



(51) International Patent Classification:

A61B 3/16 (2006.01) G02C 7/04 (2006.01)
G02B 1/04 (2006.01)

(21) International Application Number:

PCT/EP2017/057139

(22) International Filing Date:

27 March 2017 (27.03.2017)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

16163369.8 31 March 2016 (31.03.2016) EP

(71) Applicant: **KONINKLIJKE PHILIPS N.V.** [NL/NL];
High Tech Campus 5, 5656 AE Eindhoven (NL).

(72) Inventors: **DELLIMORE, Kiran, Hamilton, J.**; High
Tech Campus 5, 5656 AE Eindhoven (NL). **KARAKAYA,**
Koray; High Tech Campus 5, 5656 AE Eindhoven (NL).
VALSTER, Susanne, Maaik; High Tech Campus 5,
5656 AE Eindhoven (NL). **VAN LIESHOUT, Ron, Mar-**
tinus, Laurentius; High Tech Campus 5, 5656 AE Eind-
hoven (NL).

(74) Agents: **LEDEBOER, Johannes, Albertus** et al.; High
Tech Campus 5, 5656 AE Eindhoven (NL).

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN,
KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA,
MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG,
NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS,
RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY,
TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN,
ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,
TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU,
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,
LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— as to applicant's entitlement to apply for and be granted a
patent (Rule 4.17(ii))

[Continued on next page]

(54) Title: A CONTACT LENS, A SYSTEM AND A METHOD OF MEASURING A PHYSIOLOGICAL CHARACTERISTIC OF AN EYE OF A SUBJECT

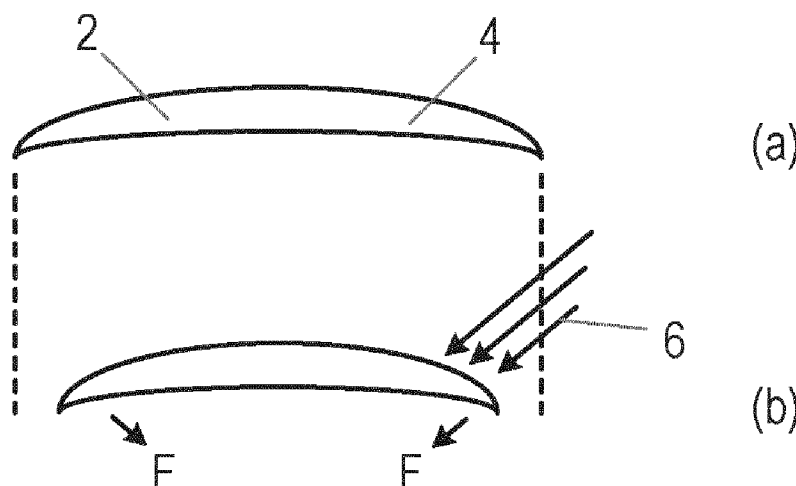


Figure 2

(57) Abstract: There is provided a contact lens for use in measuring a physiological characteristic of an eye of a subject; the contact lens comprising a first material, wherein the first material is such that a property of the first material changes in response to incident light, and wherein the first material is arranged such that, when the contact lens is worn on the eye and light is incident on the first material, the contact lens applies a force to the eye.



Published:

— *with international search report (Art. 21(3))*

A contact lens, a system and a method of measuring a physiological characteristic of an eye of a subject

TECHNICAL FIELD OF THE INVENTION

The invention relates to a contact lens for use in measuring a physiological characteristic of an eye of a subject and a system and a method of measuring a physiological characteristic of an eye of a subject.

5

BACKGROUND TO THE INVENTION

Ocular hypertension is a common problem, which involves an elevation of the pressure of the fluid in the eye, i.e. aqueous humor. Aqueous humor (or aqueous fluid) is the clear fluid that is produced in the eye by the ciliary body and it drains from the eye through a structure called the trabecular meshwork. This body is located in the periphery of the anterior chamber, where the cornea and iris meet. The ocular pressure is typically referred to as the intraocular pressure (IOP) and is linked to the build up of aqueous fluid. Elevated IOP is of great concern because it can lead to optic nerve damage and is the clinically established risk factor for the development of glaucoma (i.e., a condition of increased pressure within the eyeball, causing gradual loss of sight) or even to permanent vision loss. Normal (i.e. healthy) IOP ranges between 10-21 mm Hg, while ocular hypertension is diagnosed if the IOP is > 21 mmHg in one or both eyes (measured on 2 or more occasions). However, there can be a significant diurnal variation in the IOP throughout the course of a day which can make diagnosing ocular hypertension and glaucoma challenging.

20

Elevation in the pressure of the aqueous humor, leading to ocular hypertension, can occur as a result of several factors:

1. Excessive aqueous humor production – If the ciliary body produces too much aqueous fluid, the pressure in the eye increases, causing an increase in IOP.
2. Inadequate aqueous drainage – Too slow drainage of aqueous fluid from the eye disrupts the normal balance of production and drainage of the eye's clear fluid which can lead to high eye pressure.

25

3. Side effects of certain medications – e.g. Steroid medicines (including eye drops) used to treat asthma and other conditions have been shown to increase the risk for ocular hypertension.

4. Eye trauma – Blunt or chemical injury to the eye can affect the balance of aqueous production and drainage from the eye, leading to ocular hypertension. Sometimes this can occur months or even years after the injury has occurred.

5. Other eye conditions and diseases – e.g., pseudoexfoliation syndrome, pigment dispersion syndrome, uveitis and corneal arcus.

6. Other factors – Race, age, gender and family history (genetics) are significant risk factors for ocular hypertension. In addition, individuals with thinner-than-normal central corneal thickness measurements may be at greater risk of ocular hypertension and glaucoma.

Several methods are currently used to measure IOP, including applanation tonometry, Goldmann tonometry, Perkins tonometry, dynamic contour tonometry, electronic indentation tonometry, rebound tonometry, pneumatonometry, impression tonometry, non-corneal and transpalpebral tonometry, non-contact tonometry, ocular response analysis and palpation. However, a major disadvantage of all of these methods is that they require the involvement of an expert operator, typically an ophthalmologist. The ‘gold standard’ and most widely used method is Goldmann tonometry which involves measurement of the amount of force needed to temporarily flatten (i.e. applanate) part (e.g. an area of 3.06 mm²) of the cornea. Typically 5.5g (55 mN) is applied to produce corneal indentation, with up to 15g (150 mN) applied in some cases. This is accomplished by gently placing a disinfected prism mounted on a tonometer head against the cornea, which is then observed by the examiner using a cobalt blue filter to view two green semi circles. The force applied to the tonometer head is then adjusted using a dial connected to a variable tension spring until the inner edges of the green semicircles in the viewfinder meet. When an area of 3.06 mm² has been flattened, the opposing forces of corneal rigidity and the tear film are roughly approximate and cancel each other out allowing the IOP in the eye to be determined from the force applied based on the Imbert-Fick law:

$$\text{IOP} = (\text{Force [N]} / \text{Area of contact [m}^2]) * 0.0075 \text{ (mmHg/Nm}^{-2}) \quad (\text{Equation 1})$$

However, recently, several new approaches have been developed for making less-obtrusive measurements of IOP, while also not requiring the involvement of an ophthalmologist. One such technique is non-contact air puff tonometry. This works by

measuring the time from the generation of an air puff until the cornea is flattened or
applanated, which is detected via an electro-optical system. Higher IOP is indicated by a
longer time taken to flatten the eye. Historically, non-contact tonometers have two
drawbacks: 1) they require topical anaesthesia administration, and 2) they are not considered
5 to be an accurate way to measure IOP but instead a fast and simple way to screen for high
IOP. However, modern non-contact tonometers have been shown to correlate well with
Goldmann tonometry measurements and are particularly useful for measuring IOP in children
and other non-compliant patient groups. A variation of the non-contact air puff tonometer is
the ocular response analyzer which does not require topical anaesthesia and provides
10 additional information on the biomechanical properties of the cornea. It uses an air pulse to
deform the cornea into a slight concavity. The difference between the pressures at which the
cornea flattens inward and outward is measured by the machine.

SUMMARY OF THE INVENTION

15 Despite the conventional apparatus described above, there remains a need for a
simple and unobtrusive apparatus and technique for measuring IOP, and other physiological
characteristics of the eye.

According to a first aspect, there is provided a contact lens for use in
measuring a physiological characteristic of an eye of a subject; the contact lens comprising a
20 first material, wherein the first material is such that a property of the first material changes in
response to incident light, and wherein the first material is arranged such that, when the
contact lens is worn on the eye and light is incident on the first material, the contact lens
applies a force to the eye. Thus, the contact lens enables a force to be applied to the eye of the
subject in a relatively unobtrusive manner, since the contact lens, which is already generally
25 unobtrusive for the wearer, can be actuated to generate the force through the use of light.

In some embodiments, the property of the first material changes in response to
incident light having a particular wavelength or wavelengths. This has the advantage that the
application of the force by the contact lens will only be triggered by light of the particular
wavelength or wavelengths.

30 In some embodiments, the property of the first material that changes in
response to incident light is the shape and/or size of the first material. In some embodiments,
the change in the size and/or shape of the first material is any of an increase in the size/length
of the first material when light is incident on the first material, a decrease in the size/length of
the first material when light is incident on the first material, an increase in the volume of the

first material when light is incident on the first material, or a decrease in the volume of the first material when light is incident on the first material. In some embodiments, the first material is a light-responsive polymer. In some embodiments, the light-responsive polymer is a nano-composite film, a liquid-crystalline elastomer, a polymer with liquid crystals, an azobenzene- or spiropyran- or Triphenylmethane-based system, salicylideneaniline, or a polypeptide-based system, or any combination thereof.

In alternative embodiments, the property of the first material that changes in response to incident light is the wettability of the first material. In some embodiments, the first material is a light-responsive polymer. In some embodiments, the light-responsive polymer is a polymer comprising or containing spiropyran moieties grafted onto membrane surfaces.

In some embodiments, the contact lens is formed entirely from the first material. This can make the contact lens easier to manufacture. In alternative embodiments, the contact lens comprises one or more regions or layers of the first material. These regions or layers can be arranged to provide a required force by the contact lens in response to incident light.

In some embodiments, the contact lens further comprises one or more regions of a hydrophilic material. In some embodiments, the one or more regions of the hydrophilic material are located on a side of the contact lens that is arranged to contact the eye. This has the advantage that the one or more regions of the contact lens will grip the liquid on the eye and improve the transfer of the force to the eye. In some embodiments, the contact lens further comprises one or more regions of a hydrophobic material. These one or more regions, in combination with the one or more regions of the hydrophilic material, can also improve the transfer of the force to the eye.

In some embodiments, the contact lens further comprises two or more visible markings, and wherein the visible markings are arranged so that the spacing therebetween changes when the contact lens is being used to apply the force to the eye. These embodiments have the advantage that the response of the eye to the applied force can be measured by observing the change in the spacing of the visible markings when the force is applied.

In some embodiments, the contact lens further comprises a radio frequency, RF, antenna. These embodiments have the advantage that an indication of the response of the eye to the applied force can be communicated from the RF antenna to an external reader device. In some embodiments, the RF antenna is arranged such that a characteristic of the RF antenna changes when the contact lens is being used to apply the force to the eye. These

embodiments have the advantage that the RF antenna is used to sense the response of the eye to the applied force, and no separate sensor for sensing the response of the eye is required.

According to a second aspect, there is provided a system for measuring a physiological characteristic of an eye of a subject, the system comprising a contact lens as described above; a light source; a measurement device for measuring the response of the eye to the applied force; and a control unit for analyzing the measured response of the eye to determine a measurement of the physiological characteristic. Thus, the system enables a force to be applied to the eye of the subject in a relatively unobtrusive manner through the use of light to actuate the contact lens, and a physiological characteristic of the eye can be measured from the response of the eye to the applied force.

In some embodiments, the measurement device is an imaging device that is configured to obtain one or more images of the eye and the contact lens.

In some embodiments, the control unit is configured to analyze the one or more images of the eye and the contact lens to determine a change in specular reflection from the surface of the contact lens when the force is applied to the eye by the contact lens.

In alternative embodiments, the contact lens further comprises two or more visible markings, and wherein the visible markings are arranged so that the spacing therebetween changes when the contact lens is applying the force to the eye, and wherein the control unit is configured to analyze the one or more images of the eye and the contact lens to determine a change in the spacing between the visible markings when the force is applied to the eye by the contact lens.

In alternative embodiments, the control unit is configured to analyze the one or more images of the eye and the contact lens to determine a change in an interference pattern for the contact lens due to differences in light reflection from the front and back of the contact lens when the force is applied to the eye by the contact lens.

In alternative embodiments, the contact lens further comprises a radio frequency, RF, antenna; the measurement device is a reader unit that is configured to receive a signal from the contact lens; and the control unit is configured to analyze the received signal to determine the measurement of the physiological characteristic.

According to a third aspect, there is provided a method of measuring a physiological characteristic of an eye of a subject, the method comprising illuminating a contact lens worn on the eye of the subject with light, wherein the contact lens comprises a first material and the first material is such that a property of the first material changes in response to the light, and wherein the first material is arranged such that the contact lens

applies a force to the eye in response to the light; measuring a response of the eye of the subject to the applied force; and determining a measurement of the physiological characteristic using the measured response. Thus, the method enables a force to be applied to the eye of the subject in a relatively unobtrusive manner through the use of light to actuate the contact lens, and a physiological characteristic of the eye can be measured from the response of the eye to the applied force.

In some embodiments, the step of measuring comprises obtaining one or more images of the eye and the contact lens.

In some embodiments, the step of determining the measurement of the physiological characteristic comprises analyzing the one or more images of the eye and the contact lens to determine a change in specular reflection from the surface of the contact lens when the force is applied to the eye by the contact lens.

In alternative embodiments, the contact lens further comprises two or more visible markings, and wherein the visible markings are arranged so that the spacing therebetween changes when the contact lens is applying the force to the eye, and wherein the step of determining the measurement of the physiological characteristic comprises analyzing the one or more images of the eye and the contact lens to determine a change in the spacing between the visible markings when the force is applied to the eye by the contact lens.

In alternative embodiments, the step of determining the measurement of the physiological characteristic comprises analyzing the one or more images of the eye and the contact lens to determine a change in an interference pattern for the contact lens due to differences in light reflection from the front and back of the contact lens when the force is applied to the eye by the contact lens.

In alternative embodiments, the contact lens further comprises a radio frequency, RF, antenna; the step of measuring comprises receiving a signal from the contact lens; and the step of determining the measurement of the physiological characteristic comprises analyzing the received signal to determine the measurement of the physiological characteristic.

More generally, the contact lens can be as described in any of the embodiments of the first aspect described above.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention, and to show more clearly how it may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings, in which:

5 Figure 1 is an illustration of a contact lens according to the invention;

 Figure 2 is an illustration of the use of a contact lens according to the invention to apply force;

 Figure 3 is an illustration of a contact lens according to a first specific embodiment;

10 Figure 4 is an illustration of a contact lens according to a second specific embodiment;

 Figure 5 is an illustration of a contact lens according to a second specific embodiment;

15 Figure 6 is a flow chart illustrating a method of measuring a physiological characteristic of an eye of a subject according to the invention;

 Figure 7 is an illustration of a first exemplary system for measuring a physiological characteristic of an eye of a subject;

 Figure 8 is an illustration of a second exemplary system for measuring a physiological characteristic of an eye of a subject;

20 Figure 9 is an illustration of a contact lens comprising an antenna according to an exemplary embodiment; and

 Figure 10 is a flow chart illustrating a method of measuring a physiological characteristic of an eye of a subject according to an embodiment.

25 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As noted above, despite the various different types of conventional apparatus that are available, measuring intraocular pressure (IOP) remains a generally obtrusive process for the subject. In particular, to measure IOP it is necessary in several techniques and apparatus to apply a force to the eye (for example via an air puff or pressing a prism against
30 the eye), and this force is applied in a relatively obtrusive way.

The invention provides a contact lens that can be used to apply a force to an eye of a subject for the purposes of measuring IOP, or for measuring any other physiological characteristic of the eye in which a force is to be applied to the eye to make the measurement. As is known, a contact lens (or a pair of contact lenses) can generally be worn relatively

unobtrusively by a subject for a significant length of time (e.g. for several hours or even days), and the contact lens according to the invention is configured so that a force can be selectively applied by the contact lens when an IOP (or other physiological characteristic) measurement is to be made. Since the force required to make the IOP measurement is relatively small, the IOP measurement can be made almost or completely unobtrusively for the subject.

Figure 1 illustrates a contact lens 2 according to a general embodiment of the invention. Figure 1(a) shows a front view of the contact lens 2 and Figure 1(b) shows a side view of the contact lens 2. The term “contact lens” should be understood to refer to any device that is suitable for wearing in or on the eye for an extended period of time. It should be appreciated that contact lenses according to embodiments of the invention are preferably, but need not be, transparent. The contact lens 2 is generally circular with a concave curvature configured to contact a corneal surface of an eye.

In accordance with the invention, to enable the contact lens 2 to be used to apply a force to the eye, the contact lens 2 comprises a material 4 that is responsive to light. In particular, the material 4, which is also referred to herein as a ‘first’ material, is responsive to light in the sense that a property of the material 4 changes when light is incident on the contact lens 2. The property of the material 4 that changes should be a property that can lead to a force or strain being generated by the contact lens 2. In some embodiments, the first material 4 can be responsive to a particular wavelength or wavelengths of light (so the property of the material 4 only changes when light of a particular wavelength or wavelengths illuminates the material 4).

In some embodiments, the material 4 is responsive to light with a wavelength between 400-475 nm, e.g. in the blue/violet part of the visible spectrum. In other embodiments, the material 4 is responsive to light with a wavelength corresponding to the green and/or red (or infra-red) parts of the spectrum. It will be appreciated that the wavelength or wavelengths of light that the material 4 is responsive to can depend on the specific nature/type and/or configuration of the material 4.

In some embodiments, the property of the material 4 that changes in response to incident light can be the shape and/or size of the material 4. Therefore, illuminating the contact lens 2 (and in particular the first material 4 in the contact lens 2) with light (or light of a particular wavelength or wavelengths) can cause the shape and/or size of the material 4 to change in response to light, which can apply a force to the eye of the subject. In some embodiments, depending on the type and/or configuration of the first material 4, the change

in the size and/or shape of the material 4 can be any of an increase in the size/length of the material 4 when light is incident on the first material 4, a decrease in the size/length of the material 4 when light is incident on the first material 4, an increase in the volume of the material 4 when light is incident on the first material 4, or a decrease in the volume of the material 4 when light is incident on the first material 4.

Figure 2 is an illustration of the use of a contact lens 2 according to the invention to apply force. In Figure 2(a) the contact lens 2 is in a 'relaxed' state, i.e. the contact lens 2, when worn by a subject, does not apply any force, or any appreciable force, to the eye of the subject. In this state, light of the particular wavelength or wavelengths is not incident on the contact lens 2 (or light at the particular wavelength or wavelengths is incident on the contact lens 2 but below an intensity level required to actuate the first material 4). As shown in Figure 2(b), when light 6 at the particular wavelength or wavelengths is incident on the contact lens 2 (or light at the particular wavelength or wavelengths is incident on the contact lens 2 with an intensity above a minimum threshold), the shape and/or size of the first material 4 changes so that the shape of the contact lens 2 moves into a 'force' state in which the contact lens 2 applies a force F to the eye. In the embodiment shown in Figure 2(b) the change in the shape and/or size of the first material 4 results in a contraction in the diameter of the contact lens 2 and the eye being squeezed by the contact lens 2. However, it will be appreciated that the effect of the change in size and/or shape of the first material 4 on the shape of the contact lens 2 can depend on the arrangement or configuration of the first material 4 in the contact lens and the nature of the change in size and/or shape of the first material 4 in response to the incident light.

The change in size and/or shape from the state shown in Figure 2(a) to the state shown in Figure 2(b) can be relatively instantaneous, or take up to a few seconds, depending on the nature/type and/or configuration of the first material 4.

In some embodiments, the first material 4 can be a light-responsive polymer, i.e. a polymer that is responsive to light. For example, the light-responsive polymer can be a nano-composite film, a liquid-crystalline elastomer, another form of polymer with liquid crystals, an azobenzene- or spiropyran- or Triphenylmethane-based system, salicylideneaniline, or a polypeptide-based system, or any combination thereof.

In some alternative embodiments, the property of the material 4 that changes in response to incident light is the wettability of the material 4. Therefore, illuminating the contact lens 2 (and in particular the first material 4 in the contact lens 2) with light (or light of a particular wavelength or wavelengths) can cause the wettability of the material 4 to change

in response to light, which can apply a force to the eye of the subject. Good wettability is important for force transfer between the contact lens 2 and the eye. In particular, the material 4 can be such that the incident light changes the surface of the contact lens 2 such that it switches between hydrophilic and hydrophobic states, and the switching between these two states will enable a stable, reproducible contact between the eye and the contact lens 2.

In these alternative embodiments, the first material 4 can be a light-responsive polymer, for example a polymer comprising or containing spiropyran moieties grafted onto membrane surfaces, which exhibit reversible wettability-switching and protein adhesion.

It will be appreciated that the first material 4 can have a known response to incident light, and therefore the force applied by the contact lens 2 to the eye can be controlled through the selective illumination of the contact lens 2 with light.

A contact lens 2 according to the invention shown in Figures 1 and 2 can be used to apply a force of the order of 5-200 milliNewtons (mN) to the eye. This amount of force is sufficient to measure IOP, since in Goldmann tonometry forces in the region of 55mN and 150mN are used.

It will also be appreciated that the first material 4 may be such that on removal of the incident light, the property of the first material 4 reverts to an original value or state (e.g. an original size and/or shape or wettability). Alternatively, the first material 4 may be such that the property of the first material 4 reverts to an original value or state (e.g. an original size and/or shape or wettability) on application of light of a different wavelength, or white light.

In some embodiments, the contact lens 2 can be formed entirely from the first material 4, but in other embodiments the contact lens 2 can be formed partly from the first material 4, and partly from one or more other materials. These other materials can be materials that are conventionally used to construct and form contact lenses. For example the other materials can include a silicone hydrogel. Where the contact lens 2 is partly formed from the first material 4, the contact lens 2 can comprise one or more regions of first material 4, and/or the contact lens 2 can comprise one or more layers of first material 4 within the structure of the contact lens 2.

Figure 3 illustrates a contact lens 2 according to a first specific embodiment of the invention. In this embodiment, the contact lens 2 comprises a plurality of regions 8 made from the first material 4. The rest of the contact lens 2 is formed from a second material (e.g. a conventional material used in contact lenses). In the illustrated embodiment, the contact lens 2 comprises eight regions 8 of the first material 4 spaced generally evenly around the

contact lens 2. In this embodiment, when light is incident on the first material 4, the first material 4 reduces in size and results in the diameter of the contact lens 2 being reduced, as indicated by arrows 10. This reduction in size squeezes the eye behind/underneath the contact lens 2 (i.e. applies a force to the eye). Those skilled in the art will appreciate that the arrangement shown in Figure 3 is merely exemplary, and other arrangements and configurations of the first material 4 can be used.

In some embodiments, to improve the application of the force from the contact lens 2 to the eye, the contact lens 2 can comprise one or more regions of a hydrophilic material. The one or more regions of hydrophilic material can be located at least on the side of the contact lens 2 that is in contact with the eye during use. As the surface of the eye is covered with a liquid (the tear film), the hydrophilic material will therefore grip the liquid and thus the eye more than a hydrophobic material (which would repel the liquid). It will be appreciated that the hydrophilic material and the first material 4 can be located in different parts of the contact lens 2 or in different layers of the contact lens 2. In some embodiments, the first material 4 can be a hydrophilic material.

An exemplary embodiment of a contact lens 2 comprising a hydrophilic material is shown in Figure 4. In this embodiment, the contact lens 2 comprises a first material 4 as described above, and a region 12 of hydrophilic material arranged around the periphery of the contact lens 2. Region 12 is shown as an annulus in Figure 4, but it will be appreciated that region 12 can take other shapes, and/or multiple regions 12 can be provided. Thus, in this embodiment, when the first material 4 is illuminated with light and the first material 4 causes the contact lens 2 to contract to apply a force, the annulus 12 of hydrophilic material improves the grip of the contact lens 2 to the eye, and thereby improves the application of the force to the eye.

In some embodiments, the contact lens 2 can also include one or more regions 14 of hydrophobic material in addition to the one or more regions 14 of hydrophilic material. In the embodiment shown in Figure 4, the region 14 is located in the center of the contact lens 2, but it will be appreciated that the region 14 can take different shapes and/or locations as desired.

Another exemplary embodiment of a contact lens 2 comprising a hydrophilic material is shown in Figure 5. In this embodiment, the contact lens 2 comprises a plurality of regions 16 of hydrophilic material that are interspersed with a plurality of regions 18 of hydrophobic material.

Figure 6 illustrates a method of measuring a physiological characteristic of an eye of a subject according to an embodiment of the invention. This method measures a physiological characteristic of the eye using any of the contact lenses 2 described above. In preferred embodiments, the physiological characteristic is the IOP of the eye. However, in other embodiments, the physiological characteristic is a property of the tear film on the eye, for example the stability of the tear film, a volume of the tear film, a thickness of the tear film, a change in the thickness of the tear film, a thickness or relative thickness of one or more particular layers of the tear film (e.g. lipid layer, intermediate layer or mucin layer), a change in the thickness or relative thickness of one or more particular layers of the tear film, the recovery of the tear film following the application of a force, a rheological property of the tear film, the viscosity of the tear film, or the break-up of the tear film.

In a first step, step 101, a contact lens 2 worn on the eye of the subject is illuminated with light. As described above, the contact lens 2 comprises a first material 4 and the first material 4 is such that a property of the first material 4 changes in response to the light. The light may be of a particular wavelength or a wavelength selected from a range of particular wavelengths, and causes the contact lens 2 to apply a force to the eye.

Once the force is applied to the eye, a response of the eye to the applied force is measured (step 103). Various embodiments of step 103 are described in more detail below, but briefly, a measurement device is provided that is able to measure the response of the eye to the applied force. In some embodiments the measurement device comprises an imaging device that can be used to obtain images of the eye and contact lens 2, and the images are processed to identify changes in specular reflection and/or an interference pattern indicative of the response of the eye to the applied force. In other embodiments, the contact lens 2 can comprise a radio frequency (RF) antenna that is arranged in the contact lens 2 such that the strain in the antenna wire is changed by the shape of the eye, and a signal from the RF antenna can be measured by the measurement device and processed to determine the response of the eye to the applied force.

Once the response of the eye to the applied force is measured, a measurement of the physiological characteristic, e.g. IOP, is determined using the measured response (step 105). This step can be performed by a control unit that receives the measurement of the response of the eye to the applied force from the measurement device.

Figure 7 is an illustration of a first exemplary system for measuring a physiological characteristic of an eye of a subject in which the method of Figure 6 can be implemented. The system comprises a contact lens 2 as described above that is to be worn on

the eye 20 of a subject (it will be appreciated that the contact lens 2 is shown as spaced from the eye 20 in Figure 7 simply for ease of illustration), a light source 22 that is for emitting light towards the contact lens 2 in order to change the property of the first material 4 in the contact lens 2 and thereby apply a force to the eye 20. The light source 22 can be configured to emit light at any required wavelength, and where the first material 4 is responsive to a particular wavelength or wavelengths of light, the light source 22 can be configured to emit light at one of those particular wavelengths. The light source 22 can be any suitable type of light source, including one or more lasers or light emitting diodes, LEDs.

In some embodiments, the light source 22 can be configured to be used in the vicinity of (i.e. near) the contact lens 2, e.g. within 10cm of the contact lens 2 or less. In other embodiments, the light source 22 can be configured to be used some distance from the contact lens, e.g. more than 10cm from the contact lens 2.

The light from the light source 22 can be coupled to the contact lens 2, or to a relevant part of the contact lens 2, using an optical waveguide, e.g. an optical fiber. In the case of an optical fiber, there can be appropriate light coupling (e.g. side coupling) to the contact lens 2. Where the light source 22 is used further from the contact lens 2, a 'grating' can be provided that can couple the light to the contact lens 2.

The system also comprises a measurement device in the form of an imaging device 24 that is for obtaining one or more images of the eye and contact lens 2. The imaging device 24 can obtain images before, during and after the force has been applied to the eye 20 by the contact lens 2. The imaging device 24 can be a camera, or any other type of light sensitive apparatus.

Although not shown in Figure 7, the system also comprises a control unit that is connected to the imaging device 24 and that analyses the image or images obtained by the imaging device 24 to determine the physiological characteristic. The control unit may also control the light source 22 to emit light in order to initiate the measurement of the physiological characteristic. The control unit may be provided in the same device as the imaging device 24, or it may be provided in a separate component of the system.

The control unit can be implemented in numerous ways, with software and/or hardware, to perform the required function(s). The control unit may comprise one or more microprocessors that may be programmed using software to perform the required functions. The control unit may be implemented as a combination of dedicated hardware to perform some functions and a processor (e.g., one or more programmed microprocessors and associated circuitry) to perform other functions. Examples of controller components that may

be employed in various embodiments of the present disclosure include, but are not limited to, conventional microprocessors, application specific integrated circuits (ASICs), and field-programmable gate arrays (FPGAs).

In some embodiments, the control unit analyses the images to identify changes in specular reflection from the surface of the contact lens 2, i.e. changes in the reflection of light from the smooth surface of the contact lens 2. In particular the control unit determines a measure of the specular reflection from the contact lens 2 before the force is applied and a measure of the specular reflection from the contact lens 2 while the force is being applied. The amount of change in the specular reflection from the relaxed state to the force-applying state provides an indication of the physiological characteristic to be measured. For example, where the physiological characteristic is IOP, the amount of change in the specular reflection from the relaxed state to the force-applying state provides an indication of the IOP. Higher IOP will lead to a smaller change in specular reflection (i.e. due to less deformation of the eye 20 when the force is applied caused by high IOP). Therefore, the determined change in the specular reflection from the relaxed to the force-applying state can be compared to one or more threshold values to determine whether the determined change corresponds to a high, low, or healthy value of the IOP. The threshold values can be specific to the subject, or based on averages of a population of healthy/unhealthy subjects.

In some embodiments, specular reflection can be detected using slit-lamp photography or biomicroscopy of the ocular surface (which is sometimes used in clinical practice for assessing corneal damage, etc.).

As an alternative to identifying changes in specular reflection, the contact lens 2 can be provided with two or more visible lines or other markings thereon and the control unit can analyze the images of the contact lens 2 to determine the distance/spacing between the lines or other markings. The change in the spacing from the relaxed state to the force-applying state (which is generally a decrease in the spacing if the contact lens 2 contracts to apply the force) provides an indication of the physiological characteristic to be measured. The change in the spacing between the lines can be monitored as a function of the applied force. In the case of IOP, as noted above high or higher IOP results in less deformation of the eye 20 for a given applied force compared to lower IOP, which leads to a smaller decrease in spacing between the lines when the force is applied.

In some embodiments, it is possible to determine an absolute value for IOP by applying two different amounts of force to the eye of the subject and measuring the response of the eye (e.g. the change in the specular reflection or the change in line spacing) for each

force. The difference in the responses for each force can be correlated to an absolute value of IOP. Alternatively, since the change in the shape of the contact lens 2 is linked to the applied force (the magnitude of which is known), determining the change in shape of the contact lens 2 from the reflection measured from the lens surface or change in line spacing) can be used to
5 determine an absolute value of IOP.

In other embodiments, light interference can be used to determine the measurement of the physiological characteristic. In particular, changes of the interference (or wave propagation) pattern on the eye 20 and/or the contact lens 2 as a result of strain induced by the applied force can be determined by analyzing the images obtained by the imaging
10 device 24. This approach is based on the principle that leads to colors being visible on the surface of a soap bubble. For example colors are visible on a soap bubble as they arise from interference of light reflecting off the front and back surfaces of the thin soap film.

Depending on the thickness of the soap film, different colors interfere constructively and destructively. In a similar way, an interference pattern can be visible or otherwise measurable
15 on a contact lens 2 due to differences in light reflection from the front and back of the lens 2 under the strain induced by the applied force. In particular, applied strain results in changes in thickness of the contact lens 2 (where the changes are proportional to the Poisson's Ratio of the material). This change is measurable from an interference pattern, and conversely the interference pattern can be used for calculating the stress acting on the contact lens 2, and
20 hence calculate the IOP.

Figure 8 is an illustration of a second exemplary system for measuring a physiological characteristic of an eye of a subject in which the method of Figure 6 can be implemented. The system comprises a contact lens 2 as described above that is to be worn on the eye 20 of a subject (it will be appreciated that the contact lens 2 is shown as spaced from
25 the eye 20 in Figure 8 simply for ease of illustration), a light source 22 that is for emitting light towards the contact lens 2 in order to change the property of the first material 4 in the contact lens 2 and thereby apply a force to the eye 20. The light source 22 can be configured to emit light at any required wavelength, and where the first material 4 is responsive to a particular wavelength or wavelengths of light, the light source 22 can be configured to emit
30 light at one of those particular wavelengths. Embodiments of the light source 22 can be as described above with reference to Figure 7.

The system also comprises a measurement device in the form of a reader unit 26 that is for obtaining measurements of the strain in the contact lens 2. The reader unit 26 can obtain measurements of the strain before, during and after the force has been applied to

the eye 20 by the contact lens 2. The reader unit 26 can be any type of device that has a radio frequency (RF) antenna for receiving a signal transmitted from the contact lens 2. In some embodiments, the reader unit 26 can also comprise a transmitter for transmitting an interrogation signal to the contact lens 2 to cause the contact lens 2 to transmit a signal to the reader unit 26.

Although not shown in Figure 8, the system also comprises a control unit that analyses the received signal to determine the strain and thus determine the physiological characteristic. The control unit might be part of the reader unit 26 or it might be a separate component of the system. The control unit may also control the light source 22 to emit light in order to initiate the measurement of the physiological characteristic. The control unit may be provided in the same device as the reader unit 26, or it may be provided in a separate component of the system.

The control unit can be implemented in numerous ways, with software and/or hardware, to perform the required function(s). The control unit may comprise one or more microprocessors that may be programmed using software to perform the required functions. The control unit may be implemented as a combination of dedicated hardware to perform some functions and a processor (e.g., one or more programmed microprocessors and associated circuitry) to perform other functions. Examples of controller components that may be employed in various embodiments of the present disclosure include, but are not limited to, conventional microprocessors, application specific integrated circuits (ASICs), and field-programmable gate arrays (FPGAs).

In some embodiments the reader unit 26 is arranged to be worn on a body part of the subject. In some such embodiments the reader unit 26 comprises, or is attachable to, a pair of spectacles. In some embodiments the reader unit 26 comprises, or is attachable to, an item of wearable head gear, such as a head band, headphones, a hat, etc. In some embodiments the reader unit 26 comprises, or is attachable to, an item of gear arranged to be worn on a body part other than the head, such as a wrist band, watch, arm band, neck brace, necklace, etc. In other embodiments the reader unit 26 is a hand-held device. The reader unit 26 can be incorporated into a portable electronic device such as a smartphone or tablet computer.

In these embodiments, to enable the contact lens to transmit a signal to the reader unit 26, the contact lens further comprises an RF antenna. An exemplary contact lens 56 having a lens body 60 and an RF antenna 62 according to this embodiment is shown in Figure 9. Although not shown in Figure 9, it will be appreciated that the contact lens 56

comprises a first material 4 that can be used to apply a force to the eye 20 in response to incident light as described above. In accordance with this embodiment, the configuration of the RF antenna 62 (and thus the properties of a signal transmitted by the RF antenna 62) depend on the strain in the contact lens 56, and thus the signal from the RF antenna 62 relates to the IOP in the eye 20.

The RF antenna 62 can be in the form of a wire embedded in or fixedly mounted on the lens body 60. In such embodiments a change in the shape of the contact lens 56 to apply the force to the eye 20 causes an alteration of the strain experienced by the antenna wire. In some alternative embodiments the RF antenna 62 comprises a slotted patch antenna embedded in or fixedly mounted on the lens body 60. In such embodiments both the strain in the antenna material and the size of the slot are altered by a change in the shape of the contact lens 56.

Due to the piezoresistive effect, the resistance of a conductor (such as an antenna wire) varies in dependence on the strain experienced by that conductor. The strain depends on the degree of stretching or bending being experienced by the conductor. Therefore, the resistance of the antenna wire varies in dependence on whether the contact lens 56 is in the relaxed state or the force-applying state, and also on the extent to which the contact lens 56 deforms the eye 20 when the force is being applied. Thus the resistance of the antenna wire depends on the IOP since higher IOP will lead to a smaller change in shape of the RF antenna 62 (i.e. due to less deformation of the eye 20 when the force is applied caused by high IOP). Changing the resistance of an antenna wire causes changes in the antenna transfer functions (e.g. the resonance frequency of the antenna, the quality factor (QF), etc.). This effect can be amplified by utilizing an antenna configuration which experiences a relatively high amount of stretching in response to a given change in shape of the contact lens 56.

Changes to the antenna transfer functions can be detected in the control unit from the signal received from the RF antenna 62 by the reader unit 26, without requiring contact between the receiver and the RF antenna 62. Advantageously, this means that the sensor output of the contact lens of Figure 9 can be read remotely, causing little or no discomfort or inconvenience for the subject.

Using a measured change in an antenna transfer function, such as QF, it is possible to calculate (using known techniques) the resistance change which caused the observed change in the antenna transfer function. The resistance change will be related to the underlying shape change of the contact lens 56 by a correlation function, the exact form of

which will depend on specific factors such as the form of the antenna wire, the form of the contact lens 56, and the relative arrangement of the antenna wire and the contact lens 56. In some embodiments a calibration graph or look-up table relating antenna wire resistance to contact lens deformation is created in respect of each particular design of the contact lens 56, to enable the shape change of the contact lens 56 to be determined from a calculated resistance change. In some embodiments the control unit is arranged to determine a correlation function relating resistance change to shape change, and to apply this to the calculated resistance values.

Similarly, the shape of the contact lens 56 will be related to the underlying IOP by a correlation function, the exact form of which will depend on specific factors such as the nature and/or arrangement of the contact lens 56. In some embodiments the control unit is arranged to determine a correlation function relating shape change to IOP value, and to apply this to the calculated shape change values.

In some alternative embodiments, the contact lens 56 comprises a strain gauge and a separate RF antenna 62. It will be appreciated that in some embodiments the output of the contact lens 56 can be based on the detection of a property other than strain. For instance, in some embodiments conductive plates are disposed in or on the contact lens 56 such that the distance between the plates is altered by a change in shape of the contact lens 56. The dielectric constant of the material of the contact lens between the plates will also be altered by a change in shape of the contact lens 56. The plates thus form a variable capacitor, the capacitance of which depends on the shape of the contact lens 56. In some embodiments the contact lens 56 comprises particles of a conductive material (e.g. graphite, gold spheres, etc.) suspended in the material forming the contact lens 56, which in such embodiments is selected to have low or no conductivity. In such embodiments changes in the shape of the contact lens 56 alters the distances between the conductive particles, which in turn alters the conductance of the contact lens 56. Various ways of detecting changes in electrical properties such as conductance and/or capacitance suitable for implementing in a contact lens will be known to the skilled person. In some embodiments, the contact lens 56 can comprise a sensor that directly measures IOP or other parameter indicative of IOP and provides the measurement signal to the RF antenna.

In preferred embodiments the RF antenna 62 is part of a passive antenna circuit, which means that no power supply is required for the contact lens 56. In some embodiments the RF antenna 62 is tuned to a predefined frequency for a given strain state (i.e. a given shape of the contact lens 56). In some embodiments the RF antenna 62 and

associated circuitry is formed from a transparent conductive material, e.g. indium tin oxide (ITO), so as not to impair the sight of the subject. In some embodiments the RF antenna 62 and associated circuitry is arranged around the perimeter of the contact lens 56 so as not to impair the sight of the subject.

5 In some embodiments, the reader unit 26 comprises an RF transceiver for transmitting RF energy to and receiving RF energy from the contact lens 56. The RF transceiver comprises an RF signal generator, an antenna 93 and a tuning circuit. In preferred embodiments the transceiver is arranged to transmit RF energy in a frequency including frequencies up to a few tens of MHz. Preferably the transceiver is arranged to transmit RF
10 energy in a range away from commonly used communication bands, and also below the energy absorption range of tissue. Preferably the transceiver is able to be tuned to receive a wide range of RF frequencies (e.g. because the resonance frequency of the contact lens antenna 62 may change in accordance with changes in the IOP.

In some embodiments, the control unit is arranged to determine a value of the
15 IOP based on RF energy received from the contact lens 56. In some such embodiments the control unit is arranged to measure a transfer function of the antenna 62 at a first time and at a second, later, time. For example the first time can be a time before a force is applied to the eye 20 and the second time can be a time during which the force is being applied to the eye 20. The measured transfer function can comprise any of: a quality factor (QF), a resonance
20 frequency, harmonics of a resonance frequency, time constants of an RLC circuit of the RF antenna 62.

In some embodiments the control unit is arranged to determine a resistance of the RF antenna 62 based on the measured transfer function. In some embodiments the control unit is arranged to determine a change in shape of the contact lens 56 based on a determined
25 resistance of the contact lens RF antenna 62, e.g. by comparing a determined resistance value to a calibration graph or look-up table relating antenna wire resistance to shape of the contact lens 56. In some embodiments the control unit is arranged to determine a value of IOP based on a determined shape of the contact lens 56, e.g. by comparing a determined shape of the contact lens 56 to a calibration graph or look-up table relating the shape of the contact lens 56
30 to IOP value.

The operation of the reader unit 26 and control unit will be further described with reference to Figure 10, which illustrates a method for determining a physiological characteristic of the eye.

In a first block 501 of the method the control unit, using the transmitter and receiver in the reader unit 26, measures an antenna transfer function at a first time, to determine an initial value for that antenna transfer function. During the performance of block 501 the reader unit 26 is positioned such that the distance between the reader unit 26 and the contact lens 56 is less than a maximum read range of the reader unit 26. The measuring comprises the control unit transmitting (using the antenna) RF energy in the direction of the contact lens 56. In some embodiments the frequency of the transmitted RF energy is in the range 13-14 MHz. In some embodiments the transmitted RF energy comprises a pulse having a duration and a variable frequency over the duration. In some embodiments the transmitted RF energy is varied between at least two different frequencies. In some embodiments the transmitted RF energy is varied between three different frequencies. In some embodiments the transmitted RF energy is varied over a continuous range of frequencies. The measuring further comprises the RF antenna 62 of the contact lens 56 receiving the RF energy transmitted by the reader unit 26.

The RF energy received by the contact lens RF antenna 62 induces an RF voltage in the contact lens RF antenna 62, which causes the RF antenna 62 to emit RF energy. The RF energy emitted by the RF antenna 62 is then received by a receiver (antenna) in the reader unit 26. The RF voltage in the RF antenna 62 is linked to the RF voltage in the reader unit antenna, such that the two antennas are coupled in a manner similar to weakly coupled transformer coils. A characteristic relating to the RF signal received by the reader unit antenna is detected and recorded by the control unit. In some embodiments the characteristic comprises the amplitude of the received RF signal. In some embodiments the characteristic comprises the voltage in the reader unit antenna. In some embodiments the characteristic is continuously detected and recorded for at least the duration over which the RF energy was transmitted by the reader unit 26. In some embodiments the control unit generates a time-series of values of the characteristic.

The measuring further comprises calculating a value of the transfer function based on the characteristic relating to the received RF signal. In some embodiments the calculating is performed by the control unit.

In a particular example in which the transfer function comprises a QF and the characteristic comprises the amplitude of the received RF signal, the calculating is performed as follows. The QF describes the width of the frequency spectrum of an antenna at 3dB below the peak. To calculate a QF it is therefore necessary to measure the spectrum of the received RF energy at at least two frequencies. A suitable calculation process comprises

determining the maximum amplitude of the received signal and a corresponding frequency, f_0 , of the transmitted signal; determining a first frequency, f_1 , of the transmitted signal corresponding to an amplitude 3dB less than the maximum amplitude; determining a second frequency, f_2 , of the transmitted signal corresponding to an amplitude 3dB less than the maximum amplitude; and calculating a QF value using:

$$QF = \frac{f_0}{f_2 - f_1} . \quad (\text{Equation 2})$$

However; it is often the case that the shape of the antenna band-pass characteristic (in particular the fact that it is symmetric) is known. In such cases $f_2 - f_0 = f_0 - f_1$, meaning that it is only necessary to determine the peak frequency f_0 , and one of the -3dB frequencies (either f_1 or f_2).

In examples in which the characteristic comprises the voltage in the reader unit antenna, the calculating process is slightly different. In such examples the maximum voltage is determined and this value is multiplied by 0.707 in order to obtain the equivalent -3dB value. The frequencies corresponding to the maximum voltage and the -3dB equivalent voltage are then determined and input into equation 2.

When an initial value for the antenna transfer function has been determined, the method moves to block 502 in which the force is applied to the eye 20 by contact lens 56 in response to incident light. Applying the force to the eye 20 will increase the strain in the contact lens 56 and thus there will be a change in the strain/resistance of the RF antenna wire.

In block 507, while the force is being applied, the control unit measures the antenna transfer function at a second time, to determine a final value for that antenna transfer function (the term “final” is used merely to distinguish this value from the initial value, and is not intended imply that no further values of the antenna transfer function are determined). The determination of the final antenna transfer function value is performed in the same manner as the determination of the initial antenna transfer function value. In some embodiments the second time is immediately after the first time, i.e. such that the control unit is continuously determining an updated antenna transfer function value, i.e. before, during and after the application of a force to the eye.

In block 508 the control unit determines the IOP from the change in the strain between the first time and the second time using the initial antenna transfer function value and the final antenna transfer function value. In some embodiments the determining

comprises calculating a resistance change which caused the observed change in the antenna transfer function; calculating a change in the strain experienced by the contact lens antenna 62 based on the initial and final antenna transfer function values; or determining a change in shape of the contact lens 56, e.g. using a calibration graph or look-up table relating antenna wire resistance to shape change, or relating antenna wire strain to shape change.

It will be appreciated that the initial antenna transfer function and the final antenna transfer function used in step 508 do not have to be consecutive measurements of the antenna transfer function value.

There is therefore provided a simple and unobtrusive apparatus and technique for measuring IOP, and other physiological characteristics of the eye.

Variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfil the functions of several items recited in the claims. 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 advantage. A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems. Any reference signs in the claims should not be construed as limiting the scope.

CLAIMS:

1. A contact lens for use in measuring a physiological characteristic of an eye of a subject; the contact lens comprising:

a first material, wherein the first material is such that a property of the first material changes in response to incident light, and wherein the first material is arranged such that, when the contact lens is worn on the eye and light is incident on the first material, the contact lens applies a force to the eye.

2. A contact lens as claimed in claim 1, wherein the property of the first material that changes in response to incident light is the shape and/or size of the first material.

3. A contact lens as claimed in claim 2, wherein the change in the size and/or shape of the first material is any of an increase in the size/length of the first material when light is incident on the first material, a decrease in the size/length of the first material when light is incident on the first material, an increase in the volume of the first material when light is incident on the first material, or a decrease in the volume of the first material when light is incident on the first material.

4. A contact lens as claimed in claim 1, wherein the property of the first material that changes in response to incident light is the wettability of the first material.

5. A contact lens as claimed in claim 2, 3 or 4, wherein the first material is a light-responsive polymer.

6. A contact lens as claimed in any of claims 1-5, wherein the contact lens comprises one or more regions or layers of the first material.

7. A contact lens as claimed in any of claims 1-5, wherein the contact lens is formed entirely from the first material.

8. A contact lens as claimed in any of claims 1-6, wherein the contact lens further comprises one or more regions of a hydrophilic material.

9. A contact lens as claimed in claim 8, wherein the one or more regions of the hydrophilic material are located on a side of the contact lens that is arranged to contact the eye.

10. A contact lens as claimed in claim 8 or 9, wherein the contact lens further comprises one or more regions of a hydrophobic material.

11. A contact lens as claimed in any of claims 1-10, wherein the contact lens further comprises two or more visible markings, and wherein the visible markings are arranged so that the spacing therebetween changes when the contact lens is being used to apply the force to the eye.

12. A contact lens as claimed in any of claims 1-11, wherein the contact lens further comprises a radio frequency, RF, antenna.

13. A contact lens as claimed in claim 12, wherein the RF antenna is arranged such that a characteristic of the RF antenna changes when the contact lens is being used to apply the force to the eye.

14. A system for measuring a physiological characteristic of an eye of a subject, the system comprising:

a contact lens as claimed in any of claims 1-13;

a light source;

a measurement device for measuring the response of the eye to the applied force; and

a control unit for analyzing the measured response of the eye to determine a measurement of the physiological characteristic.

15. A method of measuring a physiological characteristic of an eye of a subject, the method comprising:

illuminating a contact lens worn on the eye of the subject with light, wherein

the contact lens comprises a first material and the first material is such that a property of the first material changes in response to the light, and wherein the first material is arranged such that the contact lens applies a force to the eye in response to the light;

measuring a response of the eye of the subject to the applied force; and

5 determining a measurement of the physiological characteristic using the measured response.

1/8

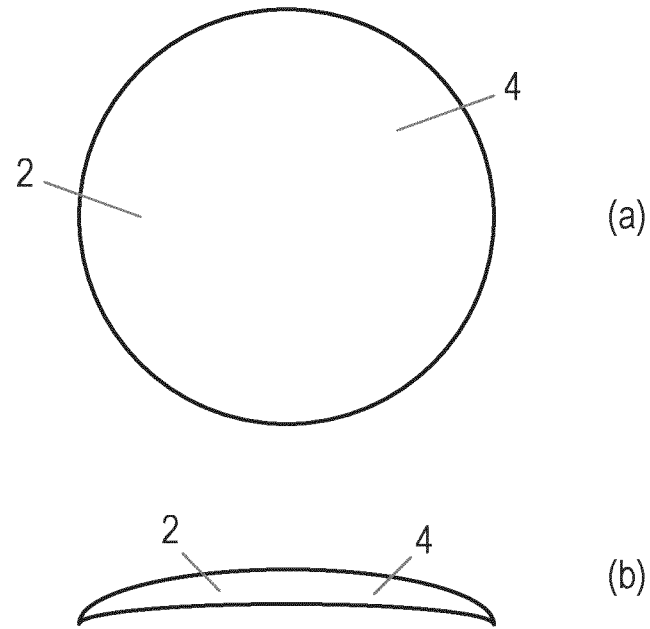


Figure 1

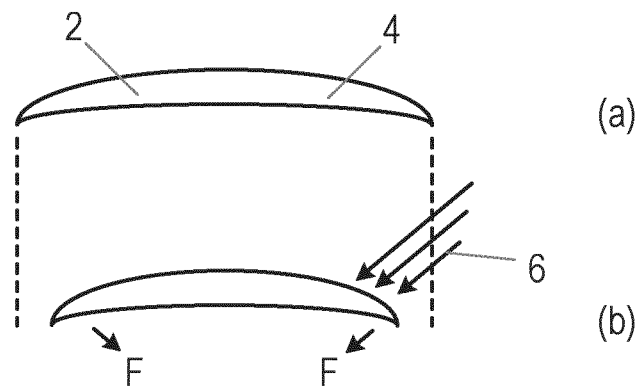


Figure 2

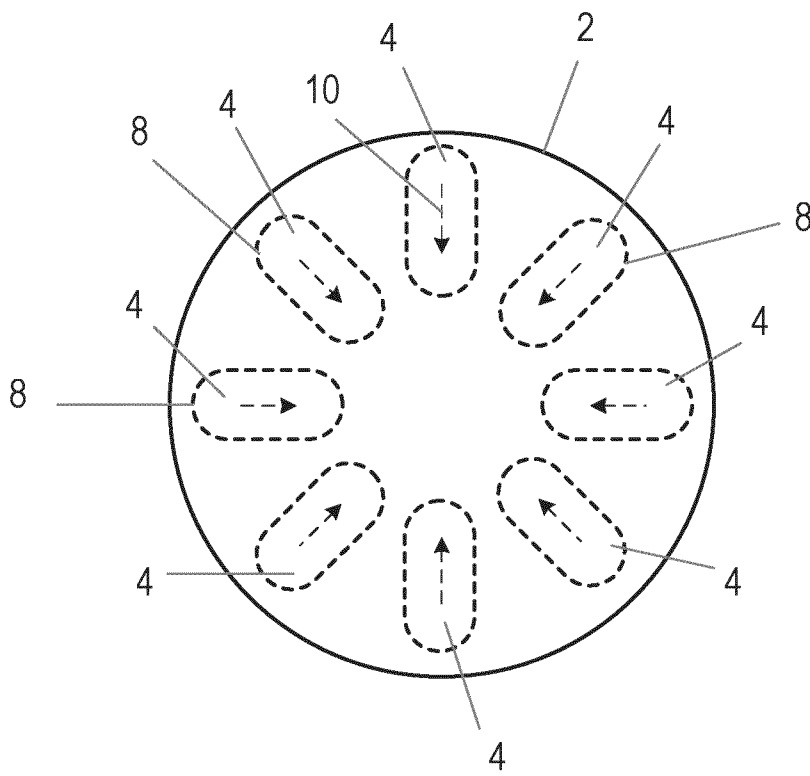


Figure 3

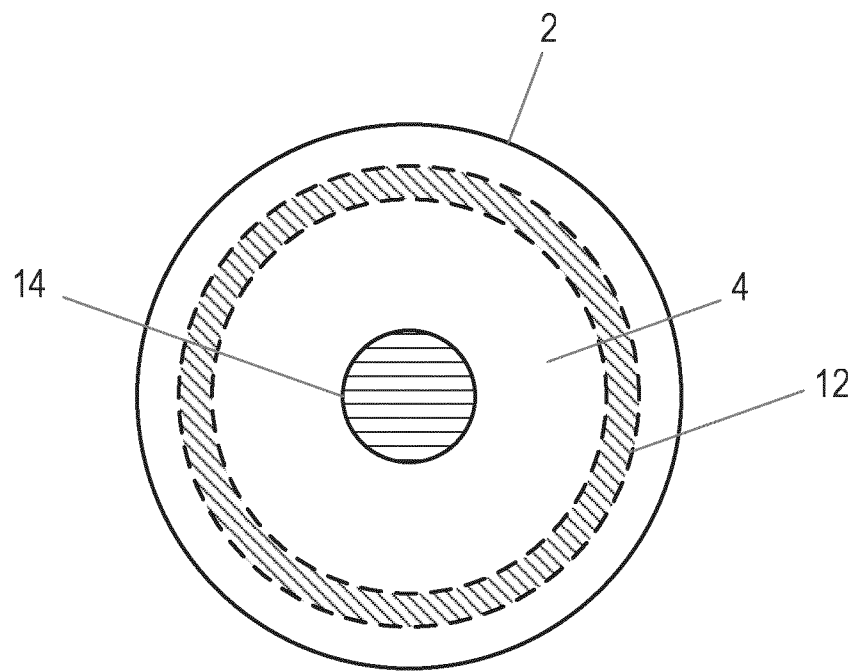


Figure 4

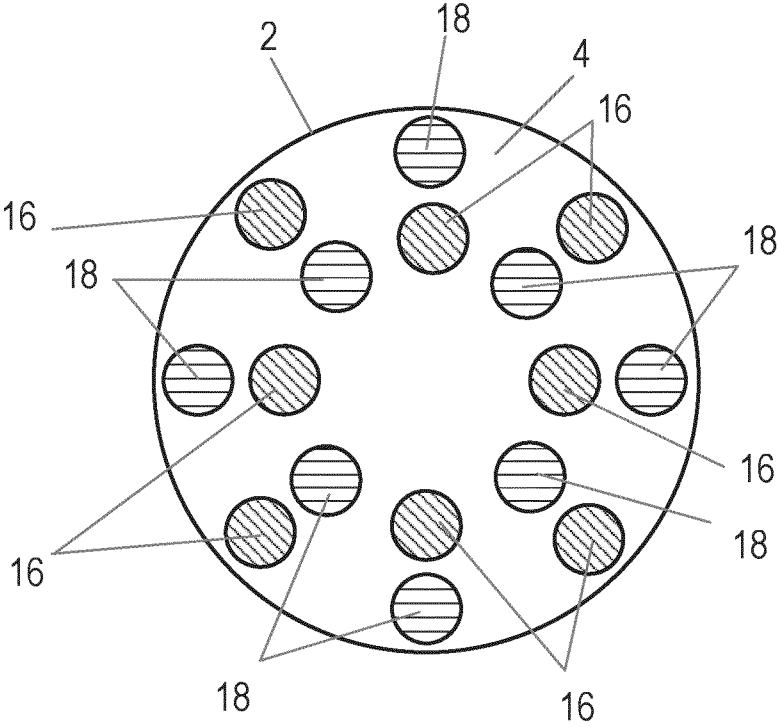


Figure 5

5/8

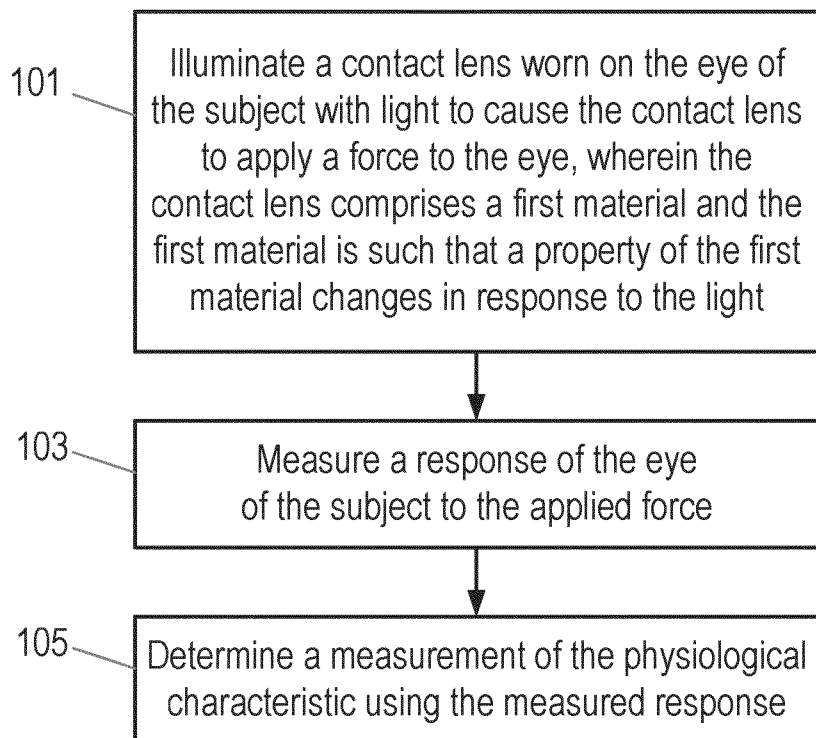


Figure 6

6/8

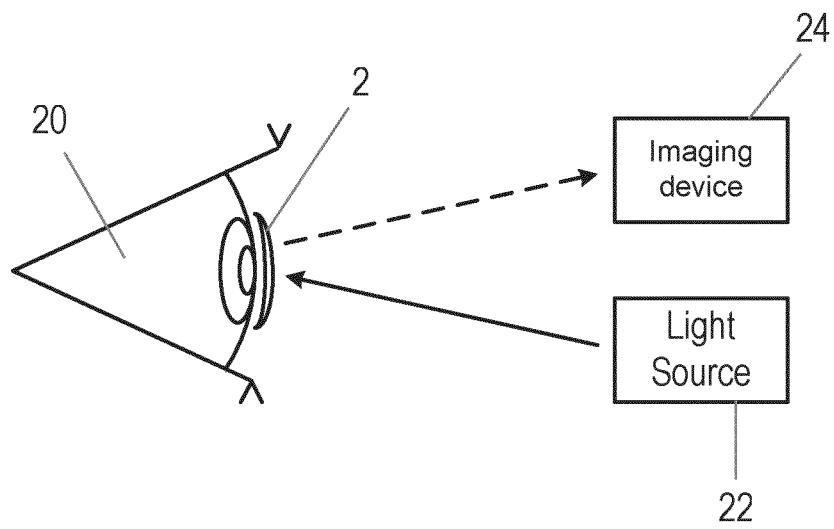


Figure 7

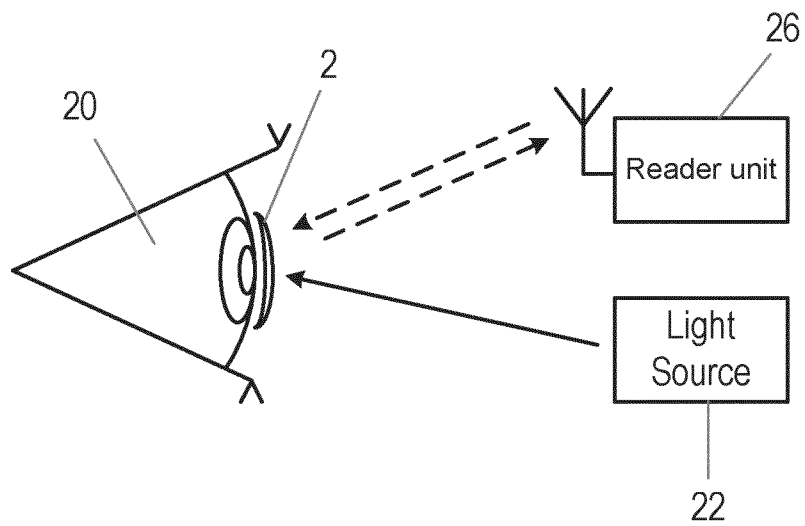


Figure 8

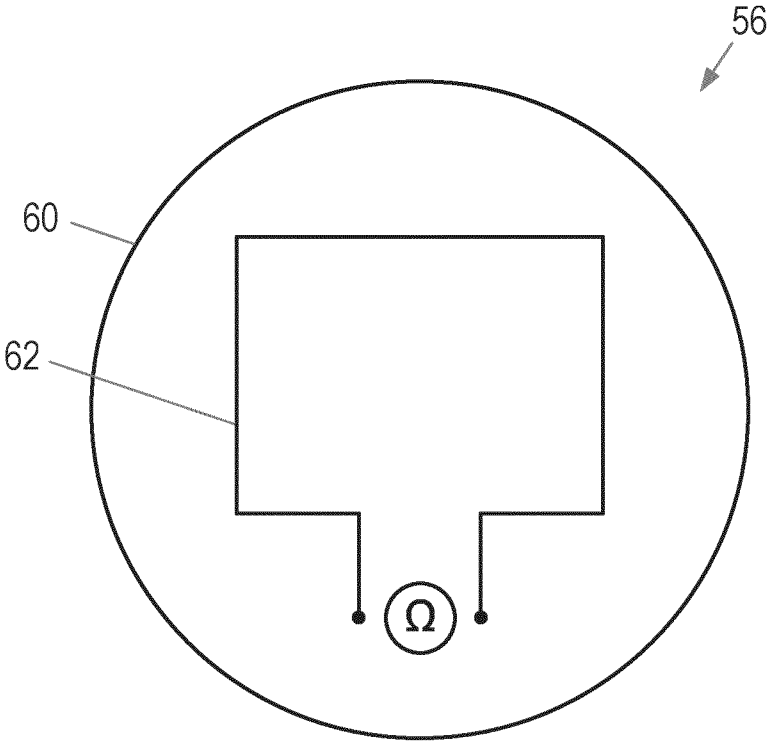


Figure 9

8/8

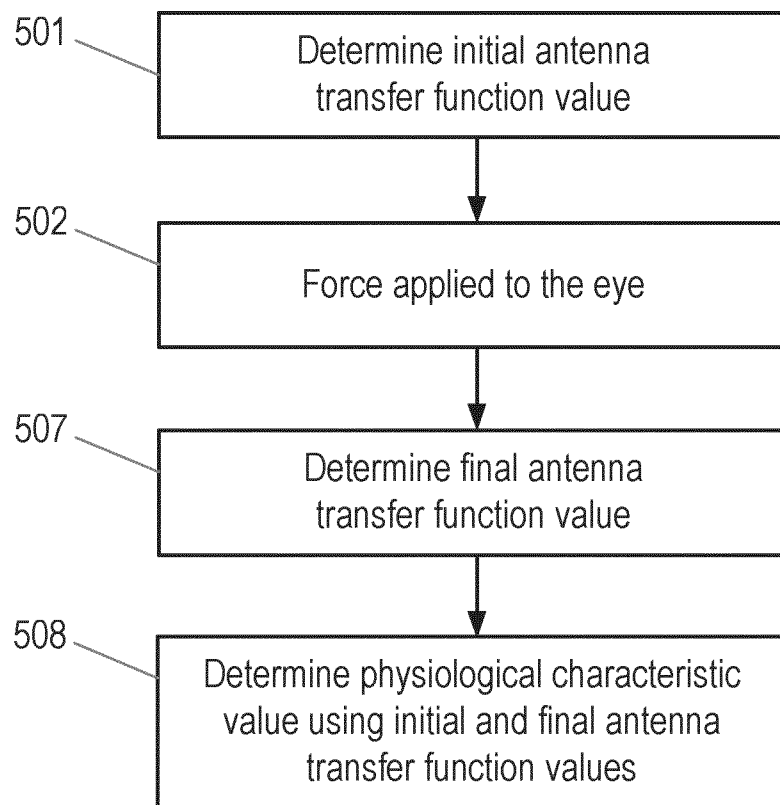


Figure 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/057139

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B3/16 G02B1/04 G02C7/04
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)
A61B G02B G02C

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 A	US 2014/055740 A1 (SPAULDING RUSSELL T [US] ET AL) 27 February 2014 (2014-02-27) paragraphs [0015], [0040], [0063] - [0070]	1-13 14,15
X A	US 2012/069254 A1 (BURTON EHREN RAY [US]) 22 March 2012 (2012-03-22) paragraphs [0026] - [0028] claims 1,5-10	1-13 14,15
X A	US 6 174 464 B1 (GARRITY NORMAN E [US]) 16 January 2001 (2001-01-16) column 3, lines 3-11 column 3, line 44 - column 4, line 12	1-13 14,15
	----- -/--	



Further documents are listed in the continuation of Box C.



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

23 June 2017

Date of mailing of the international search report

07/07/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Olapinski, Michael

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2017/057139

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/248415 A1 (ALVAREZ-CARRIGAN NAYIBY [US] ET AL) 13 October 2011 (2011-10-13)	1-13
A	paragraphs [0026] - [0028], [0045], [0057]	14,15
A	----- WAGNER NATALIE ET AL: "Light-induced wettability changes on polymer surfaces", POLYMER, ELSEVIER SCIENCE PUBLISHERS B.V, GB, vol. 55, no. 16, 2 June 2014 (2014-06-02), pages 3436-3453, XP029013803, ISSN: 0032-3861, DOI: 10.1016/J.POLYMER.2014.05.033 the whole document	1-15
A	----- IKEDA T ET AL: "ANISOTROPIC BENDING AND UNBENDING BEHAVIOR OF AZOBENZENE LIQUID-CRYSTALLINE GELS BY LIGHT EXPOSURE", ADVANCED MATERIALS, WILEY - V C H VERLAG GMBH & CO. KGAA, DE, vol. 15, no. 3, 5 February 2003 (2003-02-05), pages 201-205, XP008045631, ISSN: 0935-9648, DOI: 10.1002/ADMA.200390045 figures 2-4 the whole document	1-15
A	----- ZAHID MAHIMWALLA ET AL: "Azobenzene photomechanics: prospects and potential applications", POLYMER BULLETIN, SPRINGER, BERLIN, DE, vol. 69, no. 8, 26 June 2012 (2012-06-26), pages 967-1006, XP035121779, ISSN: 1436-2449, DOI: 10.1007/S00289-012-0792-0 figure 6 pages 972-975 the whole document	1-15
A	----- US 2011/015512 A1 (PAN TINGRUI [US] ET AL) 20 January 2011 (2011-01-20) the whole document	1-15
A	----- US 2011/184271 A1 (VECIANA JAUME [ES] ET AL) 28 July 2011 (2011-07-28) the whole document	1-15
A	----- US 2013/184554 A1 (ELSHEIKH AHMED [GB] ET AL) 18 July 2013 (2013-07-18) the whole document	1-15
6 1	A ----- CN 105 116 564 A (SHENZHEN INST OF ADV TECH CAS) 2 December 2015 (2015-12-02) the whole document -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2017/057139

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014055740	A1	27-02-2014	AU 2013216695 A1 13-03-2014
			AU 2016234956 A1 13-10-2016
			BR 102013021884 A2 11-08-2015
			CA 2824748 A1 27-02-2014
			CN 103631030 A 12-03-2014
			EP 2703877 A1 05-03-2014
			JP 2014044426 A 13-03-2014
			KR 20140027889 A 07-03-2014
			RU 2013139580 A 10-03-2015
			SG 2013062005 A 28-03-2014
			TW 201415115 A 16-04-2014
			US 2014055740 A1 27-02-2014
US 2012069254	A1	22-03-2012	CN 103842890 A 04-06-2014
			EP 2761364 A1 06-08-2014
			HK 1198592 A1 30-04-2015
			KR 20140065428 A 29-05-2014
			US 2012069254 A1 22-03-2012
			US 2015085212 A1 26-03-2015
			US 2015085213 A1 26-03-2015
			WO 2013049000 A1 04-04-2013
US 6174464	B1	16-01-2001	NONE
US 2011248415	A1	13-10-2011	AR 080896 A1 16-05-2012
			AU 2011240892 A1 25-10-2012
			CA 2795802 A1 20-10-2011
			CN 102834741 A 19-12-2012
			CN 105278008 A 27-01-2016
			EP 2558888 A2 20-02-2013
			HK 1175255 A1 02-12-2016
			HK 1220773 A1 12-05-2017
			JP 5897547 B2 30-03-2016
			JP 2013524296 A 17-06-2013
			KR 20130092404 A 20-08-2013
			RU 2012148121 A 20-05-2014
			SG 184420 A1 29-11-2012
			TW 201207095 A 16-02-2012
			US 2011248415 A1 13-10-2011
			US 2015115484 A1 30-04-2015
			WO 2011130137 A2 20-10-2011
US 2011015512	A1	20-01-2011	US 2011015512 A1 20-01-2011
			WO 2009111726 A2 11-09-2009
US 2011184271	A1	28-07-2011	CA 2726935 A1 10-12-2009
			CN 102098956 A 15-06-2011
			EP 2305100 A1 06-04-2011
			ES 2330405 A1 09-12-2009
			JP 2011521759 A 28-07-2011
			US 2011184271 A1 28-07-2011
			WO 2009147277 A1 10-12-2009
US 2013184554	A1	18-07-2013	CN 103415244 A 27-11-2013
			EP 2629658 A2 28-08-2013
			GB 2485042 A 02-05-2012
			JP 5992424 B2 14-09-2016
			JP 2013544558 A 19-12-2013

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2017/057139

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		KR 20140024835 A	03-03-2014
		US 2013184554 A1	18-07-2013
		WO 2012052765 A2	26-04-2012

CN 105116564 A	02-12-2015	CN 105116564 A	02-12-2015
		WO 2017028551 A1	23-02-2017
