Device and method for detecting an ice cover layer on a sample

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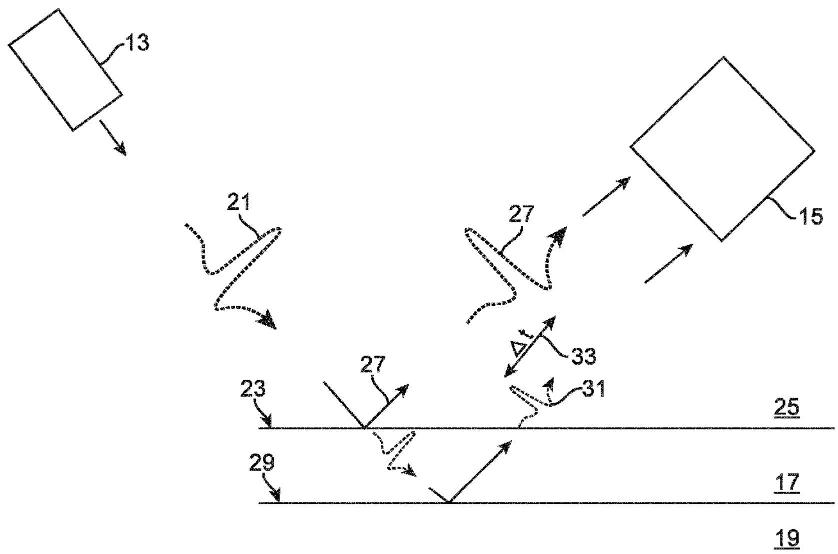

FIG. 3

(57) **Abstract:** A device for detecting an ice cover layer on a sample comprises: a source for generating and emitting pulses of electromagnetic radiation, the pulses of electromagnetic radiation being directable on a sample, a detector for detecting pulses of the electromagnetic radiation reflected from the sample, and the detector being configured to determine, in dependence on at least one of the detected pulses, whether the sample is covered with a cover layer of ice.

WO 2020/109406 A1

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DEVICE AND METHOD FOR DETECTING AN ICE COVER LAYER ON A SAMPLE

The present invention relates to a device and a method for detecting an ice cover layer on a sample.

There are various applications for which it would be desirable to determine whether there is an ice cover layer on a sample. For example, it is very common in the food industry to apply an ice glaze coating as a cover layer on a food product in order to extend the guarantee period of the food product.

In some regions of the world it is also a common problem that during winter time an ice cover layer may build up on a road. Such an ice cover layer is often called black ice or glaze ice or glazed frost. Black ice on a road may lead to severe accidents.

It is therefore an object to provide an easy to use and reliable device and a method for detecting an ice cover layer on a sample.

The object is satisfied by a device for detecting an ice cover layer on a sample in accordance with the features of claim 1. The object is also satisfied by a method for detecting an ice cover layer on a sample in accordance with the features of claim 11. Preferred embodiments of the present invention are disclosed in the dependent claims.

In accordance with the present invention, a device for detecting an ice cover layer on a sample comprises a source for generating and emitting pulses of electromagnetic radiation which are directed or directable on a sample, and a detector for detecting pulses of the electromagnetic radiation reflected from the sample. The detector is further configured to determine, in dependence on at least one of the detected pulses, whether the sample is covered with a cover layer of ice.

The detector can be configured to determine a time delay between a detected first pulse and a subsequently detected second pulse of the electromagnetic radiation and to determine quantitatively or qualitatively in dependence on the time delay whether the cover layer of ice is present on the sample. In particular, the first pulse and the second pulse which are detected at the detector may have their origin in a single pulse emitted from the source. The first pulse may in particular be the portion of the original pulse which is reflected on an upper surface of the ice cover layer. The second pulse may originate from the portion of the original pulse which penetrates through the ice cover layer and which is reflected on the interface between the ice cover layer and the sample. The travelling time of the second pulse is therefore slightly longer than the travelling time of the first pulse which explains why there is a time delay between the first pulse and the second pulse. The detection of the time delay can be used to qualitatively determine whether there is a cover layer of ice on the sample. Moreover, the time delay can also be used to quantitatively determine the thickness of the cover layer of ice on the sample.

The source may be configured to emit a sequence of pulses of electromagnetic radiation. There may be a defined time difference between consecutive pulses emitted by the source. The time difference may in particular correspond to the repetition rate of the pulses output by the laser.

The detector may be configured to employ a predefined threshold value which is below the time difference. The detector may be configured to determine the time delay between a detected first pulse and the subsequently detected second pulse. The detector may further check whether the time delay is below the predefined threshold value. In this way, the detector can assume that the first pulse and the second pulse have their origin in the same pulse emitted from the source, where the first pulse and the second pulse were reflected on different interfaces of an ice cover layer.

In some embodiments, the detector may be configured to detect at least one pulse of the electromagnetic radiation and to determine in dependence on at least one characteristic of the pulse whether the cover layer of ice is present on the sample. The reflection of a pulse of electromagnetic radiation from a road surface which is covered by an ice layer may be different than the reflection of the pulse from a road which is not covered by ice. Therefore, there may be a change in at least one characteristic, for example in the intensity of the detected pulse, in dependence on whether the pulse is reflected from a cover layer of ice on a sample or directly from an ice-free sample surface, which can for example be a road surface.

The device may comprise at least one moveable component for moving the source and/or the detector relative to the sample. The source and/or the detector may for example be mounted on a translation stage, so that they can be moved with respect to the sample. This allows for a scanning of the surface of the sample. Thereby, it can for example be determined whether the surface of the sample is completely covered with a cover layer of ice.

The device may comprise at least one moveable component for moving the sample relative the source and/or the detector. The moveable component may for example be a conveyor belt on which the sample, for example a frozen food product, is transported while examined for a cover layer of ice. Optionally, the conveyor belt can be stopped while a sample is examined.

The electromagnetic radiation may be laser radiation and/or electromagnetic radiation in the Tera-Hertz frequency regime, in particular with frequencies from 0.3 to 3 THz, or in the infrared frequency regime or in the frequency regime of visible light. Tera-Hertz radiation can pass through non-conducting material and can penetrate through ice. Thus, it can be used to determine qualitatively or quantitatively the presence of an ice layer on a sample.

In some embodiments, the Tera-Hertz frequency range can be regarded to range from 0.3 to 10 Tera-Hertz. In some embodiments, microwaves can be regarded to end at 300 GHz which is, thus, the highest microwave frequency.

Electromagnetic waves in the THz frequency range cannot penetrate liquid nor gaseous water because water molecules possess inter-molecular resonances in the THz region. The physical mechanism that is responsible for the absorption of THz waves in water is unique for electromagnetic waves in the THz frequency range and does not occur for any other frequencies like microwaves or infrared. Therefore, it is quite surprising that ice, which is water in a solid state, is almost perfectly non-absorbent to electromagnetic waves in the THz frequency range.

In some embodiments, using electromagnetic waves in the THz frequency range provides the capability of measuring the electric field of the light as a function of time. This can be done by use of a stroboscopic effect, which can be measured with much smaller time steps and hence much thinner thicknesses of layers can be detected, for example in comparison with a similar detection technique that uses electromagnetic waves in the infrared range. The fastest infrared photodetectors have response times in the order of 15 picoseconds. This results in a thickness resolution in ice which is larger than 1 cm, depending on the exact ice composition and emitter/detector setup. Ice layers that are significantly thinner than 1 cm cannot be seen using infrared light. Using electromagnetic waves in the THz frequency range, ice layers that are 3-4 orders of magnitude thinner can be detected.

The sample may be a frozen food product, such as frozen shrimp, frozen fish, frozen meat or frozen vegetable.

The sample may be a road or a street which may have a cover layer of ice on it. Such a cover layer of ice is also called black ice.

The sample might be an aircraft or a ship or any other land, air or sea vehicle. For the detection of ice formation on aircraft bodies, it is instrumental for such detection that very thin ice cover layers can be measured. Often, a person examining an aircraft is not able to see an ice layer on the body of an aircraft with the human eye. Then, the person would have to touch the aircraft body. It can then be necessary to start the security check once again. This can be avoided by using a device in accordance with the present invention for detecting an ice cover layer on an aircraft.

The sample might also be a wind turbine. A wind turbine might be equipped with a device in accordance with the present invention. In some embodiments, it can be enough to provide a few detectors on a whole wind farm.
The source and the detector may share a common lens, in particular a focusing lens, the lens being arranged to focus pulses of electromagnetic radiation provided by the source on the sample. The lens being further arranged to collect the reflected pulses from the sample.

The lens may therefore be arranged in the optical path of the source and may thus be used to deliver the pulses from the source to the sample. The lens may also be used by the detector, and it may in particular be placed in the optical path of the detector. As such, the lens may serve as a collector lens for the pulses reflected from the sample, in particular from a first surface or a second surface of an ice layer on the sample. The first surface is the outer surface of the ice layer whereas the second surface is the inner surface of the ice layer facing the surface of the sample. The pulses provided by the source and the pulses reflected by the sample may therefore - at least for some distance - travel along opposite directions such that the pulses from the source can be focused by the lens onto the sample and the reflected pulses can enter the optical system associated with the detector by traveling through the lens.

A beam splitter or another suitable optical element can be arranged to direct the reflected pulses towards the detector. The beam splitter can be designed and/or arranged with respect to the source such that pulses from the source can travel through the beam splitter.

The source, detector, lens and/or beamsplitter may be arranged in a single housing or in separate housings.

The invention also relates to a food processing apparatus for processing frozen food, such as frozen shrimp, frozen fish, frozen meat or frozen vegetable, and the food processing apparatus may comprise a device for detecting an ice cover layer in accordance with the present invention.

The food processing apparatus may also comprise a conveyor belt for transporting frozen food, and the source and the detector of the device may be mounted in such a way with respect to the conveyor belt that samples of frozen food transported by the conveyor belt can be monitored for the presence of an ice layer on the surface of the samples.

The invention also relates to a vehicle, such as a car, truck or motorcycle, which comprises a device in accordance with the present invention. The device may be employed to detect black ice on road surface on which the vehicle is running.

The invention also relates to a stationary road monitoring system comprising a device for detecting black ice on a road surface in accordance with the present invention. The stationary road monitoring system can for example be mounted above a road surface at a location that is known for the occurrence of black ice.

The invention also relates to a method for detecting an ice cover layer on a sample which comprises the steps of:

- generating pulses of electromagnetic radiation and directing the pulses of electromagnetic radiation towards a sample,
- detecting pulses of the electromagnetic radiation reflected from the sample, and
- determining, in dependence on at least one of the detected pulses, whether the sample is covered with a cover layer of ice.

The method may further comprise the steps of:
- determining a time delay between a detected first pulse and a subsequently detected second pulse of the electromagnetic radiation, and
- determining, in dependence on the time delay, whether the cover layer of ice is present on the sample.

The method may further comprise the step of determining a thickness of the cover layer of ice in dependence on the time delay.

In some embodiments, the method may comprise the steps of:
- detecting at least a pulse of electromagnetic radiation reflected from the sample, and
- determining, in dependence on at least one characteristic of the pulse, whether the cover layer of ice is present.

The invention also relates to the use of a device in accordance with the present invention for detecting a cover layer of ice on a sample, such as a frozen food product or a frozen road.

The invention also relates to a food processing apparatus for processing frozen food, such as frozen shrimp, frozen fish, frozen meat or frozen vegetable, the food processing apparatus comprising:

a source for generating and emitting pulses of electromagnetic radiation, the pulses of electromagnetic radiation being directable on a sample, a detector for detecting pulses of the electromagnetic radiation reflected from the sample,

wherein the detector is configured to determine a time delay between a detected first pulse and a subsequently detected second pulse of the electromagnetic radiation and to determine in dependence on the time delay whether a cover layer of ice is present on the sample, and

wherein the detector is configured to determine a thickness of the cover layer of ice in dependence on the time delay.

One or more exemplary embodiments of the present invention will hereinafter be described in conjunction with the following drawing figures, where like numerals denote like elements, and

Fig. 1 shows a block diagram of a device for detecting an ice cover layer on a sample, in accordance with the present invention,

Figs. 2 and 3 serve to explain a way of functioning of a variant of a device in accordance with the present invention,

Fig. 4 shows schematically a further variant of a device in accordance with the present invention,

Fig. 5 shows schematically another variant of a device in accordance with the present invention, and

Fig. 6 shows schematically a further variant of a device in accordance with the present invention.

The block diagram of Fig. 1 illustrates a device 11 for detecting an ice cover layer 17 on a sample 19 (see in Fig. 2). The device comprises a source 13, for example a laser, for generating and emitting pulses of electromagnetic radiation. The pulses of electromagnetic radiation are directable on the sample 19. The device 11 comprises a detector 15 for detecting pulses of the electromagnetic radiation that are reflected from the sample 19. The detector 15 is configured to determine, in dependence on at least one of the detected pulses, whether the sample 19 is covered with the cover layer of ice 17.

Figs. 2 and 3 serve to explain in more detail how a variant of the device 11 may operate for detecting the ice cover layer 17 on the sample 19, which may for example be a frozen food product such as a shrimp. The source 13, which may for example be a laser or another source of electromagnetic radiation that emits radiation for example in the Tera-Hertz frequency regime, emits a pulse 21 of electromagnetic radiation. This outgoing pulse 21 of electromagnetic radiation is directed on the sample 19. When the pulse 21 is incident on a first interface 23 between the surrounding 25 and the ice cover layer 17, a portion of the pulse is reflected resulting in a first reflected pulse 27 travelling towards the detector 15. The reflection of the first pulse 27 at the first interface 23 is due to a difference between the index of refraction of the surrounding 25 (for example air) and the index of refraction of the ice cover layer 17.

The portion of the incident pulse 21 which passes through the ice layer 17 is at least partly reflected at an interface 29 between the ice cover layer 17 and the sample 19. This reflection is also due to the difference between the index of refraction of the ice cover layer 17 and the index of refraction of the sample 19.

The reflection on the second interface 29 results in a second pulse 31 which is travelling towards the detector 15. The detector can detect the arrival of the reflected first pulse 27 and the arrival of the reflected second pulse 31 as well as a time delay 33 in between the two pulses 27, 31.

The device 11 may thus carry out a time-of-flight measurement with respect to the first pulse 27 and the second pulse 31. The measured time delay 33 between the two pulses 27, 31 can serve as an indication or confirmation that a cover layer of ice 17 is present on the sample 19. For example, the device 11 can be adapted to assume that the cover layer of ice 17 is present, if the measured time delay 33 is below a predefined threshold value. This threshold value is preferably set below the time span between two consecutive pulses 21 that are emitted by the source 13. In this way, it can be ensured that the detected first pulse 27 and the detected second pulse 31 have their origin in the same pulse 21 that is incident on the cover layer of ice 17.

As shown in Fig. 3, the source 13 is arranged with respect to the sample 19, which, e.g., may be lying on a conveyor belt 35 or on a xy-translation stage, in such a way that the pulses emitted by the source 13, like pulse 21, are incident on the sample 19. Optionally, optical elements may be used to direct the pulses 21 from the source 13 to the sample 19. A xy-translation stage may be used to move the position of the spot of the incident pulses 21 on the cover layer and thus may allow for scanning the surface of the sample 19 in order to determine whether the surface is completely covered with ice.

The detector 15 is arranged with respect to the sample 19 such that reflected pulses, like pulses 27 and 31, can be detected by the detector 15. The laws of reflection are taken into account in the positioning of the detector 15 with regard to the sample 19 and the source 13. Taking account of the laws of reflection and of the positions of the source 13, the detector 15, and the sample 19, the distance of travel of the pulse 31 through the cover layer 17 can be determined. Furthermore, the thickness of the cover layer 17 can be determined at least approximately.

The source 13 may also be arranged such that the pulses 21 emitted by the source 13 are incident in an orthogonal direction on the cover layer of ice 17. Thus, the reflected pulses, like pulses 27 and 31, will travel in substance anti-parallel to the pulses 21 incident on the cover layer 17. The source 13 and the detector 15 can therefore be located in the vicinity of each other, for example in a single housing of the device 11. In the set-up as shown in Fig. 3 the source 13 and the detector 15 may be arranged in different housings.

The source 13 and the detector 15 of a device 11 for detecting an ice cover layer on a sample 19 can - as shown in Fig. 4 - be part of a food processing apparatus 37. The apparatus 37 further comprises a conveyer belt 35 for transporting samples 19 along a transport direction T to, e.g., a packaging machine. The samples 19 can be frozen food products such as frozen shrimp, frozen fish, frozen vegetables, frozen meat. The device 11 can be used, as explained above, to determine whether the samples 19 on the conveyor belt 37 are covered with a cover layer of ice (not shown in Fig. 4) and thus to ensure an improved product quality of the food products.

As shown in Fig. 5, a device 11 for detecting a cover layer of ice can also be integrated in a vehicle 39 that may travel on a road 41. The device 11 can be adapted to emit pulses 43 of electromagnetic radiation, for example in the Tera-Flertz frequency regime, such that they are incident on the road 41. The device 11 can detect pulses 45 reflected from the road 41. By use of a time of flight method as illustrated above with regard to Figs. 2 and 3, the device 11 can determine, based on the detection of a time delay between two subsequently detected reflected pulses 45, whether there is a cover layer of ice (not shown in Fig. 5) on the road 41.

The detection of a cover layer of ice on the road 41 can in particular be carried out while the vehicle 39 is driving along the driving direction D. An acoustic or visual alert can be provided to the driver when a cover layer of ice is being detected.

In an alternative detection method, the device 11 may monitor one characteristic of the detected reflected pulses 45 while the vehicle 39 is traveling along the driving direction D. The characteristic may change when the vehicle moves from an ice-free first road section to a second road section that is covered with ice. The characteristic may be the intensity of a reflected pulses 45. The intensity of the reflected pulses 45 may change and may in particular increase after the vehicle 41 has entered the second road section. Such a change in intensity may be taken as an indication for the presence of ice on the road 41, and the device 11 may provide an alert to the driver.

As illustrated in Fig. 6, the source 13 and the detector 15 may share a common lens 47, which may be a focusing lens. The lens 47 could also be a lens system which may provide a focusing effect. The lens 47 is arranged such that the pulses 43 from the source 13 can be focused on a sample 19. The reflected pulses 45 that travel in the opposite direction with respect to the pulses 43 can pass through the lens 47. A beam splitter 49 is configured to separate the reflected pulses 47 and to direct them on the detector 15.

The source 13, the detector 15, the lens 47 and/or the beam splitter 49 can be arranged in a single housing or in different housings.

In some exemplary embodiments, the source 13 is adapted to emit pulses having a center frequency in the Tera-Hertz frequency range ranging from 0.3 to 3 THz. Such radiation has a sufficient penetration depth through an ice layer and is therefore usable to monitor samples, like frozen food products, for the presence of an ice cover layer.

LIST OF REFERENCE SIGNS

11	device
13	source
15	detector
17	cover layer of ice
19	sample
21	pulse
23	first interface
25	surrounding
27	pulse
29	second interface
31	pulse
33	time delay
35	conveyor belt
37	food processing apparatus
39	vehicle
41	road
43	pulse
45	pulse
47	beam splitter
49	lens
T	transport direction
D	driving direction

Claims

1. A device for detecting an ice cover layer on a sample, the device (11) comprising:

   a source (13) for generating and emitting pulses (21, 43) of electromagnetic radiation, the pulses (21, 43) of electromagnetic radiation being directable on a sample (19, 41),

   a detector (15) for detecting pulses (27, 31, 45) of the electromagnetic radiation reflected from the sample (19, 41), and

   the detector (11) being configured to determine, in dependence on at least one of the detected pulses (27, 31, 45), whether the sample (19, 41) is covered with a cover layer of ice (17).

2. The device in accordance with claim 1,
   characterized in that
   the detector (11) is configured to determine a time delay (33) between a detected first pulse (27) and a subsequently detected second pulse (31) of the electromagnetic radiation and to determine in dependence on the time delay (33) whether the cover layer of ice (17) is present on the sample (19).

3. The device in accordance with claim 2,
   characterized in that
   the detector (11) is configured to determine a thickness of the cover layer of ice (17) in dependence on the time delay (33).

4. The device in accordance with claim 1,
   characterized in that
   the detector (11) is configured to detect at least one pulse (45) of the electromagnetic radiation and to determine in dependence on at least one characteristic of the pulse (45) whether the cover layer of ice is present on the sample (41).

5. The device in accordance with any one of the preceding claims, characterized in that
the device (11) comprises at least one moveable component for moving the source (13) and/or the detector (15) relative to the sample (19), and/or
the device (11) comprises at least one moveable component (35) for moving the sample (19) relative to the source (13) and/or the detector (15).

6. The device in accordance with any one of the preceding claims, characterized in that
the electromagnetic radiation is laser radiation and/or in the Tera-Hertz frequency regime, in particular with frequencies from 0.3 to 3 THz, or in the infrared frequency regime or in the frequency regime of visible light.

7. The device in accordance with any one of the preceding claims, characterized in that
the sample (19) is a frozen food product, such as frozen shrimp, frozen fish, frozen meat or frozen vegetable, or .
the sample (41) is a road having a cover layer of ice, or
the sample is a land, air or sea vehicle, or
the sample is a wind turbine.

8. The device in accordance with any one of the preceding claims, characterized in that
the source (13) and the detector (15) share a lens (47), in particular a focusing lens, the lens (47) being adapted to focus the pulses (43) provided by the source (13) on the sample (19) and for collecting reflected pulses (45) from the sample (19) for providing them to the detector (15).

9. A food processing apparatus for processing frozen food, such as frozen shrimp, frozen fish, frozen meat or frozen vegetable,
the food processing apparatus (37) comprising a device (11) in accordance with any one of the preceding claims.

10. A land, air or sea vehicle (39), such as a car, truck, motorcycle or service truck for use on an airport, or a stationary road monitoring system, or a wind turbine comprising a device (11) in accordance with any one of the claims 1 to 8.

11. A method for detecting an ice cover layer (17) on a sample (19, 41), the method comprising:

generating pulses (21, 43) of electromagnetic radiation and directing the pulses (21, 43) of electromagnetic radiation towards a sample (19, 41),

detecting pulses (27, 31, 45) of the electromagnetic radiation reflected from the sample (19, 41), and

determining, in dependence on at least one of the detected pulses (27, 31, 45), whether the sample (19) is covered with a cover layer of ice (17).

12. The method in accordance with claim 11,
characterized in that
the method further comprises the steps:

determining a time delay (33) between a detected first pulse (27) and a subsequently detected second pulse (31) of the electromagnetic radiation, and

determining, in dependence on the time delay (33), whether the cover layer of ice (17) is present on the sample (19, 41).

13. The method in accordance with claim 12,
characterized in that
the method further comprises determining a thickness of the cover layer of ice (17) in dependence on the time delay (33).

14. The method in accordance with claim 11,
characterized in that

the method further comprises the steps:

detecting at least a pulse (27, 31, 45) of electromagnetic radiation reflected from the sample (19, 41), and

determining, in dependence on at least one characteristic of the pulse (27, 31, 45), whether the cover layer of ice (17) is present.

15. Using a device in accordance with any one of the claims 1 to 8 for detecting a cover layer of ice (17) on a sample (19), such as a frozen food product or a frozen road or a land, air or sea vehicle, or a wind turbine.

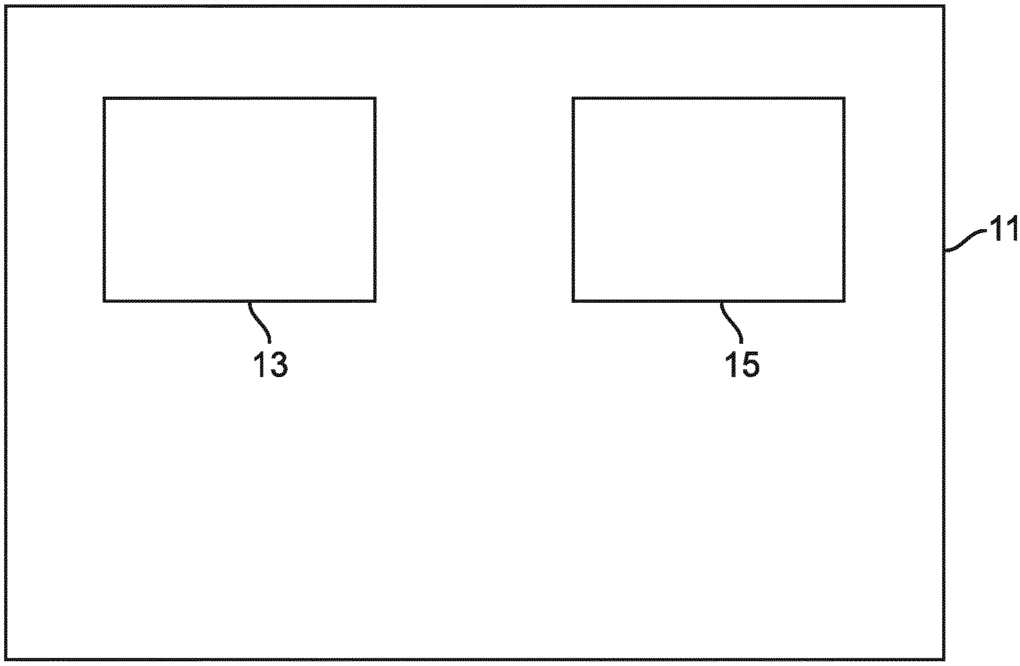

FIG. 1

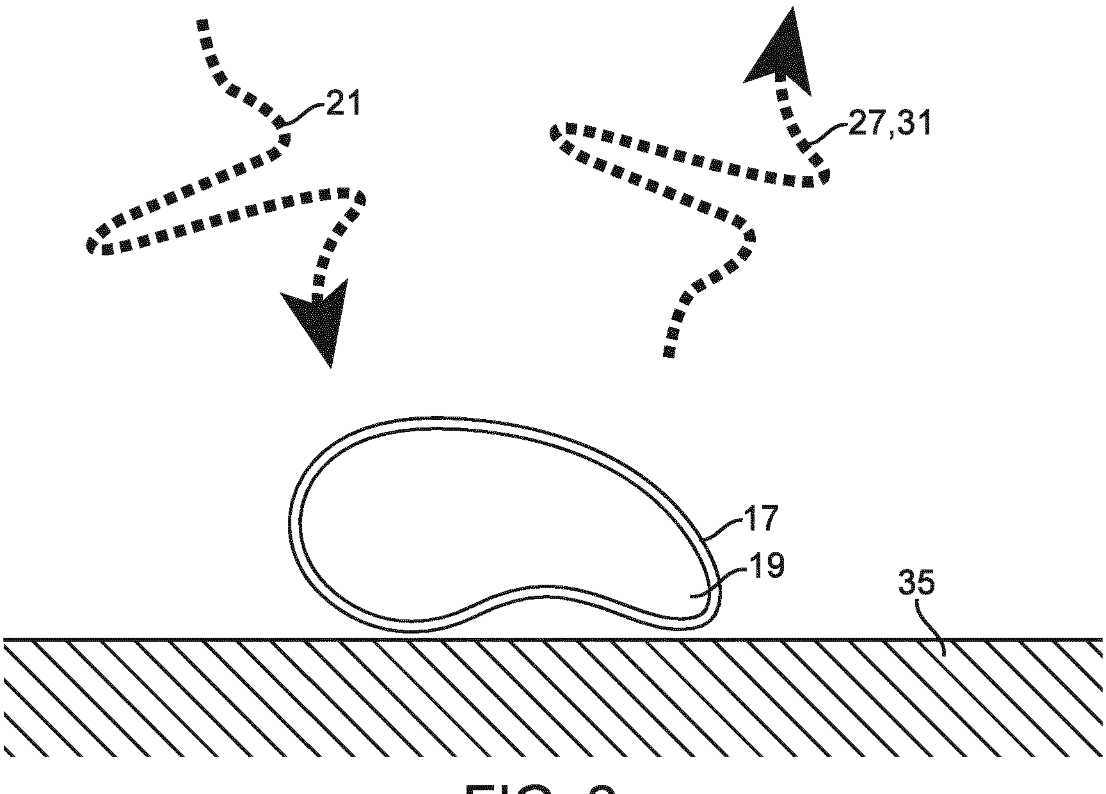

FIG. 2

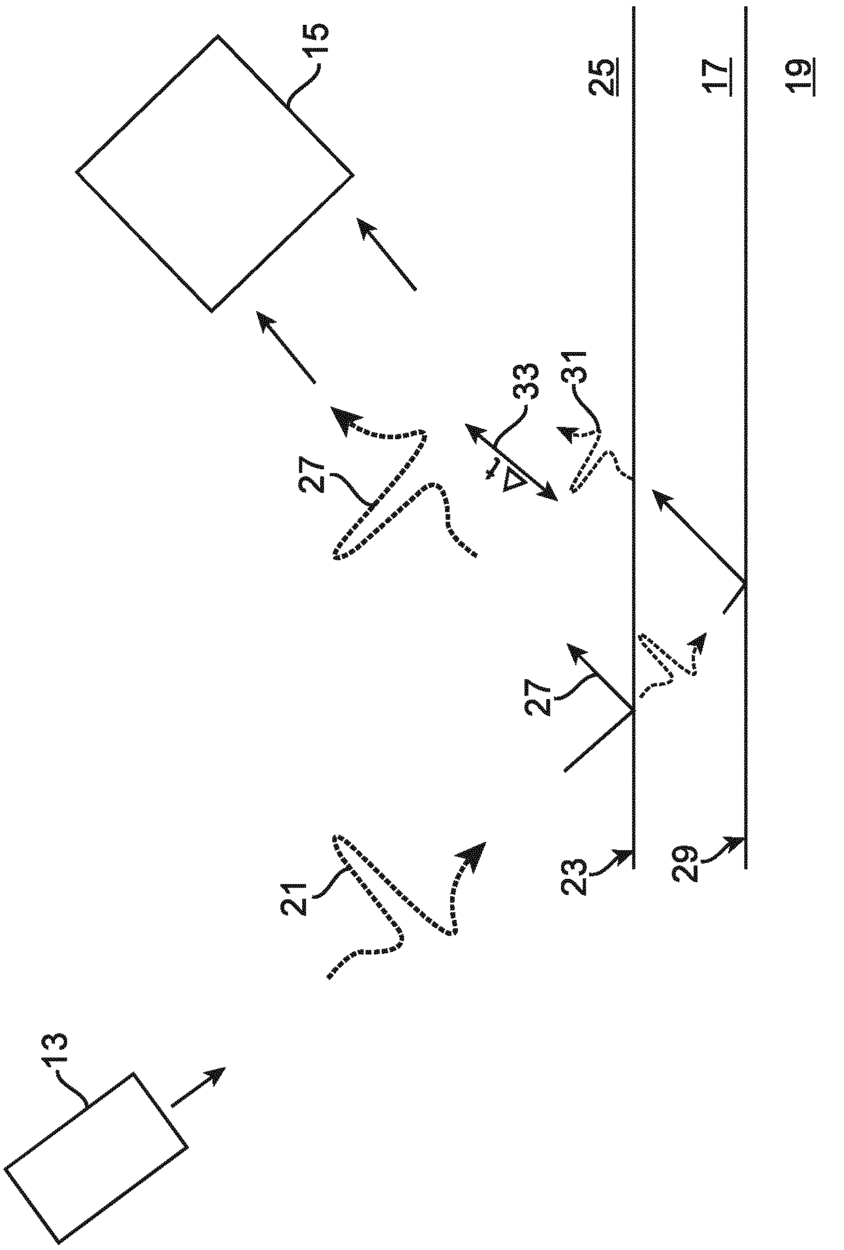

FIG. 3

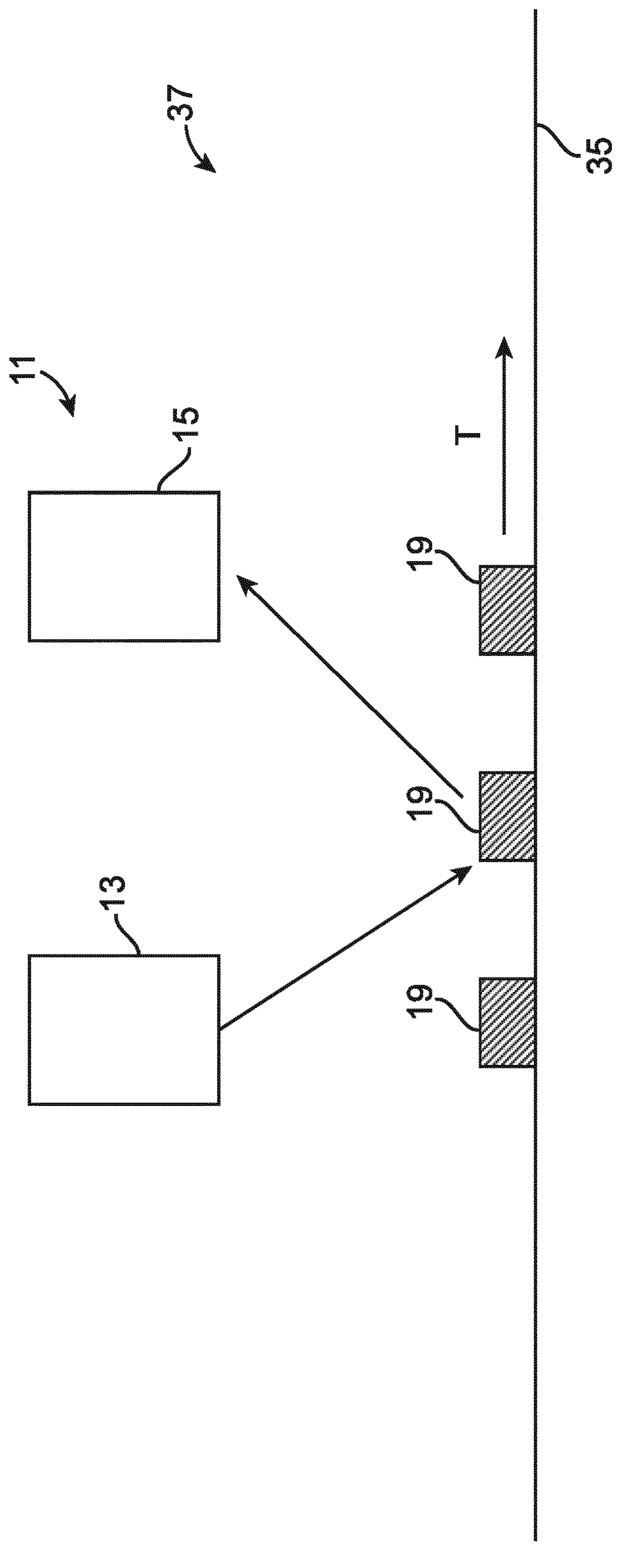

FIG. 4

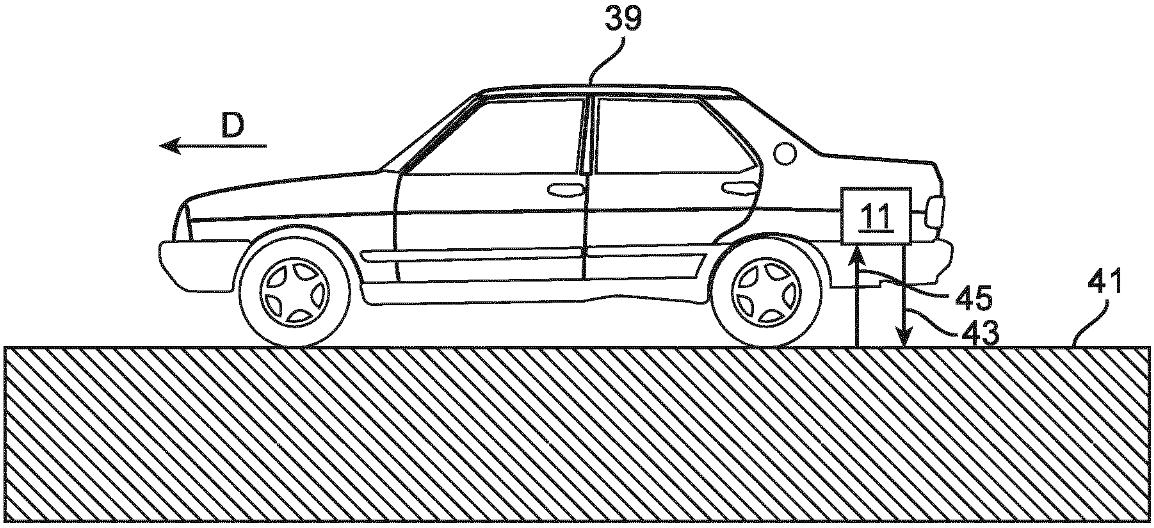

FIG. 5

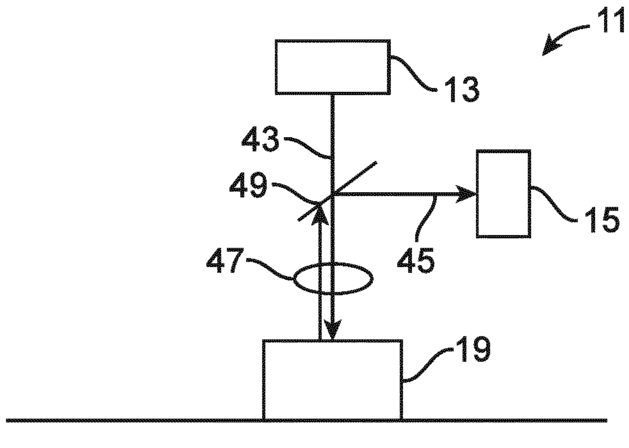

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/082781

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S7/48 G01S17/88 G01S17/95 G01S17/10 G01B15/00
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)
G01S G01B

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 , INSPEC, 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	DE 41 41 446 C1 (ANT NACHRICHTENTECHNIK GMBH) 25 February 1993 (1993-02-25) abstract; figure 1 column 1, line 3 - column 2, line 3 column 3, lines 12-37 -----	1-8, 10-15
X	GB 2 355 071 A (CINTEX LTD) 11 April 2001 (2001-04-11) abstract; figure 1 page 7, lines 4-20 -----	9
A	DE 20 2006 010023 U1 (DELIPETKOS ELIAS [DE]) 14 December 2006 (2006-12-14) the whole document -----	1-8, 10-15

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

☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
13 February 2020	28/02/2020

Name and mailing address of the ISA/	Authorized officer
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1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2019/082781

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
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GB 2355071	A	11-04-2001	NONE	
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