferred to the sensing or membrane layer. Experiments have shown that octane can be measured in the gas phase with a resolution of 2 ppm, for example.

The present invention is by no means limited to the above described preferred embodiments thereof. The rights
20 sought are defined by following claims within the scope of which many modifications can be envisaged. For example, it is possible to combine the electrode according to the present invention in a sensing-system that also uses optical, mechanical and/or piezo electrical measurement.
25 Furthermore, in case of an application involving adsorbed micro-organisms, these micro-organisms can be characterised using for example interspectroscopy.

CLAIMS

- 5 1. Capacitance electrode for use in a sensor-system
capable of capacitively sensing contaminants in a
fluid, the electrode comprising:
- a transducing element;
 - an affinity layer that in use is in contact with a
10 fluid to be measured, wherein the affinity layer
comprises a multi-array surface; and
 - an insulating layer separating the transducing
element and the affinity layer,
- 15 wherein the electrode is arranged such that in use
contaminants in the fluid may interact with the
affinity layer.
- 20 2. Capacitance electrode according to claim 1, wherein the
multi-array surface comprises different polymers and/or
polymeric mixtures.
- 25 3. Capacitance electrode according to claim 1 or 2,
wherein the insulating layer comprises an organic mono-
layer.
4. Capacitance electrode according to claim 1, 2 or 3,
wherein the insulating layer comprises an alkene and/or
alkyne that is provided with a functionalised
component.

5. Capacitance electrode according to any of claims 1-4,
wherein the affinity layer substantially comprises
particles smaller than 1 μm , such that the layer
substantially acts as a conductor when exposed to a
high-frequent alternating current and acts as an
insulator when exposed to a direct current.
6. Sensor-system for measuring contaminants in a fluid,
comprising:
- a working electrode comprising a capacitance
electrode according to any of claims 1-5;
 - a counter electrode arranged such that in use fluid
to be measured separates the working and counter
electrode; and
 - a potentiostat capacitively sensing the change in
electric properties caused by adsorption of
contaminants to the affinity layer.
7. Sensor-system according to claim 6, wherein at least
the affinity layer of the working electrode is arranged
in a cylindrical tube.
8. Sensor-system according to claim 6, or 7, further
comprising flow means capable to expose the sensor to a
substantially continuous flow of fluid.
9. Sensor-system according to claim 6, 7 or 8, further
comprising electrical means for providing a potential
difference between the working and counter electrode.

10. Sensor-system according to any of claims 6-9, further comprising additional electrical means for providing an alternating electrical field between the working and counter electrode.
- 5
11. Sensor-system according to any of claims 6-10, wherein the counter electrode comprises an affinity layer.
12. Sensor-system for detecting contaminations in a fluid and/or for treating a fluid, comprising:
- 10
- a working element comprising an affinity layer that in use is in contact with a fluid to be measured, and wherein the working element is arranged such that in use contaminants in the fluid may interact with the affinity layer; and
- 15
- photovoltaic means.
13. Micro-reactor comprising a sensor-system according to any of claims 6-12.
- 20
14. Method for measuring contaminants in a fluid, comprising the steps of:
- providing a sensor-system according to any of claims 6-12; and
- 25
- capacitively or photovoltaic sensing the change in properties of the affinity layer due to adsorption of contaminants to the affinity layer.
15. Method for producing a capacitance electrode and/or a working element according to any of claims 1-5 and/or a sensor-system according to any of claims 6-12, comprising the steps of:
- 30
- etching a silicon surface;
 - hydrosilylating the silicon surface to form a linked organic monolayer; and
- 35

- depositing the affinity layer.

16. Method according to claim 15, wherein depositing the
affinity layer involves different polymers and/or
5 polymeric mixtures for forming a multi-array affinity
layer.

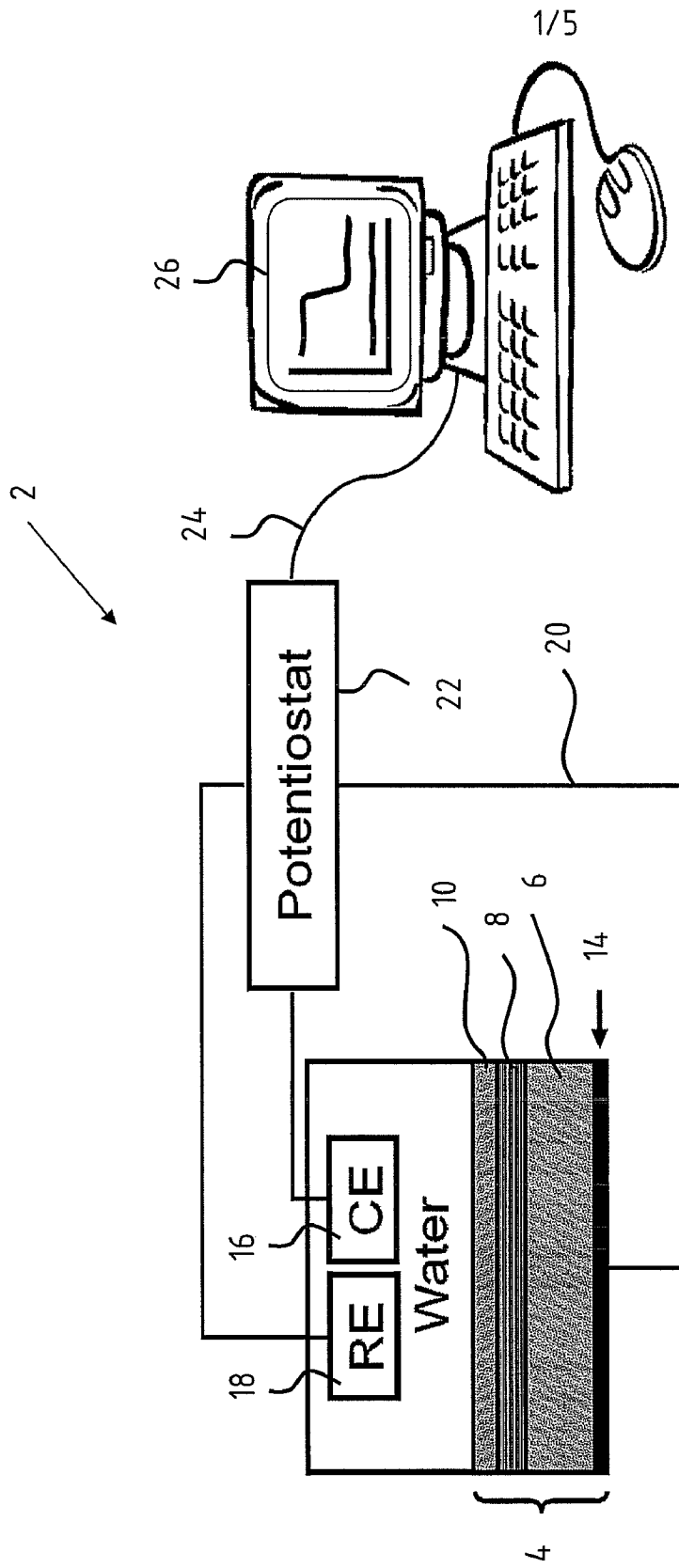


FIG. 1

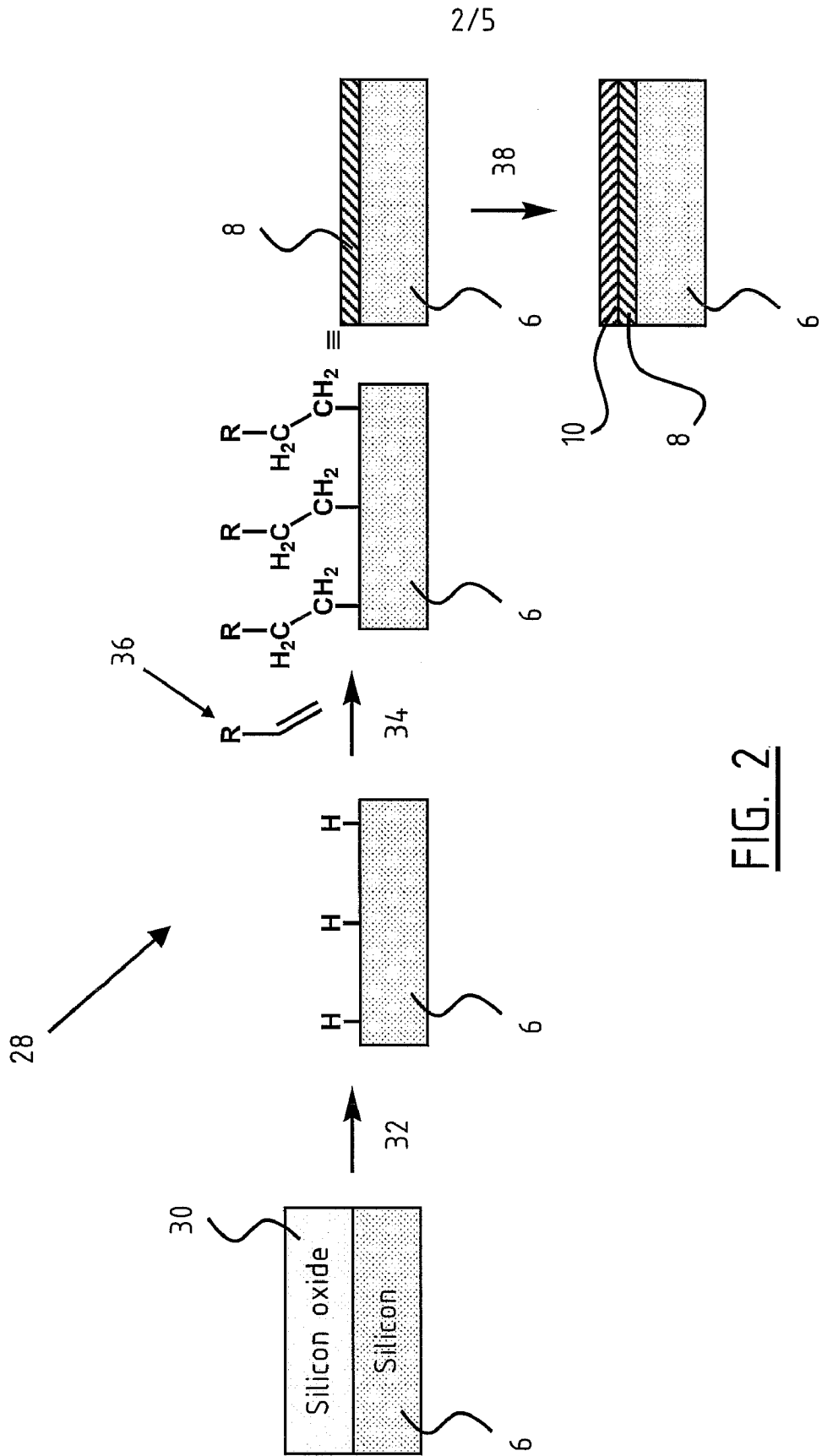


FIG. 2

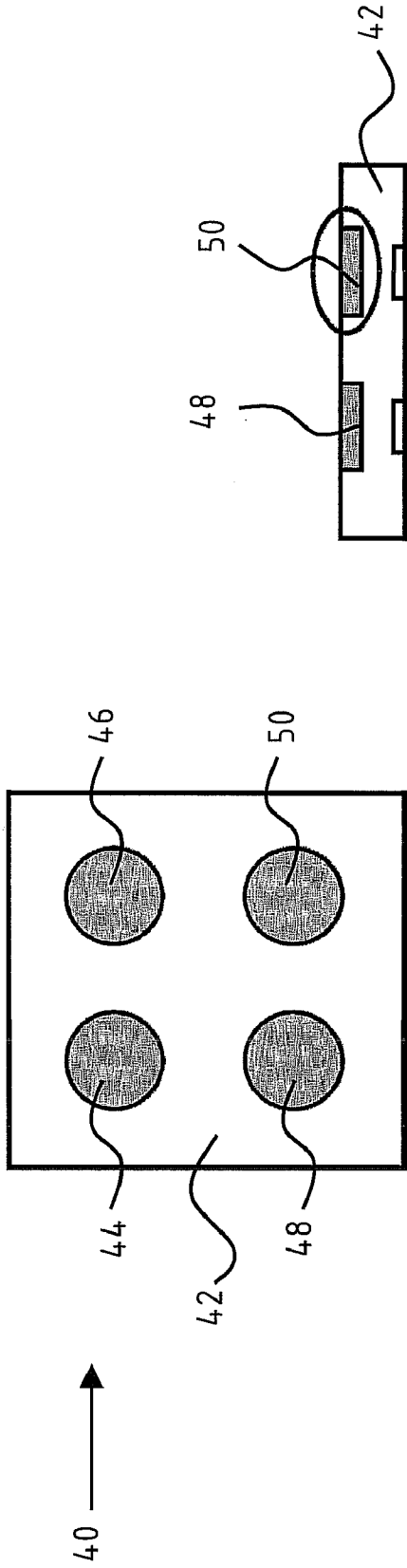


FIG. 3A

FIG. 3B

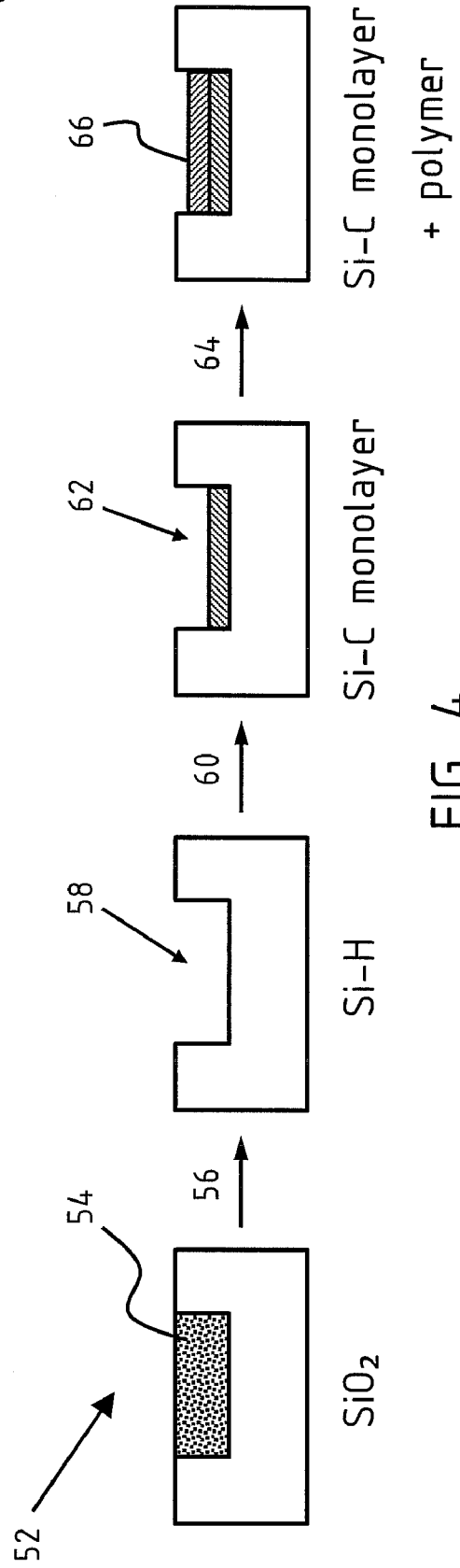


FIG. 4

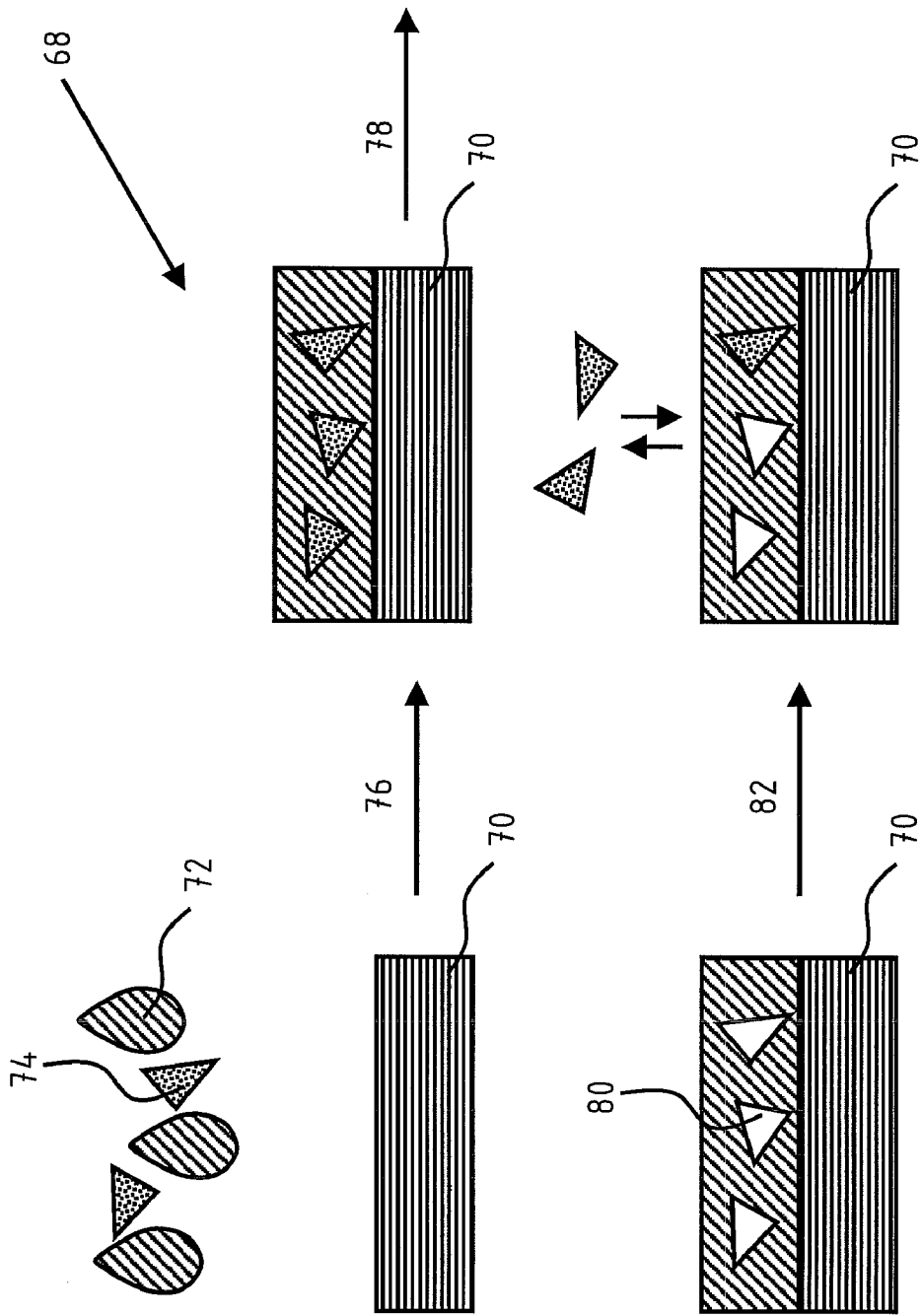


FIG. 5

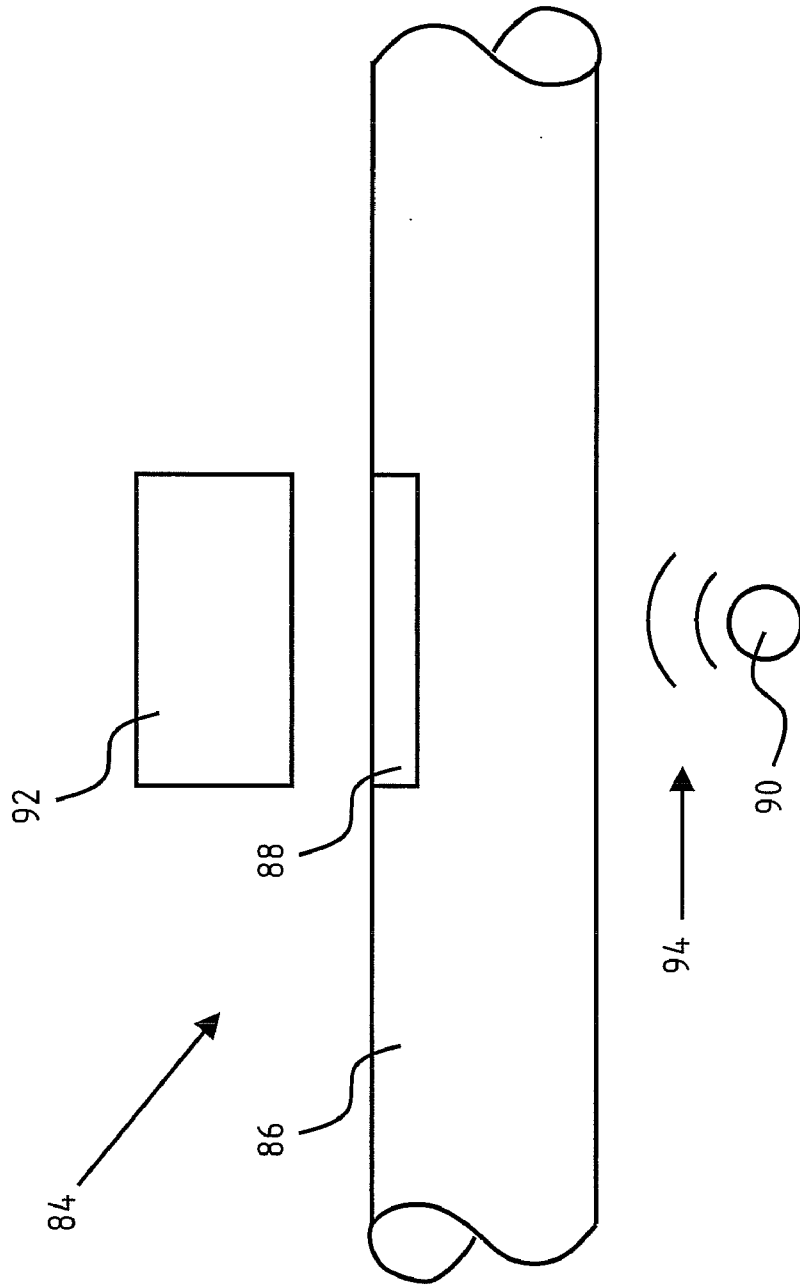


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No PCT/NL2009/050648
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A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N27/30 G01N33/18

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2006/222565 A1 (HARTIG PROSPER [DE] ET AL) 5 October 2006 (2006-10-05)	12
Y	paragraph [0082] - paragraph [0083]; figures 7,8 paragraph [0072]	1,3,5-9, 13,15
Y	EP 1 491 884 A1 (ASML NETHERLANDS BV [NL]; WAGENINGEN UNIVERSITEIT [NL]) 29 December 2004 (2004-12-29) paragraph [0022]	1,3,5-9, 13
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Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents :

<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p>
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Date of the actual completion of the international search 19 February 2010	Date of mailing of the international search report 03/03/2010
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Purdie, Douglas
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INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2009/050648

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	<p>RALUCA VOICU, RABAH BOUKHERROUB, VASILIKI BARTZOKA, TIM WARD, JAMES T C WOJTYK, DANIEL D M WAYNER: "Formation, characterization, and chemistry of undecanoic acid-terminated silicon surfaces: patterning and immobilization of DNA" LANGMUIR, vol. 20, 18 November 2004 (2004-11-18), pages 11713-11720, XP002568680 DOI: 10.1021/1a047886v results and Discussion; page 11715, column 2</p>	15
A	<p>TILL BÖCKING, KRISTOPHER A KILIAN, TRACEY HANLEY, SUHRAWARDI ILYAS, KATHARINA GAUS, MICHAEL GAL AND J JUSTIN GOODING: "Formation of tetra(ethylene oxide) terminated Si-C linked monolayers and their derivatization with glycine: an example of a generic strategy for the immobilization of biomolecules on silicon" LANGMUIR, vol. 21, 28 September 2005 (2005-09-28), pages 10522-10529, XP002568681 DOI: 10.1021/1a051191s figure 1</p>	1-16
X	<p>WO 2005/008234 A1 (INFINEON TECHNOLOGIES AG [DE]; BREDERLOW RALF [DE]; PACHA CHRISTIAN [D]) 27 January 2005 (2005-01-27) page 21, line 30 - page 23, line 8; figures 1,12</p>	1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NL2009/050648

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-11, 13-16

Capacitance electrode comprising a transducing element, an affinity layer and an insulating layer, the insulating layer separating the transducing element and the affinity layer

2. claim: 12

Sensor-system comprising a working electrode comprising an affinity layer in contact with fluid to be measured

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/NL2009/050648

Patent document cited in search report	Publication date	Patent family member(s)	Publication date	
US 2006222565	A1	05-10-2006	WO 2005012362 A1	10-02-2005
			EP 1646658 A1	19-04-2006
EP 1491884	A1	29-12-2004	WO 2005001461 A2	06-01-2005
			TW 259279 B	01-08-2006
			US 2007178707 A1	02-08-2007
WO 2005008234	A1	27-01-2005	DE 10331299 A1	03-02-2005