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Method of and system for identification or estimation of a refractive index of a liquid

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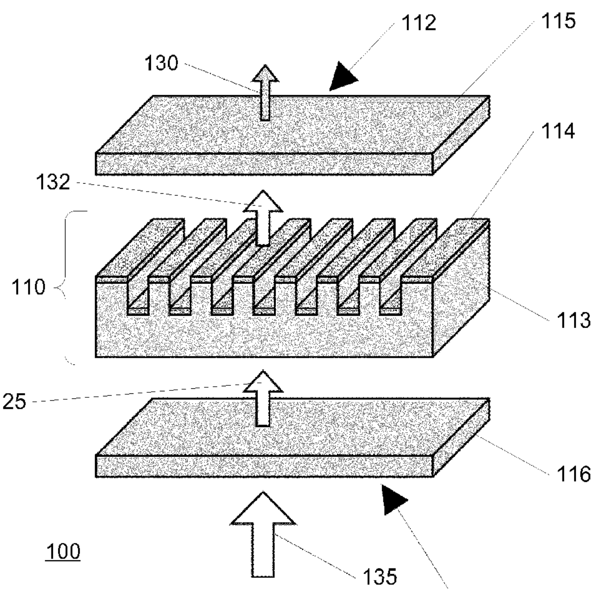

Figure 2A

(57) Abstract: This invention relates to a method of and a system (100) for identification or estimation of a refractive index of a liquid (120) comprising a light receiving part (111) adapted to receive polarised or non-polarised light (125; 135), a light emitting part (112) adapted, during use, to transmit light (130), an optical structure (110) being adapted to receive, during use, polarised light (125) via or from the light receiving part (111), and being adapted to receive, during use, a liquid (120) having a predetermined refractive index to be identified or estimated, and a first polariser (115) adapted, during use, to receive transmitted light (132) from the optical structure (110) and the received liquid (120), wherein the light receiving part (111), the received liquid (120), the first polariser (115), and the light emitting part (112) defines an optical path and wherein the system (100) is adapted, during use, to pass the received light (135) through the optical path so that a narrow wavelength range of the transmitted light (130) is influenced by the predetermined refractive index of the received liquid (120) and that the influenced narrow wavelength range, when observed by a user and/or captured by an image capturing unit (501), enables identification or estimation of the predetermined refractive index of the liquid (120). In this way, a method and a system for identification or estimation of a refractive index of a liquid is readily provided.

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METHOD OF AND SYSTEM FOR IDENTIFICATION OR ESTIMATION OF A REFRACTIVE INDEX OF A LIQUID

FIELD OF THE INVENTION

The present invention relates generally to a system (and corresponding method) for identification or estimation of a refractive index of a liquid, where the system comprises a light receiving part adapted to receive, during use, polarised or non-polarised light and a light emitting part adapted to transmit, during use, light.

BACKGROUND OF THE INVENTION

Simple and reliable refractive index identification or estimation is an important tool within many areas, e.g. within the food production industry, environmental sensing, bio-sensing, and medical diagnostics among other things.

As one example of the use of refractive index identification or estimation within food production, is e.g. the benefit for winemakers to be able to measure the sugar content in grape juice, also known as ‘Must weight’, by a refractometer in order to estimate the ripeness of grapes which the winemakers may use to select an optimal time for harvesting the grapes. Furthermore, the Must weight also indicates the amount of alcohol that can be produced if all the sugar is used for fermentation.

However, traditional refractometers normally have fairly limited capabilities beyond simply displaying a measured sugar content of a liquid and often only measure the refractive index at a single wavelength.

Patent specification US 5,610,392 discloses a method to observe film thickness and/or refractive index by colour difference. More specifically, this specification discloses observing film thickness and/or refractive index according to a colour difference where light beams from a white light source are irradiated onto the surface of a solid or liquid and the reflected light beams are coloured by partial extinction of the reflected light beams to observe the difference of film thickness and/or refractive index according to colour difference.

US patent application 2009/0079976 discloses photonic crystal (PC) sensors, sensor arrays and sensing systems incorporating PC sensors which are described as having integrated fluid containment and/or fluid handling structures. The PC sensors are further integrated into a sample handling device, such as a microwell plate. Sensors and sensing systems of the disclosure are capable of high throughput sensing of analytes in fluid samples, bulk refractive index detection, and label-free detection of a range of molecules, including biomolecules and therapeutic candidates. The disclosure also provides a commercially attractive fabrication platform for making photonic crystal sensors and systems wherein an integrated fluid containment structure and a photonic crystal structure are fabricated in a single molding or imprinting processing step amendable to high throughput processing. However, the PC sensor is mainly intended for use in a controlled lab environment with conventional optical equipment and rather complex or bulky handling of the flowing fluids, e.g. bio-samples. This renders the widespread use of this sensor costly and complex.

OBJECT AND SUMMARY OF THE INVENTION

It is an object to provide a simple system and corresponding method that readily enables identification or estimation of a refractive index of a liquid.

Additionally, an objective is to provide a system and corresponding method that enables identification or estimation of a refractive index of a liquid in a simple, quick, in-expensive, and/or reliable manner.

A further object is to identify or estimate the refractive index of a liquid as a function of wavelength, known as the dispersion profile of the liquid, in a simple and reliable way.

According to a first aspect, one or more of these objects are achieved at least to an extent by a system for identification or estimation of a refractive index of a liquid, the system comprising

- a light receiving part adapted, during use, to receive polarised or non-polarised light,
- a light emitting part adapted, during use, to transmit light,
- an optical structure

  - being adapted to receive, during use, polarised light via or from the light receiving part, and
  - being adapted to receive, during use, a liquid having a predetermined refractive index to be identified or estimated, and
- a first polariser adapted, during use, to receive transmitted light from the optical structure and the received liquid,

wherein the light receiving part, the received liquid, the first polariser, and the light emitting part defines an optical path and wherein the system is adapted, during use, to pass the received polarised light through the optical path so that a narrow wavelength range/band of the transmitted light is influenced by the predetermined refractive index of the received liquid and that the influenced narrow wavelength range/band, when observed by a user and/or captured by an image capturing unit, enables identification or estimation of the predetermined refractive index of the liquid.

In this way, a system for identification or estimation of a refractive index of a liquid is readily provided. Furthermore, identification or estimation of the predetermined refractive index of the liquid is enabled in a fast, reliable, and in-expensive manner.

It may be noted that the word ‘predetermined’ may be understood in the meaning that the refractive index is an inherent property that the liquid has but it is not yet, at least exactly, known to the user of the invention. The term ‘predetermined’ may optionally be omitted from the above definition of the invention.

Furthermore, it is to be understood that the present invention in an operational state is optically interacting with a liquid being tested, and similarly in a passive or non-operating mode, the liquid may not be present. This is reflected to some degree in the definition of the invention by the terminology ‘during use’ i.e. when a liquid is being tested.

Throughout this entire description and for embodiments, aspects, and/or combinations thereof, narrow wavelength range/band is to be understood as a wavelength range/band that is sufficiently narrow to obtain a preferred accuracy in relation to estimating a refractive index and/or dispersion profile (see later). In some embodiments and/or combinations, the narrow wavelength range/band may be selected from the interval being less than about 45 nanometers. In other embodiments and/or combinations, the narrow wavelength range/band may be selected from the interval being about 0.5, 1 or 2 to about 20 nanometers. In yet other embodiments and/or combinations, the narrow wavelength range/band may be selected from the interval being about 10 to about 20 nanometers. In further embodiments and/or combinations, the narrow wavelength range/band may be selected from the interval being about 2.5 to about 7.5 nanometers. In yet further embodiments and/or combinations, the narrow wavelength range/band may be selected from the interval being about 0.5 to about 2.5 nanometers.

The actual narrow wavelength range/band in a given implementation may depend on a requirement or wish for a given accuracy in identifying or estimating a refractive index and/or dispersion profile, i.e. on its intended application or use.

In general, the smaller the narrow wavelength range/band is, the more accurate the identification or estimation will be, as long as enough signal is detectable by an image capturing unit/sensor or observer.

The inventors have realized structures with a narrow wavelength range/band that was about 2.5 2.0, 1.5, 1.0, nanometers and less. The narrow wavelength ranges/bands of Figure 3 are e.g. between about 5 to about 10 nanometers. However, even more narrow bands of about 0.9 nm (FWHM) in an optical structure has been obtained, cf. Figure 15, the curve far right ‘all-polymer’ embodiment.

However, as another example, a narrow wavelength range/band being relatively large, e.g. about 40 nanometers, could measure a liquid’s refractive index with a relatively low accuracy of say ~0.1 refractive index unit (RIU). However, that may be fully adequate for certain applications and uses.

It is also to be understood that the presence of a narrow wavelength range/band of the transmitted light does not rule out the existence of further wavelength ranges/bands, as e.g. is explained further e.g. in connection with Figure 2 discussing the presence of both narrow transmitted wavelength ranges associated with transverse-electric (TE) and potentially a transverse magnetic (TM) guided modes and thereby potentially two wavelength ranges/bands.

In one embodiment, the optical structure comprises a first and a second material, where the refractive index of the second material is greater than the refractive index of the first material and where the second material is deposited on at least a part of the first material.

In one embodiment, the optical structure is adapted, during use, to pass received polarised light first through the first material, the second material and then the received liquid so that a component of the polarised light is reflected at the narrow wavelength range. In this way, at this so-called resonance wavelength, a component of the incident light is reflected and thereby removed from the transmitted light, thus altering the polarization at that wavelength. Only after having been passed through the first polarizer is the light outside of the resonance removed, leading to the sharp transmitted wavelength peak or range. Thus, the result is an effective change in polarization, and thus transmission through the first polarizer.

In one embodiment, the optical structure is an optical grating structure or a guided mode resonance filter (GMRF). These filters are sometimes referred to in the technical literature as photonic crystal slabs, or photonic crystal resonant reflectors.

In one embodiment, the system further comprises an electronic device comprising a light emitting unit and an image capturing unit, and wherein the system is adapted to be placed on the electronic device so that the light receiving part receives light from the light emitting unit and the light emitting part transmit light to the image capturing unit. It should be noted that the electronic device may - in some variants and embodiments of the present inventions- not be part of the invention as such, but the electronic device may be associated with the optical structure according to the invention in the sense that it may be suitable for interaction with the present invention.

In one embodiment, the electronic device is a smartphone or tablet or the like and the light emitting unit is a camera flash or a display screen and the image capturing unit is a camera of the smartphone or tablet or the like.

In one embodiment, the system is adapted to receive non-polarised light, during use, and wherein the system comprises a second polariser adapted, during use, to polarise the received non-polarised light before or when the light is received by the optical structure.

In one embodiment, the system further comprises a computational device comprising a display emitting, during use, polarised light, and wherein the system is adapted to be placed on the display, during use, thereby receiving polarised light, emitted by the display, at the light receiving part.

In one embodiment, the system further comprises a computational device comprising a display and at least one processing unit where the at least one processing unit is adapted, during use, to

- initially display on the display a plurality of different starting colours, each starting colour being associated with a given refractive index value enabling a user to select a colour best resembling for the user the colour of light emitted from the light emitting part of the system, and thereafter register a selection by a user of a colour among the displayed plurality of colours and display another plurality of different colours associated with refractive index values being closer to the refractive index value associated with the user selected colour, and/or
- display on the display a colour scale comprising a range of colours and a number of refractive index values, where each refractive index value is associated with a given colour in the range of colours.

In one embodiment, the system comprises a plurality of optical structures with varying geometrical properties, where the varying geometrical properties provide different narrow wavelength ranges of the transmitted light when receiving the liquid enabling, for each optical structure, identification of a refractive index value corresponding with the narrow wavelength range and thereby one dispersion profile data point for each of the plurality of optical structures.

In a second aspect, the present invention also relates to a method of identifying or estimating a refractive index of a liquid and embodiments thereof corresponding to the system and embodiments thereof.

More particularly, the invention relates to a method of identifying or estimating a refractive index of a liquid, the method comprising

- receiving, during use, polarised or non-polarised light in a light receiving part,
- transmitting, during use, light by a light emitting part,
- receiving, during use, polarised light via or from the light receiving part in an optical structure,
- receiving, during use, a liquid having a predetermined refractive index to be identified or estimated in the optical structure,
- receiving, during use, the transmitted light from the optical structure and the received liquid in a first polariser,

wherein

- the light receiving part, the received liquid, the first polariser, and the light emitting part defines an optical path and wherein, during use, the received polarised light is passed through the optical path so that a narrow wavelength range of the transmitted light is influenced by the predetermined refractive index of the received liquid and wherein the influenced narrow wavelength range, when observed by a user and/or captured by an image capturing unit, enables identification or estimation of the predetermined refractive index of the liquid.

The first and second aspect of the present invention may each be combined with any of the other aspects.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects will be apparent from and elucidated with reference to the illustrative embodiments as shown in the drawings, in which:

Figure 1 schematically illustrates one embodiment of an optical structure being part of embodiments of the system for identification or estimation of a refractive index of a liquid;

Figure 2A schematically illustrates an exploded view of the optical structure of Figure 1 together with further elements;

Figure 2B schematically illustrates an exploded view of another optical structure similar to Figure 2A;

Figure 3 schematically illustrates a graph illustrating a change in peak wavelength or colour being emitted from a system for identification or estimation of a refractive index of a liquid and embodiments thereof as described throughout the description where the change is caused by a change in the refractive index of the liquid;

Figure 4 schematically illustrates visual identification or estimation of refractive indexes;

Figure 5 schematically illustrates an alternative embodiment of a system for identification or estimation of a refractive index of a liquid;

Figures 6a and 6b schematically illustrate the embodiment of Figure 5 used in connection with an electronic device in the form of a smart phone;

Figure 7 schematically illustrates another alternative embodiment of a system for identification or estimation of a refractive index of a liquid, here as an example shown used in connection with a computational device in the form of a smart phone;

Figure 8 schematically illustrates a computational device in the form of a smart phone, an embodiment of a system for identification or estimation of a refractive index of a liquid, and an interactive graphical user interface (GUI) assisting a user in determining a refractive index value;

Figure 9 schematically illustrates an embodiment of a system for identification or estimation of a refractive index of a liquid that enables determining a refractive index dispersion profile of the liquid;

Figure 10 schematically illustrates an optical structure and light polarised at an angle compared to the grating structures of the topical structure;

Figure 11 schematically illustrates one embodiment of a computational device in further details for use with a system 100 for identification or estimation of a refractive index of a liquid and/or a system 102 for identification or estimation of a dispersion profile 103 of a liquid; and

Figure 12 schematically shows an optical structure with alternate high refractive index layer partly in polymer;

Figure 13 shows the resulting reflection intensity of the optical structure alternate high refractive index layer from Figure 12;

Figure 14 shows a graph with the modelled resonance shifts for three different liquids against air; and

Figure 15 is a combined graph of the normalized signal intensity for various embodiments of the optical structure according to the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 schematically illustrates one embodiment of an optical structure being part of embodiments of the system for identification or estimation of a refractive index of a liquid.

Shown is an optical structure 110 comprising a first 113 and a second 114 material, where the second material 114 is deposited on at least a part of the first material 113. The first 113 and the second material 114 together forms the optical structure 110. The optical structure 110 may e.g. be an optical grating structure e.g. in the form of a guided mode resonance filter (as is shown). In principle, the optical structure 110 may be any structure that reflects a relatively narrow wavelength range of light received by the optical structure.

In the shown embodiment, the first material 113 at one end comprises periodic height modulations, i.e. a so-called grating structure or shape. The second material 114 is deposited on top of the first material 113 at the end or part comprising the periodic height modulations. The shown embodiment may be referred to as a one dimensional grating. It is to be understood that other grating structures could be used, e.g. a two dimensional grating structure comprising periodic height modulations in two directions, which may result in narrower line widths of the transmitted wavelength peaks. This results in two wavelength peaks compared one peak of a one dimensional grating. A two dimensional grating structure may readily be designed in such a way, that one of the peaks occurs somewhere outside the visible spectrum and this is of no consequence for the relevant use.

The refractive index of the second material 114 is higher than the refractive index of the first material 113.

The first material 113 may e.g. be a low refractive index polymer or (nano-)porous dielectric/glass and the second material 114 may e.g. be a high refractive index dielectric, e.g. titanium dioxide. Other examples of suitable high refractive index dielectric are e.g. tantalum pentoxide, silicon nitride, diamond, etc.

One particular embodiment with a resonant sensor in polymer as the high refractive index material is given in Figures 12 and 13, the resonant sensor being the optical structure 110 according to the present invention. Both the first material 113 (low refractive index, LRI) and second material 114 (high refractive index, HRI) are manufactured in two different polymers as schematically shown in Figure 12. On top of the optical structure 110, the liquid for testing may be positioned in the so-called sensing region. This so-called all-polymer photonic crystal resonant reflector is presented there and shown to exhibit narrow TE-polarized reflection with a FWHM of less than 1 nm, a sensitivity of 43 nm/RIU and a detection limit of 3.9×10^{-6} RIU when sensing media with refractive indices around that of water, cf. Figure 13. The device is a two-layer structure, composed of a low refractive index polymer with a periodically modulated surface height, covered with a smooth upper-surface high refractive index inorganic-organic hybrid polymer modified with ZrO2-based nanoparticles (from micro resist technology GmbH). Furthermore, it is fabricated using inexpensive vacuum-less techniques involving only UV nanoreplication and polymer spin-casting, and is thus well suited for single-use refractive index sensing applications according to the present invention. The graph in Figure 13 shows the remarkable narrow line width.

Figure 15 shows the improvement of line width of resonance, especially for the so-called all-polymer structure shown in Figure 12 being accurate and cheap to manufacture. Sensitivity is normally lower for polymers (roughly half of TiO_2) but it may still be sufficient for many practical applications. For clarity, the curves are shifted in wavelengths in the graph to show them separately.

Alternatively, the periodic height modulations of the first material 113 could be facing the opposite way, still with the second material 114 being deposited on top of the first material 113, i.e. 113 and 114 in Figure 1 rotated 180°.

The optical structure 110 may be regarded as a tunable photonic crystal device and the inventors have successfully manufactured such a device, where the layer of the first material 113 as one example is about 100 micrometres thick (at its thickest part in the vertical direction of Figure 1). The thickness of the layer of the first material may vary e.g. according to specific structure or embodiment and may e.g. generally be in the range of about 1 micrometre to about 100 micrometres. Likewise, the thickness of the second material may also vary e.g. according to specific structure or embodiment and specific properties of used material(s). Generally, it will be as thin as possible while still being able to perform selective wavelength reflection, as explained elsewhere, e.g. usually a few tens of nanometres, depending on the material.

The use and function of the optical structure 110 is further explained in connection with Figures 2 and 10.

Figure 2A schematically illustrates a partly exploded view of the optical structure of Figure 1 together with further elements.

Shown is an optical structure 110 like the one shown and explained in connection with Figure 1 and further elements in the form of a polariser 115 – throughout the description denoted as a first polariser – being located at, towards, or adjacent to the end of the first material comprising the periodic height modulations and an additional polariser 116 – throughout the description denoted as a second polariser – being located at, towards, or adjacent to the end of the first material opposite the end comprising the periodic height modulations. Even though Figure 2A is a partly exploded view, it is to be understood that, during use or after manufacture, the first and the second polarisers 115, 116 would – in this particular embodiment – be located on top of and below the optical structure 110, respectively.

As mentioned in connection with Figure 1, the optical structure 110 could also be flipped horizontally/rotated 180° around an axis perpendicular to the plane of the figure.

The optical structure 110 and the first and second polarisers 115, 116 together forms a system 100 for identification or estimation of a refractive index of a liquid as will be explained later in further detail.

Further illustrated in Figure 2A are four arrows, where the lower arrow 135 represents non-polarised white light (entering the second polariser 116 as will be explained further in the following) and where the upper arrow 130 represents transmitted light (exiting the first polariser 115 as also will be explained further in the following). Furthermore, arrow 125 represent polarised light after exiting the second polariser 116 and before it enters the optical structure 110 while arrow 132 represent light after exiting the optical structure 110 and before it enters the first polariser 115.

Additionally, arrow 111 designates a part of the system 100 being a light receiving part and arrow 112 designates a part being a light emitting part of the system 100. It is noted, that for some embodiments of the system 100 (e.g. the one shown in Figure 7), the light receiving part 111 will not necessarily comprise a second polariser 116.

The optical structure 110 is adapted to receive, during use, a liquid (not shown; see e.g. 120 in Figures 5 and 7) having a predetermined (but initially practically unknown or unmeasured) refractive index that is to be identified or estimated. The liquid may be received ‘on top’ of the second material 114 and also in the grooves of the first material 113 as formed by the periodic height modulations.

The light receiving part 111, the second polariser 116, the optical structure 110, the received fluid 120, the first polariser 115, and the light emitting part 112 defines an optical path through which light received at the light receiving part 111 and exiting at the light emitting part 112 propagates during use. It is to be understood, that in this and some (but not all) of the other embodiments throughout the text, the second polariser 116 is the light receiving part 111 and the first polariser 115 is the light emitting part 112.

More specifically, in this particular embodiment, received light will, during use when the optical structure 110 has received a liquid (not shown; see e.g. 120 in Figures 5 and 7), propagate through the second polariser 116, the first material 113, the second material 114, the liquid and then the first polariser 115 before exiting the system 100.

The system 100, making use of a guided mode resonance filter as the optical structure 110 (as shown), will transmit only a ‘sharp’ wavelength peak or a suitable narrow wavelength range (perceivable by a user as a single colour) when illuminated at normal incidence with light, e.g. white light, in the case where two polarisers 115, 116 are used.

Guided mode resonance filters (GMRF) are periodic optical structures which can act as near perfectly reflecting mirrors for certain polarizations of incident light for a narrow wavelength range. The reflected wavelength range depends on the refractive indices of the materials comprising the GMRF, the geometry of the GMRF (e.g. period), as well as being highly dependent on the refractive index of materials placed upon the surface of the GMRF. A common implementation of a GMRF, as shown in Figures 2A and 2B, is a dielectric structure of periodic height modulations 113, which is covered by a layer of a material with a higher refractive index than that of the underlying structure 114.

When white light, polarized in parallel to the direction of the periodic height modulations (i.e. perpendicular to the direction of the grooves), impinges normally on the GMRF, wavelengths satisfying the so-called 2nd order Bragg condition are coupled into the GMRF as leaky TM (transverse magnetic) modes which travel only a short distance before being re-emitted in the backwards direction (i.e. coupled out to the zeroth order backward diffracted grating order), while wavelengths not satisfying the condition pass through the structure. This is a phenomenon known as resonant reflection and at the resonance wavelength, the GMRF can in theory have a reflection efficiency of about 100%.

Similarly, when the white incident light 125 is polarized perpendicular to the periodic height modulations (i.e. in parallel with the grooves), TE (transverse electric) leaky modes are excited and resonantly reflected. However, the TE and TM reflected bands inherently occur at different wavelengths.

When the incident white light 125 is polarized at an angle different from 0° or 90° (e.g. 45°) with respect to the direction of the height modulations (e.g. by using a second polarizer 116 or a polarized light source without using a second polarizer 116), both TE and TM modes are excited and resonantly reflected at their respective resonance wavelengths. The angle in question is shown in further detail in connection with Figure 10.

In the case of TM modes, the component of the electric field at the resonance wavelength that is perpendicular to the grooves is reflected, while the parallel component passes through. Due to the loss of the reflected component, there is an effective rotation in polarization of the transmitted light 132 at the TM resonance wavelength.

Similarly, light at the TE resonance wavelength undergoes an effective rotation in polarization, though in this case, it is the component of the electric field in parallel to the grating lines that is reflected and lost. By placing a linear polarizer 115 at the exiting side of the GMRF 112 at an angle of 90° with respect to the polarization of incident white light 125, only the light undergoing a polarization rotation at the resonance wavelengths will be able to pass through it. The system comprising the GMRF and the first polarizer 115 will therefore only allow narrow bands of light at the resonance wavelengths to pass through.

The GMRF can be designed in such a way that only TE modes can exist and thus only a single narrow wavelength band or a ‘sharp’ wavelength peak is transmitted through the system and emitted at the light emitting part 112. Since the resonance wavelength is highly sensitive (as e.g. shown and explained further in connection with Figure 3) on the refractive index of materials (e.g. a liquid) placed upon the GMRF 110 (while also being dependent on the period of the height modulations of the first material 113, layer thicknesses of the second material 114 and the specific materials used for the first and second material 113, 114), the wavelength or colour of the transmitted light 130 readily enables identification or estimation of an refractive index of a liquid material received by the optical structure 110.

The invention will work even for embodiments where both a TE mode and a TM mode exist (whereby two narrow wavelength ranges or bands will exist) as the influence (when observed by a user and/or captured by an image capturing unit) of the TM mode will often be low and/or practically negligible.

Generally, either only TE modes will exist or both TE and TM modes will exist. The TE resonance wavelength will be widest and contain the most power compared to the TM resonance wavelength and will thus provide a stronger signal. On the other hand, the TM resonance wavelength may yield a more sensitive device.

Devices utilising a single narrow wavelength range or band based only on the TM mode is also possible as well as devices utilising the ranges or bands based on both the TE and TM modes.

In this way, the system 100 for identification or estimation of a refractive index of a liquid is adapted, during use, to propagate the received polarised light (as polarised by the second polariser or alternatively by some other means or due to a specific light source being used) through the optical path so that a wavelength or colour of the transmitted light 130 is (greatly) influenced by a refractive index of the received liquid 120 whereby the wavelength or colour, when observed by a user or captured by an image capturing unit, enables identification or estimation of the predetermined refractive index of the liquid 120 in a fast, reliable, and in-expensive manner.

It is to be understood that the second polariser 116 is not needed if the light received is already polarised, as e.g. is the case in the embodiment of Figure 7.

Figure 2B schematically illustrates an exploded view of another optical structure and system similar to Figure 2A also showing the light emitting unit 502' i.e. the light source.

Utilizing the fact that GMRFs essentially behave as wavelength-selective polarizers, the resonance spectra of the GMRF can be measured in transmission by placing them between two crossed polarizers. In this setup, only light in the resonance bands is transmitted, while the remainder of the spectrum is blocked. Here, broadband light is guided from its source via an optical fiber, and then collimated with a fiber collimator before being polarized with a linear polarizer 116' at an angle, ϕ. of 45 deg. with respect to the sample grating direction. In order to limit the angles of incidence and spot light spot size, an aperture 217 is placed adjacent to the sample surface. The sample on the sensing optical structure 110 is mounted on a combined 3-axistranslation and goniometer stage and positioned such that the broadband light is normally incident on the GMRF surface. In the resonance bands, the GMRF reflects a component of the light leading to an effective rotation in polarization, which in turn enables partial transmission through the first polarizer 115' at angle, ϕ, of 45 deg., while the rest of the spectrum is blocked. A lens 218 focuses the transmitted light into an optical fiber 219 which leads it to a spectrometer for. For further details on this embodiment, the skilled readers is referred to Applied Physics Letters **105**, 071103 (2014), "*Absolute analytical prediction of photonic crystal guided mode resonance wavelengths*" by the present inventors, which is hereby incorporated by reference in its entirety.

Identification or estimation of the refractive index of the liquid may be used for many different purposes, e.g. like estimating the sugar content of e.g. juice, lemonade, wine, beer, maple syrup, honey, etc.; estimating battery acid density and/or anti-freezing compound concentration in cooling water/window cleaning water; distinguishing between oils, salinity in aquarium, and sea water; point-of-care medical diagnostics; bio-sensing; and etc.

Figure 3 schematically illustrates a graph illustrating a change in peak wavelength or colour being emitted from a system for identification or estimation of a refractive index of a liquid and embodiments thereof as described throughout the description where the change is caused by a change in the refractive index of the liquid.

Shown is a graph 500 illustrating three wavelength profiles or peaks 505, 506, and 507 obtained by a system for identification or estimation of a refractive index of a liquid according to the present invention where the wavelength profiles correspond to three liquids of different refractive indices. The liquids had refractive indices of 1.3 (505), 1.4 (506) and 1.5 (507).

The wavelength profile 505 was, as an example, obtained by placing a refractive index matching oil with a refractive index of 1.3 ‘on top’ (i.e. on top of the side having the grooves) of an optical structure (with the first material being Efiron PC 409, having a height modulation of 100 nm with a period of 384 nm, and the second material being titanium dioxide with a thickness of 30 nm) and illuminating it with collimated white light (not shown; see e.g. 135 in Figure 5) which was polarised using a second polariser (not shown, see e.g. 116 in Figures 1, 2 and 5) at an angle of ϕ = 45° with respect to the grating lines (please also refer to Figure 10). The white light source was a broad-spectrum Xenon lamp.

The light transmitted through the optical structure (not shown, see e.g. 110 in Figures 1, 2A, and 5) and liquid (not shown, see e.g. 120 in Figures 5 and 7) was passed through a first polariser (not shown, see e.g. 115 in Figures 2A, 5, and 7) oriented 90° with respect to the second polariser (not shown; see e.g. 116 in Figures 2A and 5), and then focused into an optical fibre through which it was directed into a spectrometer for analysis, resulting in the profile 505. The wavelength profiles 506 and 507 were obtained analogously, but with the following difference: the optical structure on the grating side was covered with oils with refractive indices of 1.4 and 1.5, respectively.

The wavelength profiles illustrate that when a system for identification or estimation of a refractive index of a liquid according to the present invention is used, the observed or captured light emitted from the system will give a distinct colour (as also shown in Figure 4) that is strongly tied to and therefore represents the refractive index of the liquid received in the system.

Figure 4 schematically illustrates visual identification or estimation of refractive indexes.

Shown are three captured images 510, 520 and 530 captured from a system for identification or estimation of a refractive index of a liquid according to the present invention with three different liquids having different refractive indices together with a colour scale 540 with corresponding refractive indexes ‘n’ ranging in shades from blue and ‘n=1.0’ to red and ‘n=1.6’ in increments of ‘n=0.1’.

The left image 510 illustrates a green colour and therefore the liquid resulting in this image has a refractive index of about ‘n=1.3’. Similarly, the middle image 520 and right image 530 illustrate a yellow and orange-red colour respectively, and therefore the liquids resulting in these images have refractive indices of ‘n=1.4’ and ‘n=1.5’. The three images correspond to the three wavelength profiles in figure 3 and were recorded at the same time with the same liquids.

The liquids for the three images are, as an example, refractive index matching oils.

By being presented with such a colour scale 540 and corresponding values for refractive indexes and observing the light emitted from a system according to the present invention or an image captured of it, it is possible to perform identification or estimation of a refractive index of a liquid in a simple, quick, in-expensive and/or reliable manner.

There are various ways of implementing an advantageous graphical user interface assisting a user in the identification or estimation, as will be explained further in connection with Figure 8.

Figure 5 schematically illustrates an alternative embodiment of a system for identification or estimation of a refractive index of a liquid.

Shown is a system 100 for identification or estimation of a refractive index of a liquid, comprising an optical structure 110, receiving a liquid 120 for which the refractive index is to be identified or estimated.

The optical structure 110 corresponds to the ones shown in Figures 1 and 2 and likewise comprises a first and a second polariser 115, 116 as explained in connection with Figure 2A and also has a light receiving part 111 and a light emitting part 112.

Further shown are an image capturing unit 501 and a light emitting unit/light source 502. It is to be understood that one or both of the image capturing unit 501 and the light emitting unit 502 could be part of the system 100 or be separate from it (e.g. comprised by another electronic device, e.g. as shown in the embodiments of Figures 6a, 6b, 7, and 11).

During use, a liquid for which the refractive index is to be identified or estimated is received by the system 100 or more particularly by the optical structure 110.

Non-polarised light 135 is, in this particular embodiment, emitted by the light emitting unit or light source 502 (forth only denoted light emitting unit) and received by the system 100 at its light receiving part 111 where the second polariser 116 will polarise it to an angle of about 45° with respect to the direction of the grating lines of the optical structure 110 before it enters the optical structure 110 with the liquid 120. The specific refractive index of the liquid 120 will uniquely influence a wavelength range or wavelength peak (as illustrated in Figure 3) of the received light and thereby the colour of the light transmitted through the system 100, as previously explained. When the light 132 exiting the optical structure 110 is passed through the first polariser 115, i.e. just before leaving the system 100, all white light 135 is filtered out, except the narrow wavelength range or wavelength peak that undergoes polarisation rotation by the optical structure 110 and the liquid 120, as has been described elsewhere.

In this particular embodiment, the light exiting 132 the optical structure 110 is sent to the first polariser 115 via a suitable optical system, here in the form of two 45° optical mirrors 540, 541.

The light exiting the optical structure 110 is first reflected 90° by the first optical mirror 540, the mirror being oriented about 45° with respect to the plane of the device, and then secondly reflected another 90° by the second optical mirror 541 before being received by the first polariser 115 and before exiting the system 100 as emitted light 130 at the light emitting part 112.

The emitted light 130, representing the refractive index of the received liquid 120, is received by an image capturing unit 501 recording an image of the emitted light 130. This allows for presentation and/or further processing of the image.

This particular embodiment has the advantage that the emitted light 130 is sent in the opposite direction of the received light 135 by the two optical mirrors 540, 541 whereby the light receiving part 111 and the light emitting part 112 may be located on the same surface, which may be advantageous e.g. as explained in connection with Figures 6a and 6b.

The image capturing unit 501 may e.g. be a camera sensor, a CCD or CMOS image sensor, etc., or any other kind of suitable image capturing unit.

The light emitting unit 502 may e.g. be a flash or another light source emitting non-polarised white light.

Alternatively, the light emitting unit 502 may emit polarised light, in which case the second polariser 116 is not needed, e.g. as explained further in connection with the embodiment of Figure 7.

It should be noted that the first polariser 115 alternatively could be placed before the first mirror 540 or between the two mirrors 540, 541. However, the shown configuration enables a more flat and/or compact system, which may be advantageous.

As yet another variation, the mirrors 540, 541 are not used but instead another arrangement is used such as a suitable optical system to send the emitted light 130 in the opposite (or another) direction of the received light 135. This could e.g. be done by using an optical fibre bringing the light exiting the optical structure 110 to the image sensor 501 or in any other suitable way.

Figures 6a and 6b schematically illustrate the embodiment of Figure 5 used in connection with an electronic device in the form of a smart phone.

Shown is a (part of a) computational device 200, in this particular exemplary embodiment in the form of a smart phone, comprising a display (not shown). Further schematically shown is a system 100 for identification or estimation of a refractive index of a liquid corresponding to the one(s) shown and explained in connection with Figure 5. Figure 6b shows an enlarged part of Figure 6a. Illustrated as part of the system 100 are also two optical mirrors 540, 541 and a first 115 and second polariser 116.

The computational device 200 comprises a light emitting unit 502 and an image capturing unit 501, in this particular embodiment in the form of a camera flash and a camera, respectively.

The system 100 is formed (or adjusted) so that the light receiving part (not shown; see e.g. 111 in Figures 2, 5 and 7) may be located on the camera flash and the light emitting part (not shown; see e.g. 112 in Figure 5) may be located on the camera.

In this way, the light emitting unit 502 and the image capturing unit 501 of the smart phone may readily be used to produce and obtain a digital image of the actually transmitted colour identifying or estimating the refractive index of a contained liquid, simply by taking a picture.

This also enables further data processing of the transmitted colour for enhanced functionality as will be described later making use of the existing computational power and/or network capabilities of the smart phone.

Automatic determination or estimation of the refractive index of a liquid may be provided e.g. by detecting the colour of the captured image and finding a corresponding refractive index value among values and corresponding colours e.g. stored locally or remotely in a database and/or data structure.

Alternatively, manual determination or estimation may be provided and e.g. using an advantageous graphical user interface e.g. as the one(s) explained in connection with Figure 8.

This enables that the system 100 may be fairly simple and cheap to manufacture, since advantage is made of the readily availability of smart phones and similar and their capabilities.

In one embodiment, the system 100 for identification or estimation of a refractive index of a liquid is adjustable in the sense that the distance (the horizontal distance in Figures 6a and 6b) between the light emitting part and the light receiving part may be adjusted. In this way, a single system 100 may easily be adjusted to fit and thereby be used with different models of smartphones or the like.

The system could also be in two separate parts – one part containing the light receiving part and one containing the light emitting part – where a flexible guide, e.g. like an optical fibre, optically connects the two parts. In such embodiments, the mirrors would not be needed and/or the two separate parts could even be on different surfaces or sides of the computational device.

It is to be understood that other computational devices than a smart phone may be used. Examples are e.g. a tablet or the like and in principal any computational device comprising a light emitting unit 502 and an image capturing unit 501.

Figure 7 schematically illustrates another alternative embodiment of a system for identification or estimation of a refractive index of a liquid, here as an example shown used in connection with a computational device in the form of a smart phone.

Shown is a system 100 for identification or estimation of a refractive index of a liquid 120 and a computational device 200 seen from the side. The system 100 is – during use – placed on top of the display of the smart phone 200, as will be explained further e.g. in connection with Figure 8.

The system for identification or estimation of a refractive index of a liquid 100 comprises in this embodiment, an optical structure 110 more or less corresponding in function (but not in design) to the structure of Figures 1, 2, and 5.

A difference is that the system 100 does not comprise a second polariser (while still comprising a first polariser 115).

In this embodiment, the display of the computational device 200 is used as a light source or a light emitting unit. Since light emitted from a display already will be polarised, there is no need for the second polariser, at least for certain types of displays.

The display will emit polarised light 125 that is received by the light receiving part 111 of the optical structure 110. From there on, the system 100 will work as previously described and emit transmitted light 130 having a colour determining or estimating the refractive index of a contained liquid 120.

Certain displays will emit linearly polarised light that may be completely blocked by a (first) polariser rotated 90° with respect to the polarisation of the given emitted light. The polarisation of the emitted light may be different from display to display but a given polariser, e.g. specific or suitable for certain displays or classes of displays will be usable. Some other displays may e.g. emit light where the polarisation direction of each primary colour (e.g. red, green, and blue) emitted from the display may be different. For the embodiment of Figure 7 to work with such displays, the primary colours would need to be polarised in the same direction (and then using a first polariser rotated 90° with respect to that same direction). This could e.g. be achieved by using a polarisation rotator such as a half-wave plate (based on birefringence), or other types of polarisation rotators (e.g. based on total internal reflection), etc.

In this way, a user may readily observe the emitted colour and – e.g. with the help of some software and GUI as an example explained further in connection with Figure 8 – be able to determine the refractive index of a contained liquid.

Figure 8 schematically illustrates a computational device in the form of a smart phone, an embodiment of a system for identification or estimation of a refractive index of a liquid, and an interactive graphical user interface (GUI) assisting a user in determining a refractive index value.

Shown is a computational device 200, here as an example in the form of a smart phone. Further shown is an embodiment of a system 100 for identification or estimation of a refractive index of a liquid corresponding to the one in Figure 7. The system 100 is placed on top of an area of the display of the computational device that – during use and as an example – emits polarised white light. As have been described earlier, a colour will be emitted by the system 100 where the emitted colour has been uniquely influenced by refractive index of the liquid contained in the system. So it should be understood that the colour in the area denoted 'Grating area' in 100 is the colour emitted by the system 100 and not the computational device.

Further shown is an interactive graphical user interface (GUI) running on the computational device and comprising – as an example – a first part 800 and a second part 801.

The second part 801 graphically shows a colour scale with corresponding refractive indexes ranging in shades from blue and the corresponding refractive index being 1.0 to red and the corresponding refractive index being 1.8.

The second part 801 may be used by a user to manually determine – e.g. somewhat roughly but for some uses still usable – the refractive index of the contained liquid by determining what colour on the colour scale matches the colour emitted from the system 100 and determining the corresponding refractive index value of the best matched colour.

The first part 800 may interactively be used to manually determine the refractive index of the contained liquid. The first part 800 will show three (or a different number) colours and the user should then select the colour of the shown ones that best matches the colour being emitted by the system 100. When the user's selection has been input (e.g. using a touch screen and an appropriate software programme), three new colours matching the emitted colour more closely is displayed and the user may then select one of these and so on until the user and/or the software determines that the emitted colour (and thereby the refractive index of the contained liquid) has been identified (sufficiently well).

The software programme may initially present three or another number of colours being from the mid part and the two different end parts of the colour scale. Depending on which colour is selected, the three new colours to be presented are colours that are matching more closely to the selected colour.

As an example, the programme may initially display colours associated with refractive index values being 1.1, 1.4, and 1.7. If e.g. the displayed colour associated with 1.4 was selected by the user as the colour best matching the colour being emitted by the system 100, the programme would display new colours associated with refractive index values e.g. being 1.3, 1.4, and 1.5. If then the colour associated with 1.5 was selected, the next colours could be colours associated with refractive index values e.g. being 1.45, 1.50, and 1.55 and so on until the user was happy with the result and/or the programme determines that no meaningful further division or selection should be made.

The selection of colours to present based on a selected colour could be optimised in many ways.

This provides a very intuitive and simple way of determining the refractive index of the contained liquid just by referring to the colour being emitted by the system 100 located on top of the display of the computational device 200.

As mentioned, the emitted colour of the system 100 is (in addition to the refractive index of a liquid in the optical structure) dependent on the period of the height modulations of the first material of the optical (grating) structure, the layer thicknesses of the second material, and the specific materials used for the first and second material of the optical structure. However, once a system 100 is designed these are fixed (except for the liquid of course).

Therefore, the software programme should be calibrated or programmed initially so that it shows the correct colours and associated refractive index values for the specifically used system 100 when a liquid is added. The programme could comprise a number of such profiles for different systems.

The software programme may e.g. be a suitable IOS or Android app or a programme for other operating systems.

It is to be understood that the layout and elements of the GUI parts 800 and/or 801 could be different.

The first part 800 could e.g. also display the corresponding refractive index values of the shown colours.

Figure 9 schematically illustrates an embodiment of a system for identification or estimation of a refractive index of a liquid that enables determining a dispersion profile of the liquid.

As mentioned earlier, the emitted colour of a system 100 for identification or estimation of a refractive index of a liquid is (in addition to the refractive index of a liquid in the optical structure) dependent on the period of the height modulations of the first material of the optical structure, the layer thicknesses of the second material, and the specific materials used for the first and second material of the optical structure.

This can be used to advantage to provide a system 102 for identification or estimation of a refractive index dispersion profile 103 of a liquid in an expedient way. The dispersion profile 103 is the wavelength dependence of a contained liquid’s refractive index.

In one embodiment, such a system 102 is provided by a grid, array or other suitable arrangement of optical structures, each corresponding in at least in function to the optical structure 110 explained elsewhere where each optical structure of the grid or array has suitable varying geometrical properties. In one particular embodiment, each optical structure has a different period of the height modulations of the first material of the optical (grating) structure compared to the other optical structures. It is to be understood that other variations, e.g. in addition to varying the period of the height modulations, may be used. Furthermore, it is not necessary to specifically know the geometrical properties as a calibration can be carried out once and for all using liquids of known refractive indices/dispersion so that it is known when a specific wavelength emanates from a given field, then it contains a liquid with a particular refractive index. Additionally, the ordering of the individual optical structures is in principle not relevant as long as track of what is expected from each optical structure is maintained, e.g. in a software program or similar used for deriving the dispersion profile 103.

By receiving a liquid, whose dispersion profile 103 is to be determined, in a grid or array of optical structures and using light and one or two polarisers as have been described earlier, a different colour would be emitted for each optical structure of the grid or array. Each colour would correspond to a given refractive index at that specific wavelength or colour, allowing a set of pairs of a refractive index value and associated wavelength range or peak (as given by each structure in the grid) to be obtained thereby providing a dispersion profile 103.

The colours may e.g. be captured by an image capturing unit and a software programme or similar may derive the dispersion profile 103 based on the captured colours using pre-determined information about each optical structure of the grid, such as calibration relation between emitted colour and refractive index for each of the fields, as explained below. Alternatively, for each field in the array, information such as first and second material dispersion, second material thickness, and the period of the height modulations of the first material, and emitted wavelength may be used to accurately determine the refractive index of the received liquid at the emitted wavelength or colour using a mathematical model.

Figure 14 shows a graph with the modelled resonance shifts for three different liquids (water, Cagille A 1.4900, Cargille AAA 1.3850 from Cargille Lab.) against air from Applied Physics Letters **105**, 071103 (2014), "*Absolute analytical prediction of photonic crystal guided mode resonance wavelengths*" by the present inventors, which is hereby incorporated by reference in its entirety. In short, it is demonstrated how the absolute resonance wavelengths of such structures can be predicted by analytically modeling them as slab waveguides in which the propagation constant is determined by a phase matching condition in an iterative manner. The model is experimentally verified to be capable of predicting the absolute resonance wavelengths to an accuracy of within 0.75 nm, as well as resonance wavelength shifts due to changes in cladding index within an accuracy of 0.45 nm across the visible wavelength regime in the case where material dispersion is taken into account. Furthermore, it is demonstrated that the model is valid beyond the limit of low grating modulation, for periodically discontinuous waveguide layers, high refractive index contrasts, and highly dispersive media.

More specifically, and as an example, a captured image of the colours emitted by all optical structures may be processed in order to provide a refractive index versus wavelength graph (i.e. dispersion profile) based on the captured image. Each used optical structure will transmit/emit a given wavelength peak or colour and from each wavelength peak it is possible to determine a corresponding refractive index value at that wavelength e.g. using a predetermined table between wavelengths and refractive index values or the aforementioned model. Such a predetermined table would typically be device or system specific and should be generated as part of a calibration step, made once for each specific system.

It is to be understood that instead of a grid or array of optical structures 110, the system 102 could e.g. comprise a number of optical structures in a single line or in other patterns.

Furthermore, it is to be understood that the specific number of optical structures 110 used could vary from embodiment to embodiment. One point for the dispersion profile is generally obtained for each used optical structure. A smoother dispersion profile may be obtained by using various (non-linear) extrapolation or curve fitting schemes (e.g. to Cauchy or Sellmeier functions) in connection with the obtained data points.

Alternatively, instead of varying the period of the height modulations of the first material of the optical structures you could vary other geometrical properties, e.g. by varying the thickness of the second material.

Such a system for identification or estimation of a dispersion profile of a liquid may e.g. be used in an embodiment comprising a computational device as shown in Figures 6a, and 6b.

Figure 10 schematically illustrates an optical structure and light polarised at an angle compared to the grating structures of the topical structure.

Shown is an optical structure 110, here in the form of an optical grating structure, seen from above. The optical structure corresponds to the ones e.g. shown in Figures 1, 2A, 2B, 5, and 7 and comprises a number of grating lines 150, 151, where the grey lines 150 are the periodic height modulations and the white lines 151 are the grooves of the structure, respectively.

Further illustrated, is an arrow 152 indicating – as one example – the polarisation of incident light (as a vector) and an angle θ being the angle between the polarisation and the grating structures 151, 152.

Figure 11 schematically illustrates one embodiment of a computational device in further details, where the device is for use with a system 100 for identification or estimation of a refractive index of a liquid and/or a system 102 for identification or estimation of a dispersion profile of a liquid.

Shown is a computational device or system 200 comprising at least one processing unit 201 connected via one or more communications and/or data buses 202 to an electronic memory and/or storage 203, optional communications elements 204 e.g. for communicating via a network, the Internet, a Wi-Fi connection, and/or the like, and a display 205.

The device 200 may be a more or less standard computational device, e.g. like a PC, laptop, smartphone, TV, tablet, etc. but suitably programmed to carry out the method(s) or procedure(s) as described in the various embodiments throughout the specification and variations thereof. The device could also be a specialized device for this use only.

The program may e.g. be a downloadable app, applet or application or similar e.g. an IOS or Android app.

The display 205 may e.g. be a typical integrated 2D display and more preferably a touch sensitive display able to receive input from a user by touch.

The device 200 may also comprise an image capturing unit 501 and a light emitting unit/light source 502, e.g. in the form of a built in camera and a flash, respectively.

Also shown is a system 100 for identification or estimation of a refractive index of a liquid and/or a system 102 for identification or estimation of a dispersion profile 103 of a liquid as have been described in various embodiments earlier. This/these identification or estimation system(s) could be integrated into the device 200 but preferably are separate and usable together with the device 200 as has been described earlier. This makes use of the great availability of such devices and further enables further functionality.

Identification or estimation of the refractive index of the liquid may be used for many different purposes, e.g. like estimating the sugar content of e.g. juice, lemonade, wine, beer, maple syrup, honey, etc.; estimating battery acid density, anti-freezing compound concentration in cooling water/window cleaning water; distinguishing between oils, salinity in aquarium and sea water; point-of-care medical diagnostics, bio-sensing, etc.

It may be advantageous to use a device 200 with computational and/or communications capabilities, e.g. to calculate further or derive results based on the obtained refractive index (e.g. like deriving a sugar content, calculate predictions of values, etc. based on an obtained refractive index). Furthermore, local or remote databases may be used to either store and/or retrieve obtained and/or derived data (e.g. so the development of sugar content may be registered and monitored over time, obtaining and e.g. comparing with historic results, results or values obtained and shared by others, etc.). Many different applications and uses – using information about the refractive index of a liquid – are possible.

In the claims, any reference signs placed between parentheses shall not be constructed as limiting the claim. The word "comprising" does not exclude the presence of elements or steps other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements.

The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to an advantage.

It will be apparent to a person skilled in the art that the various embodiments of the invention as disclosed and/or elements thereof can be combined without departing from the scope of the invention.

EMBODIMENTS:

Below are listed further embodiments that may be combined with any of the first and second aspects of the present invention, in particular with any of the appended claims.

1. A system (100) for identification or estimation of a refractive index of a liquid (120), the system comprising

- a light receiving part (111) adapted, during use, to receive polarised or non-polarised light (125, 135),
- a light emitting part (112) adapted, during use, to transmit light (130),
- an optical structure (110)
    - being adapted to receive, during use, polarised light (125) via or from the light receiving part (111), and
    - being adapted to receive, during use, a liquid (120) having a predetermined refractive index to be identified or estimated, and
- a first polariser (115) adapted, during use, to receive transmitted light (132) from the optical structure (110) and the received liquid (120),

wherein the light receiving part (111), the received liquid (120), the first polariser (115), and the light emitting part (112) defines an optical path and wherein the system (100) is adapted, during use, to pass the received polarised light (125) through the optical path so that a narrow wavelength range of the transmitted light (130) is influenced by the predetermined refractive index of the received liquid (120) and that the influenced narrow wavelength range, when observed by a user and/or captured by an image capturing unit (501), enables identification or estimation of the predetermined refractive index of the liquid (120).

2. The system according to embodiment 1, wherein the optical structure (110) comprises a first (113) and a second (114) material, where the refractive index of the second material (114) is greater than the refractive index of the first material (113) and where the second material (114) is deposited on at least a part of the first material (113).

3. The system according to any one of embodiments 1 – 2, wherein the optical structure (110) is adapted, during use, to pass received polarised light

(125) first through the first material (113), the second material (114) and then received liquid (120) so that a component of the polarised light is reflected at the narrow wavelength range.

4. The system according to any one of embodiments 1 – 3, wherein the optical structure (110) is an optical grating structure or a guided mode resonance filter.

5. The system according to any one of embodiments 1 – 4, wherein the system (100) further comprises an electronic device (200) comprising a light emitting unit (502) and an image capturing unit (501), and wherein the system (100) is adapted to be placed on the electronic device (200) so that the light receiving part (111) receives light from the light emitting unit (502) and the light emitting part (112) transmit light to the image capturing unit (501).

6. The system according to embodiment 5, wherein the electronic device (200) is a smartphone (200) or tablet or the like and the light emitting unit (502) is a camera flash and the image capturing unit (501) is a camera of the smartphone (200) or tablet or the like.

7. A system according to any one of embodiments 1 – 6, wherein the system (100) is adapted to receive non-polarised light (135), during use, and wherein the system (100) comprises a second polariser (116) adapted, during use, to polarise the received non-polarised light (135) before or when the light is received by the optical structure (110).

8. The system according to any one of embodiments 1 – 7, wherein the system (100) further comprises a computational device (200) comprising a display (300) emitting, during use, polarised light, and wherein the system (100) is adapted to be placed on the display (300), during use, thereby receiving polarised light, emitted by the display (300), at the light receiving part (111).

9. The system according to any one of embodiments 1 – 7, wherein the system (100) further comprises a computational device (200) comprising a

display (205) and at least one processing unit (201) where the at least one processing unit (201) is adapted, during use, to

- initially display on the display (205) a plurality of different starting colours, each starting colour being associated with a given refractive index value enabling a user to select a colour best resembling according to the user the colour of light emitted from the light emitting part (112) of the system (100), and thereafter register a selection by a user of a colour among the displayed plurality of colours and display another plurality of different colours associated with refractive index values being closer to the refractive index value associated with the user selected colour, and/or

- display on the display (205) a colour scale (540; 801) comprising a range of colours and a number of refractive index values, where each refractive index value is associated with a given colour of in the range of colours.

10. The system according to any one of embodiments 1 – 9, wherein the system comprises a plurality of optical structures (110) with varying geometrical properties, where the varying geometrical properties provide different narrow wavelength ranges of the transmitted light (130) when receiving the liquid (120) enabling, for each optical structure (110), identification of a refractive index value corresponding with the narrow wavelength range and thereby one dispersion profile data point for each of the plurality of optical structures (110).

11. A method of identifying or estimating a refractive index of a liquid (120), the method comprising

- receiving, during use, polarised or non-polarised light (125, 135) in a light receiving part (111),
- transmitting, during use, light (130) by a light emitting part (112),
- receiving, during use, polarised light (125) via or from the light receiving part (111) in an optical structure (110),
- receiving, during use, a liquid (120) having a predetermined refractive index to be identified or estimated in the optical structure (110),
- receiving, during use, the transmitted light (132) from the optical structure (110) and the received liquid (120) in a first polariser (115),

wherein

- the light receiving part (111), the received liquid (120), the first polariser (115), and the light emitting part (112) defines an optical path and wherein, during use, the received polarised light (125) is passed through the optical path so that a narrow wavelength range of the transmitted light (130) is influenced by the predetermined refractive index of the received liquid (120) and wherein the influenced narrow wavelength range, when observed by a user and/or captured by an image capturing unit (501), enables identification or estimation of the predetermined refractive index of the liquid (120).

12. The method according to embodiment 11, wherein the optical structure (110), during use, passes received polarised light (125) first through the first material (113),the second material (114) and then the received liquid (120) so that a component of the polarised light is reflected at the narrow wavelength range.

13. The method according to any one of embodiments 11 or 12, wherein the light receiving part (111), during use, receives non-polarised light (135), and wherein a second polariser (116), during use, polarises the received non-polarised light (135) before or when the light is received by the optical structure (110).

14. The method according to any one of embodiments 11 – 13, wherein at least one processing unit (201) in a system (100) is adapted, during use, to

- initially display on a display (205) a plurality of different starting colours, each starting colour being associated with a given refractive index value enabling a user to select a colour best resembling according to the user the colour of light emitted from the light emitting part (112) of, and thereafter register a selection by a user of a colour among the displayed plurality of colours and display another plurality of different colours associated with refractive index values being closer to the refractive index value associated with the user selected colour, and/or
- display on the display (205) a colour scale (530; 801) comprising a range of colours and a number of refractive index values, where each refractive index value is associated with a given colour of in the range of colours.

15. The method according to any one of embodiments 11 – 14, wherein the method comprises receiving the liquid (120) in a plurality of optical structures (110) with varying geometrical properties, where the varying geometrical properties provide different narrow wavelength ranges of the transmitted light

(130) when receiving the liquid (120) enabling, for each optical structure (110) identification of a refractive index value corresponding with the narrow wavelength range and thereby one dispersion profile data point for each of the plurality of optical structures (110).

Claims:

1. A system (100) for identification or estimation of a refractive index of a liquid (120), the system comprising

- a light receiving part (111) adapted, during use, to receive polarised or non-polarised light (125, 135),
- a light emitting part (112) adapted, during use, to transmit light (130),
- an optical structure (110)
  - o being adapted to receive, during use, polarised light (125) via or from the light receiving part (111), and
  - o being adapted to receive, during use, a liquid (120) having a predetermined refractive index to be identified or estimated, and
- a first polariser (115) adapted, during use, to receive transmitted light (132) from the optical structure (110) and the received liquid (120),

wherein the light receiving part (111), the received liquid (120), the first polariser (115), and the light emitting part (112) defines an optical path and wherein the system (100) is adapted, during use, to pass the received polarised light (125) through the optical path so that a narrow wavelength range of the transmitted light (130) is influenced by the predetermined refractive index of the received liquid (120) and that the influenced narrow wavelength range, when observed by a user and/or captured by an image capturing unit (501), enables identification or estimation of the predetermined refractive index of the liquid (120), wherein the system (100) further comprises an electronic device (200) comprising a light emitting unit (502) and an image capturing unit (501), and wherein the system (100) is adapted to be placed on the electronic device (200) so that the light receiving part (111) receives light from the light emitting unit (502) and the light emitting part (112) transmit light to the image capturing unit (501), optionally the electronic device (200) is a smartphone (200) or tablet or the like, and the light emitting unit (502) is a camera flash or a display screen and the image capturing unit (501) is a camera of the smartphone (200) or tablet or the like.

2. The system according to claim 1, wherein the optical structure (110) comprises a first (113) and a second (114) material, where the refractive

index of the second material (114) is greater than the refractive index of the first material (113) and where the second material (114) is deposited on at least a part of the first material (113).

3. The system according to any one of claims 1 – 2, wherein the optical structure (110) is adapted, during use, to pass received polarised light (125) first through the first material (113), the second material (114) and then received liquid (120) so that a component of the polarised light is reflected at the narrow wavelength range.

4. The system according to any one of claims 1 – 3, wherein the optical structure (110) is an optical grating structure or a guided mode resonance filter.

5. A system according to any one of claims 1 – 4, wherein the system (100) is adapted to receive non-polarised light (135), during use, and wherein the system (100) comprises a second polariser (116) adapted, during use, to polarise the received non-polarised light (135) before or when the light is received by the optical structure (110).

6. The system according to any one of claims 1 – 5, wherein the system (100) further comprises a computational device (200) comprising a display (300) emitting, during use, polarised light, and wherein the system (100) is adapted to be placed on the display (300), during use, thereby receiving polarised light, emitted by the display (300), at the light receiving part (111).

7. The system according to any one of claims 1 – 6, wherein the system (100) further comprises a computational device (200) comprising a display (205) and at least one processing unit (201) where at least one processing unit (201) is adapted, during use, to

- initially display on the display (205) a plurality of different starting colours, each starting colour being associated with a given refractive index value enabling a user to select a colour best resembling, according to the user, the colour of light emitted from the light emitting part (112) of the system (100), and thereafter register a selection by a user of a colour among the displayed plurality of colours and display another plurality of different colours associated with refractive index values being closer to the refractive index value associated with the user selected colour, and/or

- display on the display (205) a colour scale (540; 801) comprising a range of colours and a number of refractive index values, where each refractive index value is associated with a given colour of in the range of colours.

8. The system according to any one of claims 1 – 7, wherein the system comprises a plurality of optical structures (110) with varying geometrical properties, where the varying geometrical properties provide different narrow wavelength ranges of the transmitted light (130) when receiving the liquid (120) enabling, for each optical structure (110), identification of a refractive index value corresponding with the narrow wavelength range and thereby one dispersion profile data point for each of the plurality of optical structures (110).

9. A method of identifying or estimating a refractive index of a liquid (120), the method comprising

- receiving, during use, polarised or non-polarised light (125, 135) in a light receiving part (111),
- transmitting, during use, light (130) by a light emitting part (112),
- receiving, during use, polarised light (125) via or from the light receiving part (111) in an optical structure (110),
- receiving, during use, a liquid (120) having a predetermined refractive index to be identified or estimated in the optical structure (110),
- receiving, during use, the transmitted light (132) from the optical structure (110) and the received liquid (120) in a first polariser (115),

wherein

- the light receiving part (111), the received liquid (120), the first polariser (115), and the light emitting part (112) defines an optical path and wherein, during use, the received polarised light (125) is passed through the optical path so that a narrow wavelength range of the transmitted light (130) is influenced by the predetermined refractive index of the received liquid (120) and wherein the influenced narrow wavelength range, when observed by a user and/or captured by an image capturing unit (501), enables identification or estimation of the predetermined refractive index of the liquid (120), and

wherein the method further comprising providing an electronic device (200) comprising a light emitting unit (502) and an image capturing unit (501), and wherein the method further comprising positioning the said electronic device (200) so that the light receiving part (111) receives light from the light emitting unit (502) and the light emitting part (112) transmits light to the image capturing unit (501), optionally the electronic device (200) is a smartphone (200) or tablet or the like, and the light emitting unit (502) is a camera flash or display screen and the image capturing unit (501) is a camera of the smartphone (200) or tablet or the like.

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10. The method according to claim 9, wherein the optical structure (110), during use, passes received polarised light (125) first through the first material (113), the second material (114) and then the received liquid (120) so that a component of the polarised light is reflected at the narrow wavelength range.

11. The method according to any one of claims 9 or 10, wherein the light receiving part (111), during use, receives non-polarised light (135), and wherein a second polariser (116), during use, polarises the received non-polarised light (135) before or when the light is received by the optical structure (110).

12. The method according to any one of claims 9 – 11, wherein at least one processing unit (201) in a system (100) is adapted, during use, to

- initially display on a display (205) a plurality of different starting colours, each starting colour being associated with a given refractive index value enabling a user to select a colour best resembling, according to the user, the colour of light emitted from the light emitting part (112), and thereafter register a selection by a user of a colour among the displayed plurality of colours and display another plurality of different colours associated with refractive index values being closer to the refractive index value associated with the user selected colour, and/or

- display on the display (205) a colour scale (530; 801) comprising a range of colours and a number of refractive index values, where each refractive index value is associated with a given colour in the range of colours.

13. The method according to any one of claims 9 – 12, wherein the method comprises receiving the liquid (120) in a plurality of optical structures (110) with varying geometrical properties, where the varying geometrical properties provide different narrow wavelength ranges of the transmitted light (130) when receiving the liquid (120) enabling, for each optical structure (110) identification of a refractive index value corresponding with the narrow wavelength range and thereby one dispersion profile data point for each of the plurality of optical structures (110).

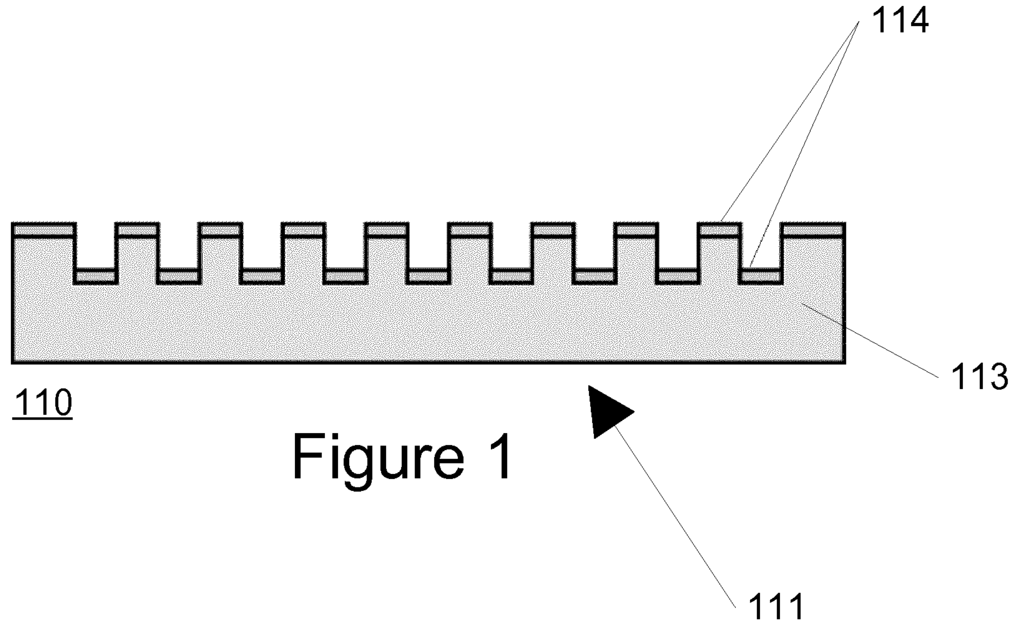


Figure 1

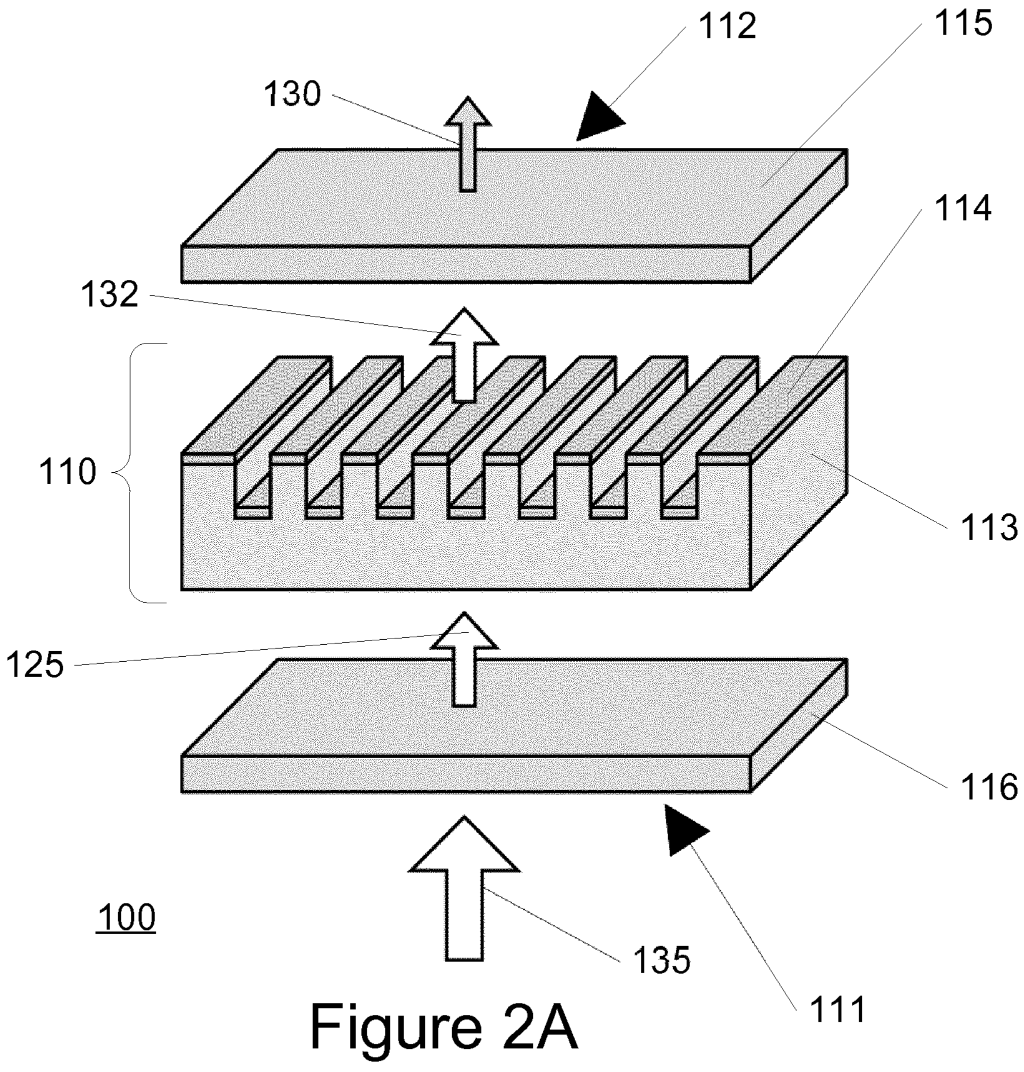


Figure 2A

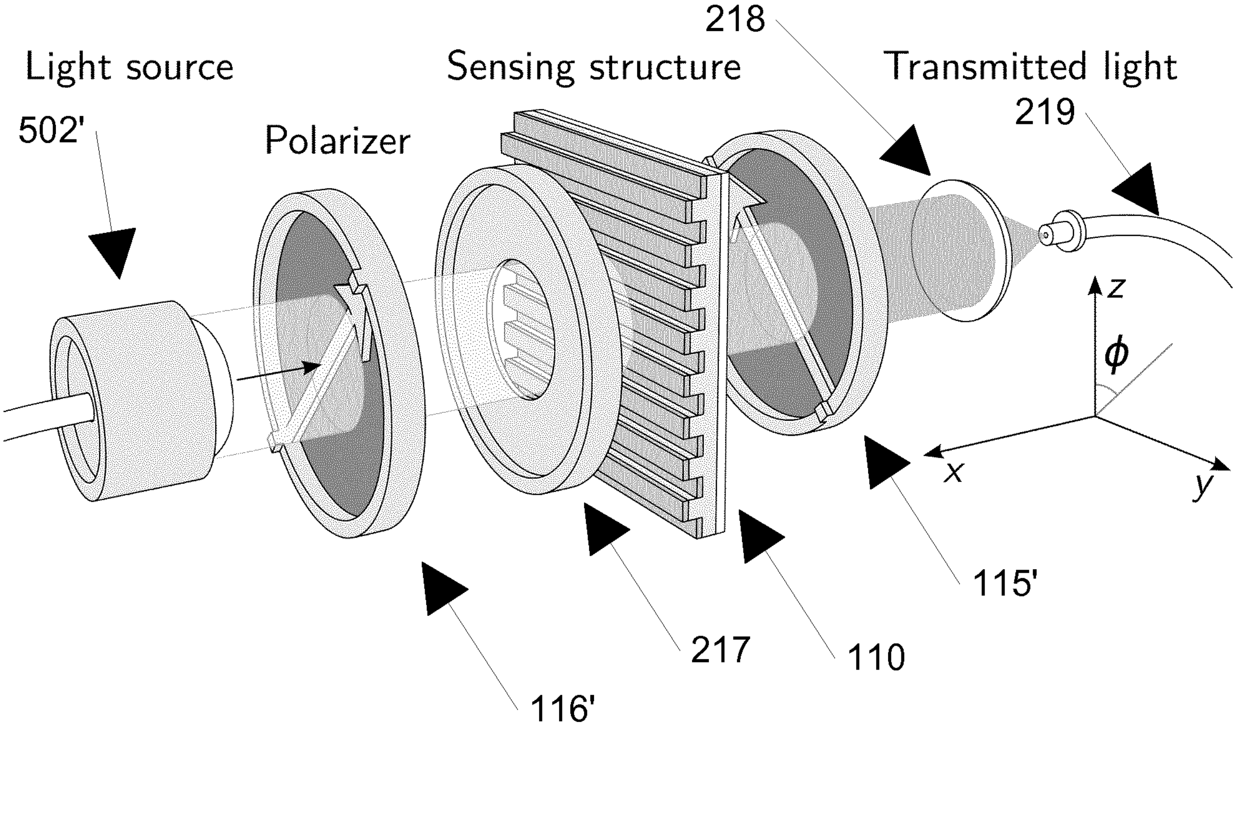
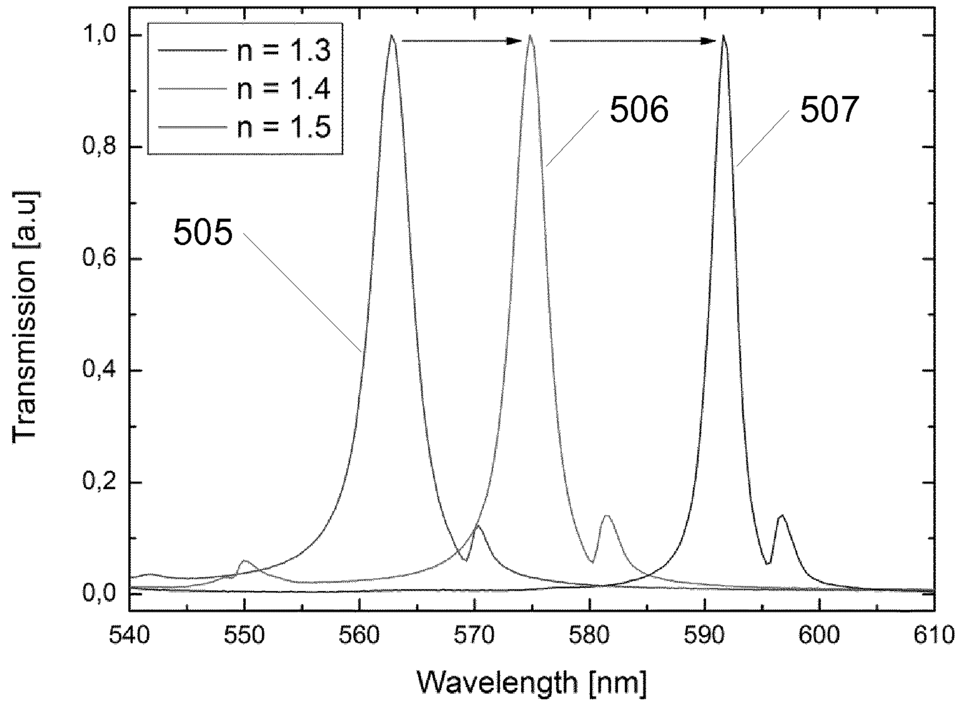
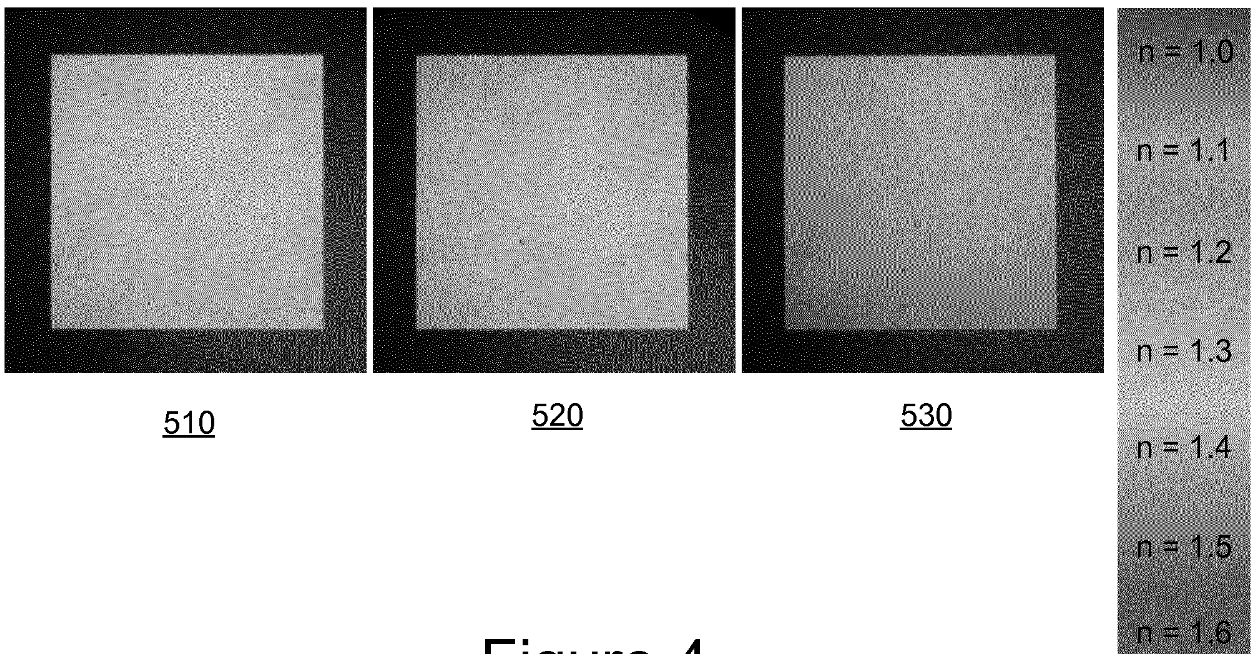

Light source
502'
Polarizer
Sensing structure
218
Transmitted light
219
z
ϕ
x
y
115'
217
110
116'

Figure 2B



500

Figure 3



510 520 530 540

Figure 4

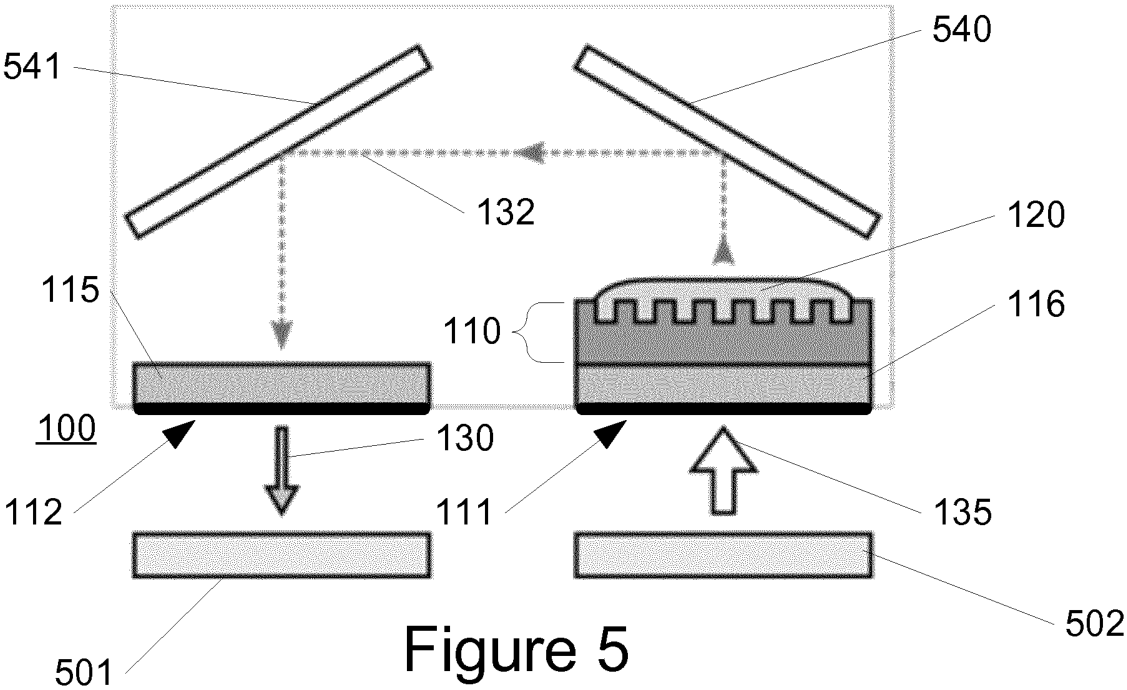


Figure 5

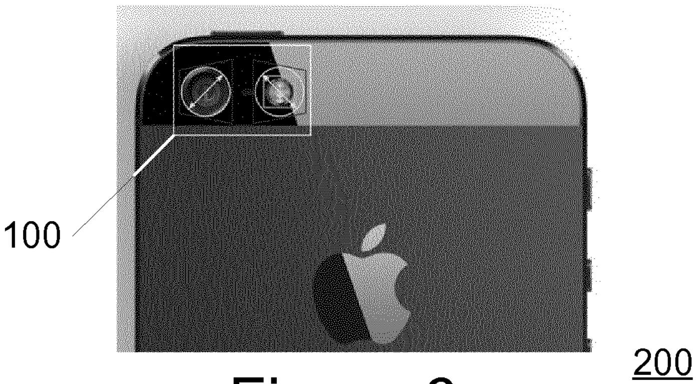


Figure 6a

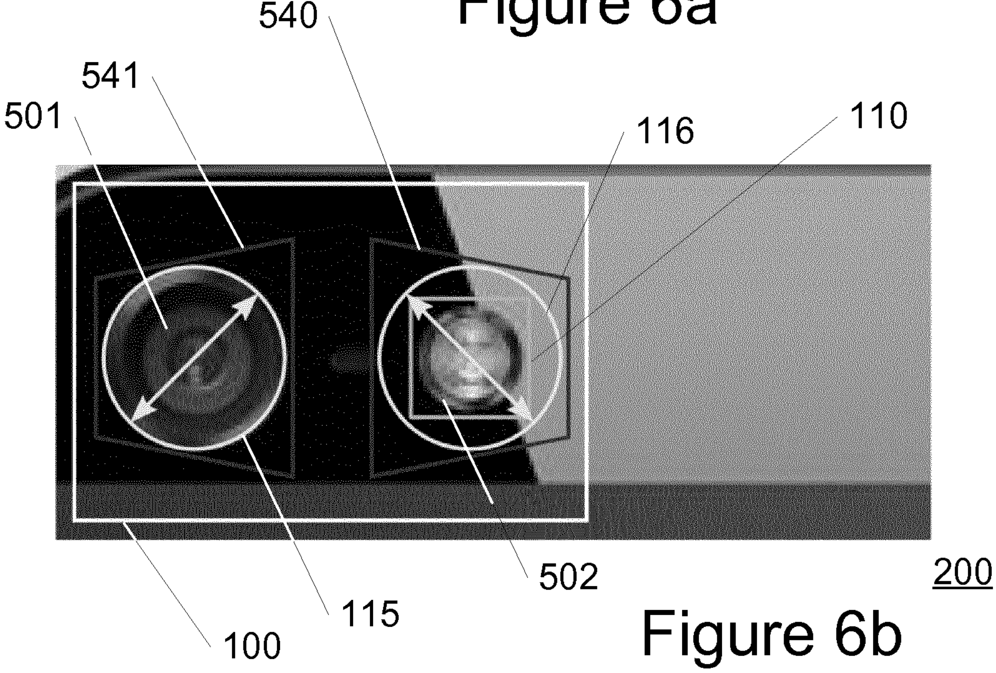


Figure 6b

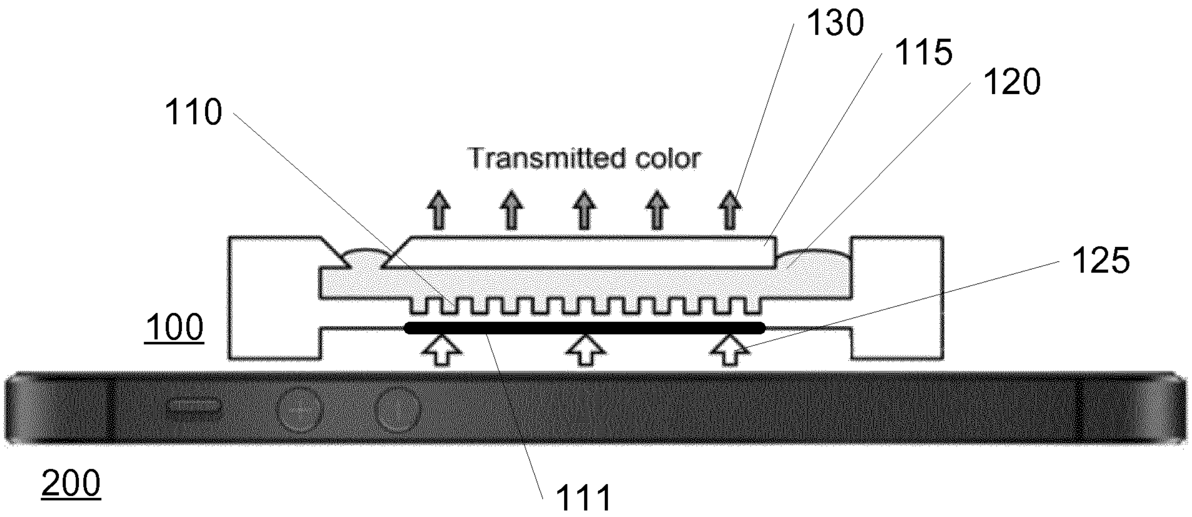


Figure 7

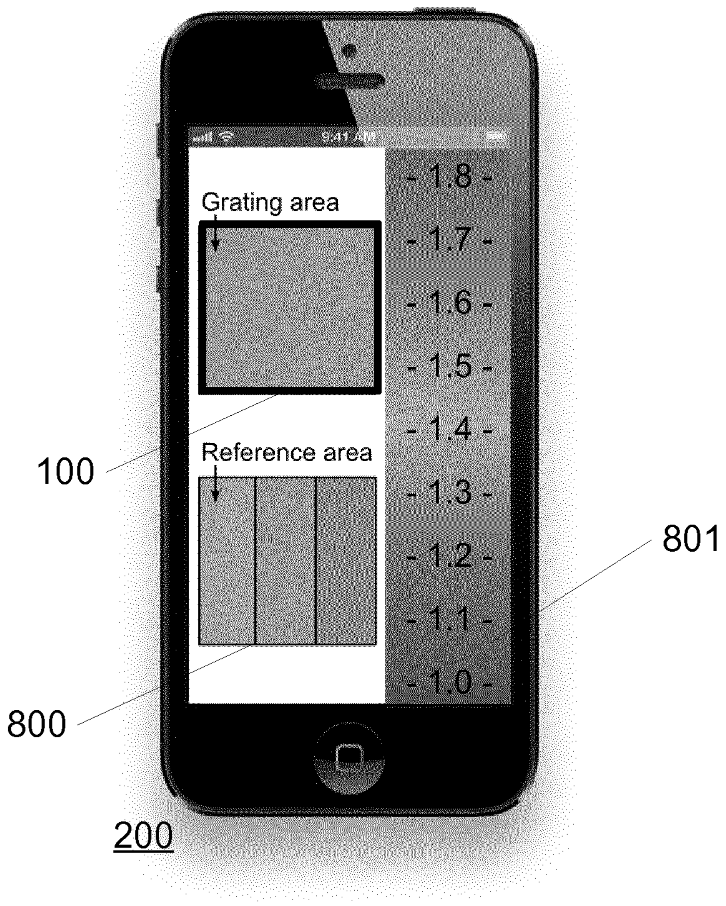
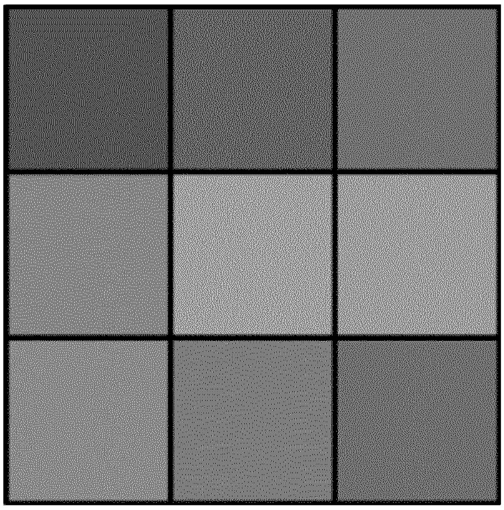
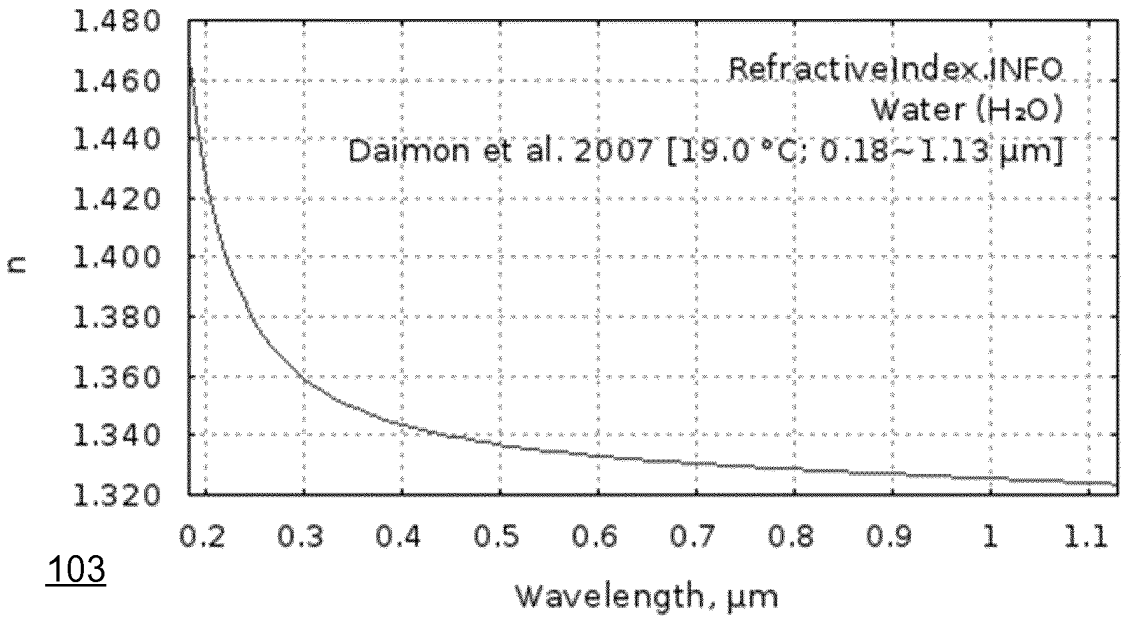


Figure 8



102



103

Figure 9

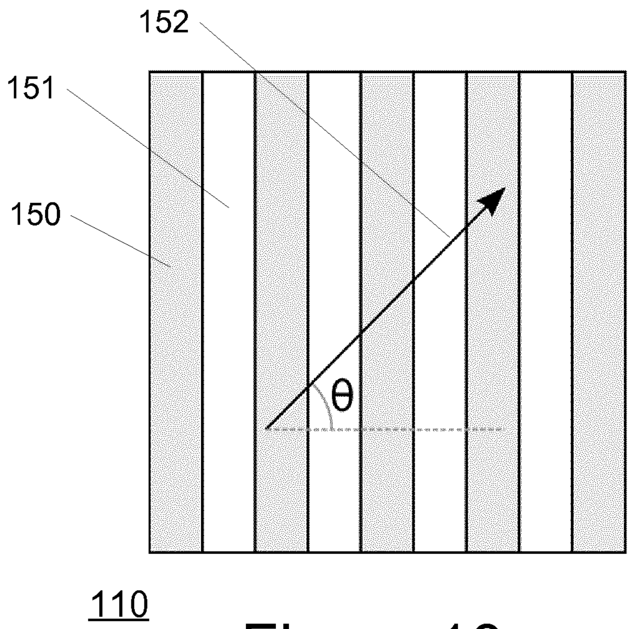


Figure 10

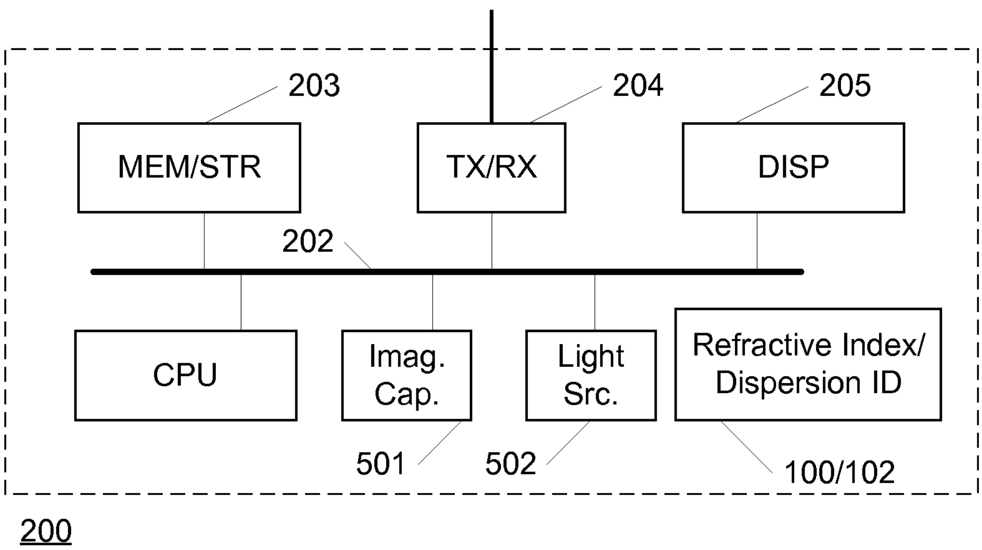


Figure 11

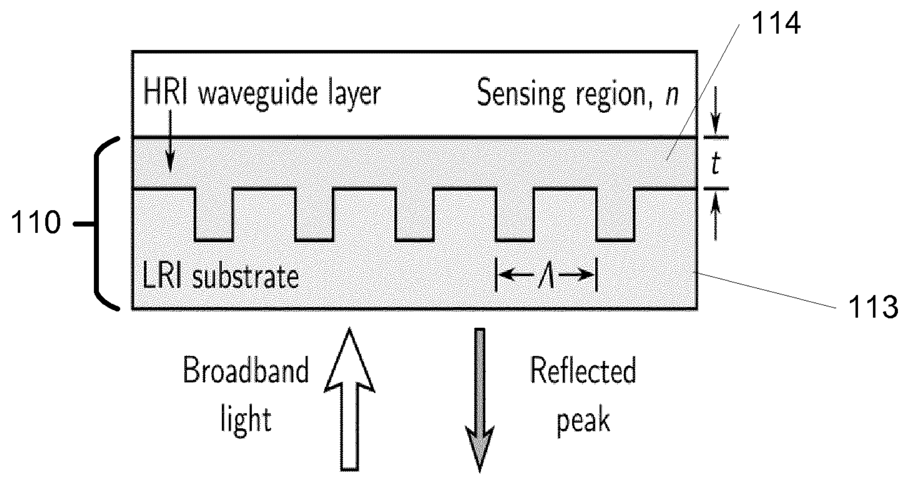

114
HRI waveguide layer
Sensing region, n
t
110
LRI substrate
Λ
113
Broadband light
Reflected peak

Figure 12

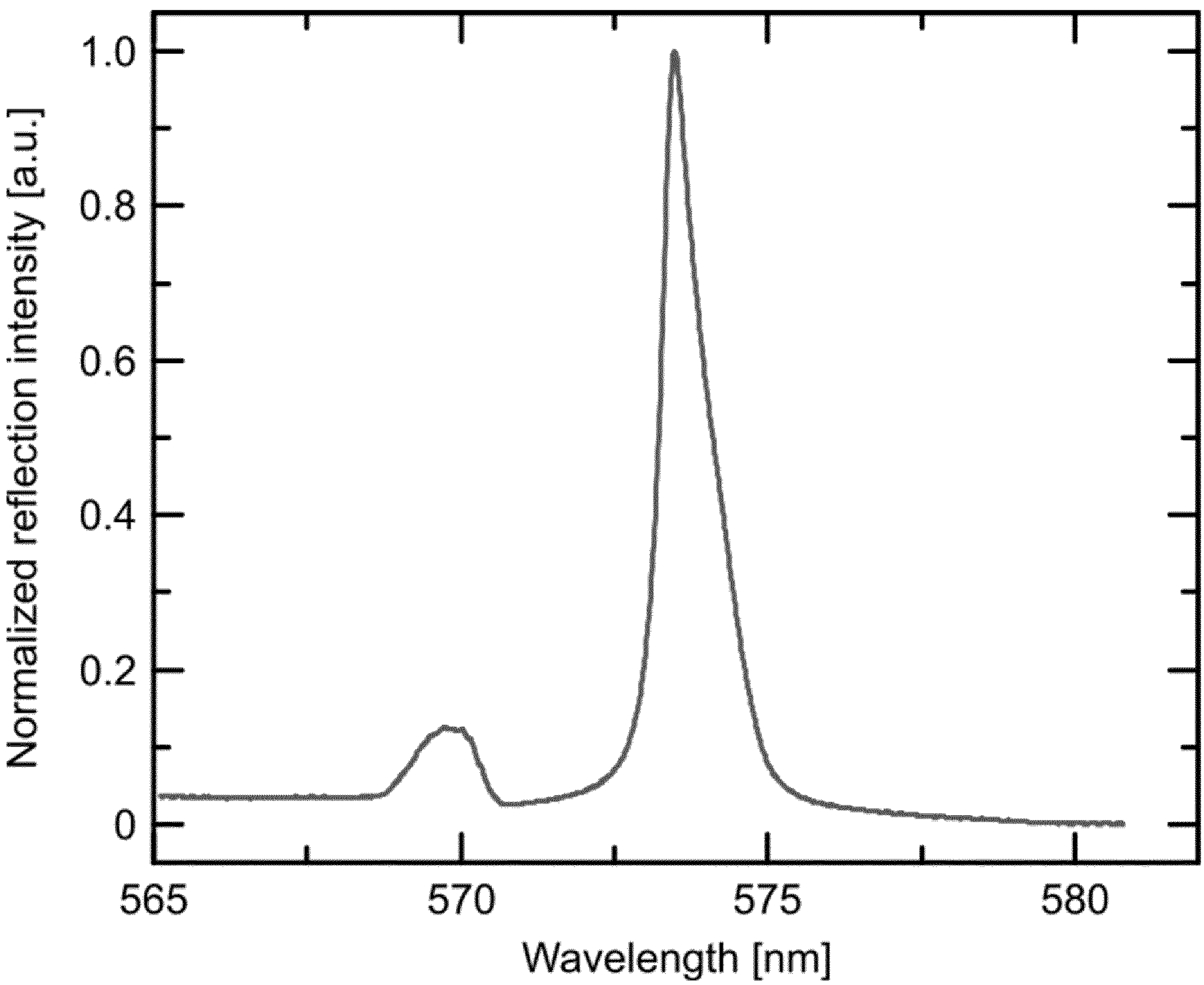

1.0
0.8
0.6
0.4
0.2
0
Normalized reflection intensity [a.u.]
565
570
575
580
Wavelength [nm]

Figure 13

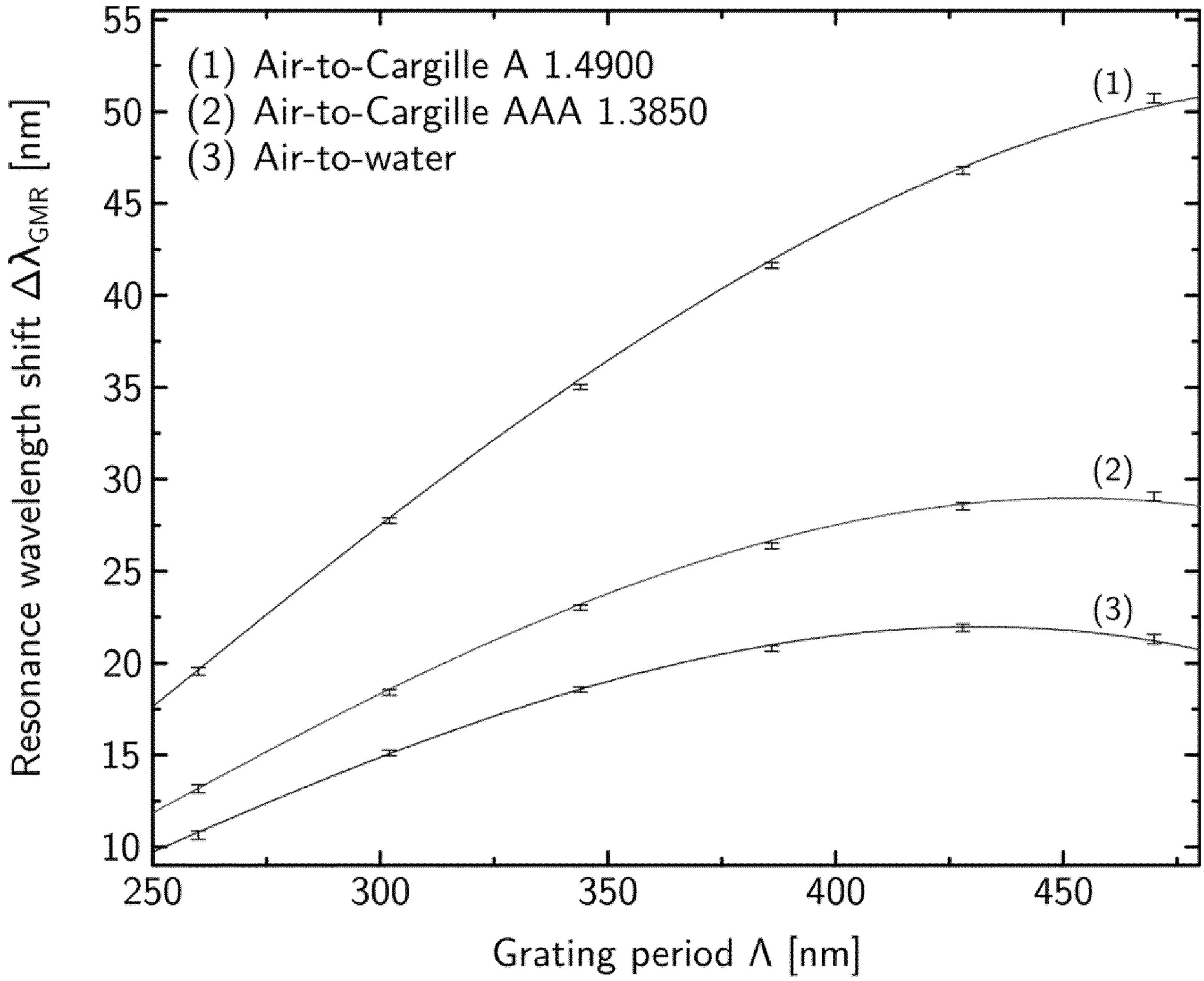

55
50
45
40
35
30
25
20
15
10
250
300
350
400
450
(1) Air-to-Cargille A 1.4900
(2) Air-to-Cargille AAA 1.3850
(3) Air-to-water
(1)
(2)
(3)
Resonance wavelength shift $\Delta\lambda_{GMR}$ [nm]
Grating period Λ [nm]

Figure 14

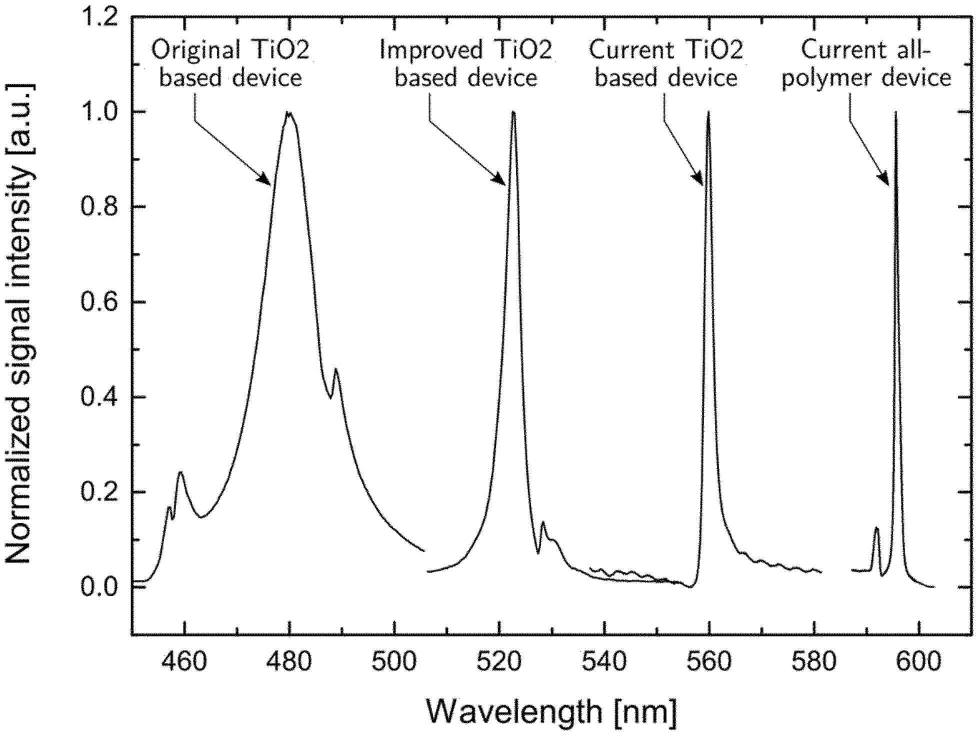

Original TiO2 based device
Improved TiO2 based device
Current TiO2 based device
Current all-polymer device
Normalized signal intensity [a.u.]
Wavelength [nm]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
460
480
500
520
540
560
580
600

Figure 15

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/057881

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N21/41
ADD.

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 practicable, 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 2009/079976 A1 (CUNNINGHAM BRIAN T [US] ET AL) 26 March 2009 (2009-03-26)	1-7,9-12
Y	paragraphs [0027], [0028], [0058] - [0060], [0073], [0079]; figures 1A,4	8,13
X	DE 40 38 791 A1 (FRAUNHOFER GES FORSCHUNG [DE]) 8 August 1991 (1991-08-08) column 3, line 44 - column 4, line 43; figure 2	1,5,9,11
X	US 5 610 392 A (NAGAYAMA KUNIAKI [JP] ET AL) 11 March 1997 (1997-03-11) cited in the application abstract; column 2, line 24 - line 31; figure 1	1,5,9,11

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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

"E" earlier application or patent but published on or after the international filing date

"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)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"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

"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

"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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 June 2015	14/07/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Weinberger, Thorsten

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2011/207137 A1 (MALIK IMRAN R [US] ET AL) 25 August 2011 (2011-08-25) paragraphs [0014], [0019]; figure 1 -----	1,9
A	US 2006/279732 A1 (WANG SEAN X [US] ET AL WANG SEAN XIAOLU [US] ET AL) 14 December 2006 (2006-12-14) paragraphs [0042], [0048]; figure 5a -----	1,9
Y	US 7 715 005 B2 (EMMERSON GREGORY DANIEL [GB] ET AL) 11 May 2010 (2010-05-11) column 8, line 6 - line 65; figure 3 -----	8,13
T	ROSENBLATT D ET AL: "RESONANT GRATING WAVEGUIDE STRUCTURES", IEEE JOURNAL OF QUANTUM ELECTRONICS, IEEE SERVICE CENTER, PISCATAWAY, NJ, USA, vol. 33, no. 11, 1 November 1997 (1997-11-01), pages 2038-2059, XP000725006, ISSN: 0018-9197, DOI: 10.1109/3.641320 the whole document -----	

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2015/057881

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			DE	69421844	T2	29-06-2000
			EP	0622624	A1	02-11-1994
			US	5610392	A	11-03-1997
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			WO	2006127840	A2	30-11-2006
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			AU	2005263893	A1	26-01-2006
			CA	2573097	A1	26-01-2006
			EP	1774290	A1	18-04-2007
			ES	2336466	T3	13-04-2010
			IL	180287	A	30-06-2011
			JP	4699459	B2	08-06-2011
			JP	2008506940	A	06-03-2008
			US	2008204747	A1	28-08-2008
			WO	2006008447	A1	26-01-2006