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(54) **FLUID BASED COOLING SYSTEM**

(57) The present invention relates to an improved UV-LED lamp that can be used for curing of a UV-curable material. The UV-LED lamp of the present invention comprise a fluid based cooling system, configured for cooling UV-LEDs (3) on the UV-LED lamp, when the UV-LED lamp is in use. The temperature of the UV-LEDs is regulated by a control system (13), adapted to control the temperature and/or the flow rate of a cooling fluid cooling the UV-LEDs, based on inputs from internal temperature

sensor (12) as well as information on the temperature and humidity of the surroundings. The control system (13) is configured such that the temperature of the UV-LEDs (3) is kept above the dew point and below a predetermined threshold value. Thereby, the present invention provides a UV-LED lamp with an increased lifespan, as both overheating of and dew forming on the UV-LEDs are avoided.

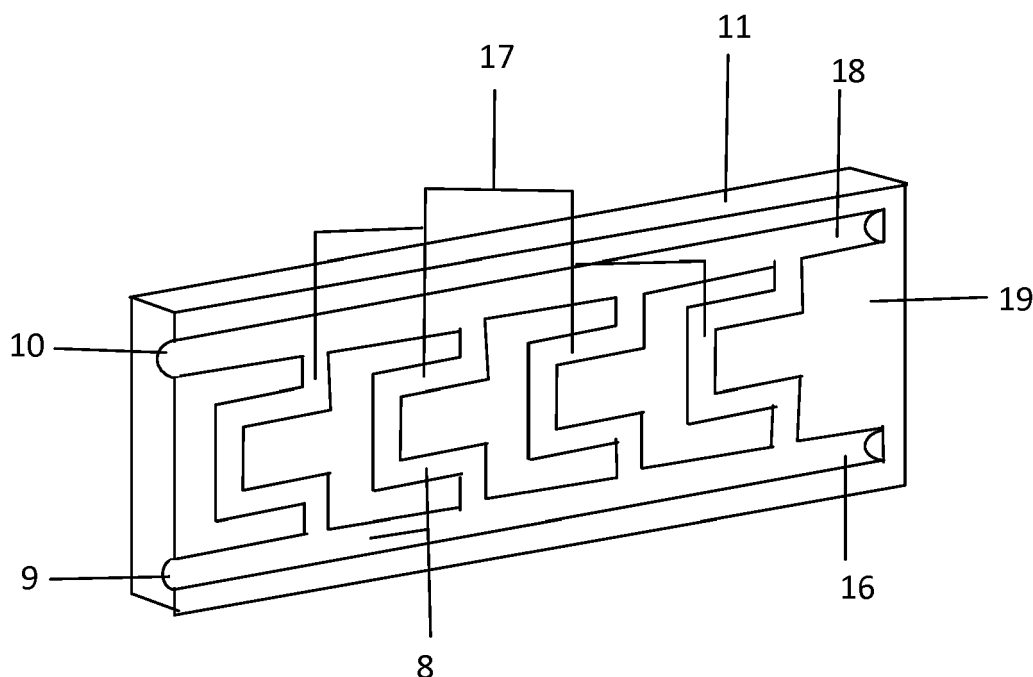


Fig. 1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to a UV-LED lamp for curing of curable materials. Furthermore, the present invention relates to a UV-LED system comprising a fluid based cooling system.

BACKGROUND OF THE INVENTION

[0002] UV curing is a process in which ultraviolet (UV) and visible light is used to initiate a reaction that generates a cross-linked network of polymers. UV curing is adaptable to various processes, including lacquering, printing, coating, decorating, stereolithographing and assembling of a variety of products and materials. The technology has been used to streamline and increase automation in many industries of the manufacturing sector, such as fine instrument finishing, furniture lacquering and other woodcraft industries. The primary advantage of curing with UV light is in the speed at which a product can be readied. In addition, the fast curing can reduce flaws and errors, as the amount of time that dust, flies or any airborne object has to settle upon an object is reduced.

The introduction of UV light emitting diodes (LEDs) for supplying UV light for curing of UV curable materials has created new alternatives for curing of some UV-sensitive materials. Preferably, the UV-LEDs emit light with wavelengths from the UV spectrum matching the absorption maxima of the photo initiator(s) in the UV curable materials, which results in a much more efficient curing than what can be obtained using wavelengths from the whole spectrum of UV light.

Chips on boards (COBs) is a technology of LED packaging, where a plurality of LED chips are packaged together as one lighting module, which can be used for different purposes, such as curing. A problem with the close packaging of LEDs is the warming of the LEDs in such COBs, as high temperatures may decrease the lifespan of the LEDs. To solve the problem of high temperature, different means for cooling the LEDs has been suggested. However, cooling may result in dew forming on the COBs that may reduce the lifespan of the LEDs as well as electronics circuits on the COB. Thus, an UV-LED lamp comprising an improved cooling system, where dew forming is prevented, would be advantageous for the industry.

OBJECT OF THE INVENTION

[0003] An object of the present invention is to provide an alternative to the prior art. In particular, it may be seen as an object of the present invention to provide a UV-LED lamp that solves the above mentioned problems of the prior art, thereby providing a UV-LED lamp with increased lifespan.

SUMMARY OF THE INVENTION

[0004] Thus, the above-described object and several other objects are intended to be obtained in a first aspect of the invention by providing a UV-LED lamp comprising:

- a cooling wall having a first surface and an opposite second surface,
- at least one fluid channel being an integrated part of the first surface of the cooling wall and comprising a first main channel being fluidly connected to a plurality of sub-channels, each sub-channel being fluidly connected to a second main channel, wherein
 - the sub-channels are shaped and dimensioned so as to provide a turbulent flow for a cooling fluid flowing in the sub-channels when the UV-LED lamp is in use,
- a fluid inlet providing a flow path for a cooling fluid to the first main channel,
- a fluid outlet providing a flow path for the cooling fluid from the second main channel out of the at least one fluid channel,
- a plurality of UV-LEDs being arranged on or adjacent to the second surface of the cooling wall, wherein
 - the sub-channels are configured for cooling the UV-LEDs by means of heat transfer from the UV-LEDs through the cooling wall to the cooling fluid flowing in the sub-channels, when the UV-LED lamp is in use,
- a plate located adjacent to the first surface of the cooling wall, so that the at least one fluid channel is formed as a closed fluid channel and the cooling fluid can flow in the at least one fluid channel without leaking cooling fluid to the surroundings,
- at least one internal temperature sensor arranged and configured for measuring a temperature of the UV-LEDs,
- a connection to a control system adapted to control the temperature and/or the flow rate of the cooling fluid, so that the temperature and/or the flow rate of the cooling fluid is/are regulated based on inputs from the at least one internal temperature sensor as well as information on the temperature and humidity of the surroundings, in a way so that the temperature of the UV-LEDs as measured by the at least one internal temperature sensor is always above the dew point and below a predetermined threshold value, when the UV-LED lamp is in use.

[0005] Thereby, the present invention provides a UV-LED lamp with an increased lifespan, as both overheating of and dew forming on the UV-LEDs are avoided.

[0006] Overheating of the UV-LEDs is avoided by continuously cooling the plurality of UV-LEDs by circulating

a cooling fluid through the at least one fluid channel, which then cools the UV-LEDs through heat exchange through the cooling wall. The temperature of the UV-LEDs is measured by at least one internal temperature sensor, which is sending the information to the control system. When the control system receives an input from one or more of the internal temperature sensors, indicating that the temperature of one or more of the UV-LEDs has increased above a predetermined threshold value for the temperature, the control system sends a signal to the system controlling the temperature of the cooling fluid to lower the temperature of the cooling fluid and/or sends a signal to the system controlling the flow rate of the cooling fluid. This results in a cooling of the UV-LEDs until the temperature of the UV-LEDs is below the predetermined temperature.

[0007] Dew forming is avoided by keeping the temperature of the UV-LEDs above the dew point. When air cools to its dew point through contact with a surface that is colder than the air, water will condense on the surface. Thus, if the cooling wall and/or the surface of the UV-LEDs is too cold, dew will form at their surface.

[0008] The dew point depends on the temperature and humidity of the surroundings. As the control system receives information on the temperature and humidity of the surroundings, the dew point can be calculated by the control system and the temperature of the UV-LEDs is not cooled below this temperature.

[0009] In a second aspect, the present invention relates to a UV-LED system comprising the UV-LED lamp as described above and further comprising a cooling system for cooling the UV-LEDs. The cooling system comprises:

- a cooling fluid source being fluidly connected to the fluid inlet and a cooling fluid drain being fluidly connected to the fluid outlet,
- a cooler for cooling of the cooling fluid contained in the fluid source, and
- a pump connected to the system and adapted to pump the cooling fluid through the system.

[0010] In some embodiments, the cooling fluid source and the cooling fluid drain are connected so as to provide a closed system where the cooling fluid is recirculated in the closed system comprising the at least one fluid channel, the inlet, the outlet, the cooling fluid source and the cooling fluid drain. This is advantageous as it is cost saving and environment friendly. Furthermore, the need for a continuous supply of cooling fluid from an external fluid source is not necessary as the fluid can be reused in the closed system. The cooling fluid is preferably a liquid. The cooling fluid may comprise anti-corrosive chemicals such as ethylene-glycol and/or propylene-glycol. The cooling fluid may comprise at least 30% glycol, such as 40% or 50% to avoid antibacterial growth and freezing issues down to 35-40 degrees Celsius.

Use:

[0011] The UV-LED lamp and the UV-LED system of the present invention are intended for curing of curable materials. However, the UV-LED lamp and the UV-LED system may also be used for other purposes.

[0012] In some embodiments, the UV-LED lamp or UV-LED system of the present invention is used for curing of UV curable material, such as ink, coating, lacquer, adhesive or polymer resin.

[0013] In preferred embodiments, the UV-LED lamp or UV-LED system of the present invention is used for curing of lacquer on furniture.

[0014] The cooling system is preferably turned on as long as the temperature of at least one of the UV-LEDs is above a predetermined temperature, such as above room temperature or such as five degrees or more above room temperature.

The UV-LEDs may need cooling before or after use. Thus, even though the UV-LEDs on the UV-LED lamp are turned off, the cooling system in the UV-LED lamp may still be turned on.

The term: "when the UV-LED lamp is in use", may refer to a situation where the UV-LEDs and the cooling system are both turned on or a situation where the UV-LEDs are turned off and the cooling system is turned on. Thus, the cooling system may be turned on before or after use of the UV-LEDs, as well as during use of the UV-LEDs.

UV-LEDs:

[0015] The UV-LED lamp comprises a plurality of ultraviolet light emitting diodes (UV-LEDs). UV-LEDs herein refer to light emitting diodes of any type and form, emitting light of a wavelength between 10 nm and 400 nm, which is in the ultraviolet spectrum.

[0016] The plurality of UV-LEDs are arranged along the cooling wall in a pattern, which depends on the intended use of the UV-LED lamp. In the same way, the density of the UV-LEDs along the cooling wall depends on the intended use and the desired intensity of the light emitted by the lamp. The total number of UV-LEDs in the UV-LED lamp depends on the intended use of the UV-LED lamp. In theory, the number of UV-LEDs may be several thousands.

[0017] Depending on the type of material to be cured, different UV-LEDs with specific wavelengths may be preferred. Preferably, the UV-LEDs emit light with wavelengths from the UV spectrum matching the absorption maxima of the photo initiator(s) in the UV curable materials, which results in a much more efficient curing than can be obtained using wavelength from the whole spectrum of UV-light. This is advantageous as it is cost saving and allows for a faster curing.

UV-LED units:

[0018] In some embodiments, the plurality of UV-LEDs

are arranged in UV-LED units along the cooling wall, and each UV-LED unit comprises at least one UV-LED, preferably more than one UV-LED, such as more than 6 UV-LEDs.

The number of UV-LEDs in each UV-LED unit depends on the intended use of the UV-LED lamp. In theory, the number of UV-LEDs in each unit may be several hundreds.

The UV-LEDs may be arranged in clusters or arrays within the UV-LED units. In some embodiments, each UV-LED unit comprises a plurality of UV-LEDs arranged in an array comprising more than one row of UV-LEDs.

For example an array may comprise Y UV-LEDs arranged in X parallel rows with Y/X UV-LEDs in each row, such as 15 UV-LEDs arranged in 5 parallel rows with 3 UV-LEDs in each row or 49 UV-LEDs arranged in 7 parallel rows with 7 UV-LEDs in each row.

Preferably, Y is between 6 and 200 UV-LEDs.

Preferably, X is between 2 and 20 UV-LEDs.

[0019] The UV-LED units may be arranged in close proximity or with space between them. The UV-LEDs are preferably arranged in close proximity within the UV-LED units in a way so that each UV-LED unit constitutes a light module and so that the light emitted from each UV-LED cannot be distinguished as more than one light source. In some embodiments, several UV-LED units are arranged in close proximity in a way so that they in total constitute one light module and so that the light emitted from the UV-LED units cannot be distinguished as more than one light source.

"Close proximity" preferably refers to 1 mm or less between two UV-LEDs. "Space" preferably refers to a distance of 1-10 mm between two UV-LEDs.

[0020] In some embodiments, the plurality of UV-LEDs are arranged directly on the second surface of the cooling wall.

In some embodiments, the plurality of UV-LEDs are arranged adjacent to the second surface.

Holding element:

[0021] One or more UV-LEDs may be arranged on a holding element. In some embodiments, each UV-LED unit is arranged on a holding element. This is advantageous as a holding element can easily be dismounted from the cooling wall and one or more UV-LEDs on a holding element can be exchanged or fixed if broken. Furthermore, it allows for easy exchange of a holding element with a new one, if one or more LEDs on the holding element are broken or need to be renewed/replaced.

[0022] Thus, the downtime for exchanging UV-LEDs on the UV-LED lamp is reduced, as a holding element can easily be dismounted from the cooling wall, and one or more UV-LEDs on a holding element can be exchanged or fixed if broken. This advantage is in addition to the fact that the lifespan of the UV-LEDs as well as any electronics comprised in the UV-lamp is increased.

[0023] In some embodiments, the holding element is an elongated plate with a thickness of less than 1 cm, preferably less than 0.5 cm, such as less than 0.3 cm.

[0024] A holding element is preferably a printed circuit board on which the UV-LEDs are mounted. The at least one internal temperature sensor may also be mounted on the electronic circuit of such a holding element.

[0025] In some embodiments, the holding elements holding the UV-LEDs constitute chips on boards (COBs).

[0026] Theoretically, the holding elements may hold any number of UV-LEDs. A holding element may hold 12 or more UV-LEDs, such as 16 or more UV-LEDs, such as 20 or more UV-LEDs, such as 24 or more UV-LEDs, such as 30 or more UV-LEDs, such as 50 or more UV-LEDs, such as 100 or more UV-LEDs.

Preferably, each holding element holds one UV-LED unit, wherein one UV-LED unit comprises between 12 and 200 UV-LEDs arranged in a dense array on the holding element.

[0027] In some embodiments, each holding element is arranged on or adjacent to the second surface of the cooling wall in a way so that heat from the UV-LEDs is transferred through the holding element and through the cooling wall to the cooling fluid flowing in the sub-channels, when the UV-LED lamp is in use.

[0028] The second surface of the cooling wall may comprise means for holding the holding elements, such as holes, so that the holding elements can be screwed or bolted to the second surface. In preferred embodiments, the second surface as well as each holding element comprise at least two holes, so that the holding elements can be screwed or bolted to the second surface. The second surface may comprise protrusions shaped and dimensioned so that they can hold the holding elements close to the second surface.

[0029] In some embodiments, the UV-LEDs are arranged on each holding element in a way so that two or more holding elements can be placed next to each other and the distance between at least two UV-LEDs from two different holding elements is the same as or at least not more than twice the distance between two UV-LEDs on a single holding element. This is advantageous as two or more holding elements can be placed in continuation of each other to constitute a light module and so that the light emitted from the UV-LEDs on two adjacent holding elements cannot be distinguished as more than one light source. This could also be obtained by making a larger holding element with more UV-LEDs. However, by arranging a smaller number of UV-LEDs on several holding elements, an easy exchange of a holding element with a new one, if one or more LEDs on the holding element are broken or need to be renewed, is possible.

[0030] For an elongated light module, several holding elements may be placed next to each other comprising parallel rows of UV-LEDs. In a preferred embodiment of the present invention, each holding element holds between 6 and 200 UV-LEDs in a square array and the holding elements are placed in continuation of each other

to provide an elongated light module consisting of more than one holding element.

Internal temperature sensors:

[0031] A problem with the close packaging of the UV-LEDs is the warming of the UV-LEDs, as high temperatures may decrease the lifespan of the UV-LEDs. The present invention provides a cooling system for that purpose. To be able to measure the temperature of the UV-LEDs, at least one, preferably a plurality of internal temperature sensors is arranged in close proximity to the UV-LEDs. The at least one internal temperature sensor is arranged and configured for continuously measuring the temperature of the UV-LEDs and send signals to the control system, which uses the information to regulate the temperature and/or the flow rate of the cooling fluid and thus the temperature of the UV-LEDs. The sending of a signal from the temperature sensor to the receiving part of the control system is preferably frequent. Preferably, a signal is sent from each temperature sensor more often than every 20 minutes, such as once every second, every 10 seconds, every minute or every 10 minutes.

[0032] In some embodiments, each UV-LED unit comprises one internal temperature sensor arranged in close proximity to the UV-LEDs, the internal temperature sensor being configured to measure the temperature of the at least one UV-LED in the UV-LED unit.

In some embodiments, a holding element holds a UV-LED unit as well as one internal temperature sensor configured to measure the temperature of at least one UV-LED in the UV-LED unit, preferably more than one, such as all the UV-LEDs in the UV-LED unit. The temperature of UV-LEDs in a UV-LED unit may vary, thus the regulation needs to take account for this and will depend on the positioning of the UV-LEDs and the internal temperature. In some embodiments, the internal temperature sensor of a UV-LED unit is positioned where most heat is expected to be accumulated, such as in the center of a UV-LED unit. In other embodiments, the internal temperature sensor is placed at a distance from the centre, such as next to the UV-LED unit. As the center of a UV-LED unit may be warmer than what is measured by a temperature sensor positioned next to the UV-LED unit, the predetermined threshold value should in such embodiments be set lower to make sure that the center of the UV-LED unit does not exceed the predetermined threshold value.

Dew forming:

[0033] The cooling may result in dew forming that may reduce the lifespan of the UV-LEDs and/or the electronic circuits on the holding elements.

[0034] A well-known approximation used to calculate the dew point, T_{dp} , given the actual ("dry bulb") air temperature, T (in degrees Celsius) and the relative humidity (in percent), RH, is the Magnus formula:

$$\gamma(T, RH) = \ln\left(\frac{RH}{100}\right) + \frac{bT}{c + T};$$

$$T_{dp} = \frac{c\gamma(T, RH)}{b - \gamma(T, RH)};$$

wherein $b=18.678$, and $c=257.14$ °C

[0035] In some embodiments, information on the dew point is manually provided to the control system.

In some embodiments, the control system receives information on the temperature and humidity of the surroundings from at least one external sensor positioned on a surface of the UV-LED lamp or in the external environment.

In some embodiments, the dew point is calculated based on information on temperature and humidity in the surroundings using the formula above. In some embodiments, another formula is used to calculate the dew point.

The surface of the UV-LED lamp on which the external sensor is placed, may be an inner or outer surface of the UV-LED lamp. The external sensor have to measure the temperature and humidity in the surroundings in a way so the dew point on the cooling wall and/or UV-LEDs can be calculated and dew forming on the cooling wall and/or UV-LEDs can be avoided.

[0036] The external sensor may be a device such as a hygrometer, which may be used to measure the dew point in the surroundings. The external sensor may consist of a polished metal mirror which is cooled as air is passed over it. The temperature at which dew forms is, by definition, the dew point. Manual devices of this sort can be used to calibrate other types of humidity sensors, and automatic sensors may be used in a control loop with a humidifier or dehumidifier to control the dew point.

[0037] In some embodiments, the control system comprises a hygrometer to provide information on the dew point.

[0038] In some embodiments, the control system comprises a humidifier and/or a dehumidifier to control the humidity in the surroundings.

The cooling wall:

[0039] The UV-LED lamp of the present invention comprises a cooling wall having a first surface and an opposite second surface, the at least one fluid channel being an integrated part of the first surface and the plurality of UV-LEDs being arranged on or adjacent to the second surface, wherein the sub-channels are configured for cooling the UV-LEDs by means of heat transfer from the UV-LEDs through the cooling wall to the cooling fluid flowing in the sub-channels, when the UV-LED lamp is in use.

[0040] In some embodiments, each sub-channel is configured for cooling one UV-LED unit by means of heat transfer from the UV-LEDs on the UV-LED unit through the cooling wall to the cooling fluid flowing in a sub-channel.

nel, when the UV-LED lamp is in use.

[0041] The cooling wall is preferably made from material with heat conducting properties, such as metal, so as to be able to absorb heat from the UV-LEDs and transfer it to the inner fluid channels where it is absorbed in the cooling fluid which is in constant movement to prevent the cooling fluid from getting too warm and loose its cooling properties.

[0042] In some embodiments, the cooling wall is made from corrosion-resistant material and/or the at least one fluid channel is coated with corrosion-resistant material on the surface coming in contact with the cooling fluid during use of the UV-LED lamp and/or the cooling fluid comprises anti-corrosive chemicals such as ethylene-glycol and/or propylene-glycol, such as at least 30% glycol, such as 40% or 50% to avoid antibacterial growth and freezing issues down to 35-40 degrees Celsius.

The at least one fluid channel:

[0043] The at least one fluid channel of the present invention comprises a first main channel being fluidly connected to a plurality of sub-channels, each sub-channel being fluidly connected to a second main channel, wherein the sub-channels are shaped and dimensioned so as to provide a turbulent flow for a cooling fluid flowing in the sub-channels, when the UV-LED lamp is in use.

[0044] To create a space where a cooling fluid can flow, the present invention further comprises a plate located adjacent to the first surface of the cooling wall, so that at least one closed fluid channel is formed and the cooling fluid can flow in the at least one fluid channel without leaking cooling fluid to the surroundings.

[0045] In preferred embodiments, the at least one integrated fluid channel is made by recesses in the first surface of the cooling wall. In other embodiments, the at least one integrated fluid channel is a plate comprising fluid channels, inserted in the second surface of the cooling wall.

[0046] In some embodiments, the plate may comprise recesses having a shape similar to the fluid channels, in a way so that the closed fluid channels are part of the cooling wall as well as the plate.

[0047] The closed fluid channels may preferably have a square, triangular or circular cross-section.

[0048] In some embodiments, the first and second main channels are parallel and extend in a longitudinal direction in the first surface of the cooling wall, and the sub-channels extend between the first and second main channels in a transverse direction in the first surface of the cooling wall.

[0049] It is advantageous to have a turbulent flow in the sub-channels, as it ensures a constant mixing of most fluid in the sub-channels as well as a homogenous temperature in the sub-channels. Hereby an efficient cooling is obtained. A turbulent flow is non-laminar.

[0050] The Reynolds number (Re) is a dimensionless quantity in fluid mechanics used to help predict flow pat-

terns in different fluid flow situations. The Reynolds number is used to predict the transition from laminar to turbulent flow.

Laminar flow occurs when $Re < 2300$ and turbulent flow occurs when $Re > 2600$.

[0051] The Reynolds number is defined as

$$Re = \frac{\rho u L}{\mu} = \frac{u L}{\nu} \quad \text{where } \rho \text{ is the density of the fluid}$$

(kg/m^3), u is the velocity of the fluid with respect to the object along which it flows (m/s), L is a characteristic linear dimension such as the diameter of a fluid channel (m), μ is the dynamic viscosity of the fluid ($\text{Pa}\cdot\text{s}$ or $\text{N}\cdot\text{s/m}^2$ or $\text{kg/m}\cdot\text{s}$), ν is the kinematic viscosity of the fluid (m^2/s).

[0052] In preferred embodiments, the Reynolds number in the sub-channels is above 2400, preferably above 2600.

[0053] In some embodiments, the arrangement of the inlet and outlet as well as the shape and dimensions of the at least one fluid channel are so that a laminar flow is established in the cooling fluid flowing in the first and second main channels, when the UV-LED lamp is in use.

[0054] In some embodiments, each sub-channel comprises at least one area, such as a corner, forcing cooling fluid flowing within the sub-channels to change direction to such an extent that a turbulent flow is provided within the sub-channels.

The sub-channels may have a curved or bending path, forcing a cooling fluid flowing in the path to change direction to provide the turbulent flow in the sub-channels. Each sub-channel may comprise at least one non-linear section, such as at least one corner.

Control system:

[0055] The UV-LED lamp of the present invention is connected to a control system adapted to control the temperature and/or the flow rate of the cooling fluid, so that the temperature and/or the flow rate of the cooling fluid is regulated based on inputs from the at least one internal temperature sensor as well as information on the temperature and humidity of the surroundings, in a way so that the temperature of the UV-LEDs as measured by the at least one internal temperature sensor, is always above the dew point and below a predetermined threshold value, when the UV-LED lamp is in use.

[0056] Should the temperature fall below the dew point, the system may be programmed to shut down, restart or stop cooling of the cooling fluid.

[0057] Preferably, each holding element holds a temperature sensor arranged on the holding element in a way so that it can measure the temperature of the UV-LEDs positioned on the holding element. The temperature sensor then sends a signal back to a control system which is also connected to the cooling system. If the temperature of the UV-LEDs is above a predetermined temperature, a signal may be sent to a heat exchanger to

lower the temperature of the cooling fluid until the temperature sensors detect an allowable temperature from the UV-LEDs. Alternatively or in combination therewith, the flow rate of the cooling fluid may be increased so that more heat is transported away from the UV-LEDs.

[0058] In a preferred embodiment, the control system comprises a computer, wherein the computer can receive signals representative of the temperature of UV-LEDs from at least one internal temperature sensor and signals from at least one external sensor representative of the temperature and humidity of the surroundings.

The computer can calculate or receive information on the dew point based on the received signals. The computer can provide at least three actions. Shut down, send a signal to a cooler, to decrease the temperature and cool a cooling fluid, or send a signal to a pump to increase the flow rate of the cooling fluid.

The temperature of the UV-LEDs is allowed to be within a predetermined range, with a lower limit determined by the dew point and a predetermined upper limit (the predetermined threshold value) where overheating of the UV-LEDs is prevented.

The lower limit may be at least one degree above the dew point, such as at least three degrees above the dew point.

[0059] In some embodiments, a temperature sensor is positioned in a way so that information on the temperature of the cooling fluid leaving the cooler can be measured and used to regulate the cooler.

If one or more of the signals received from the at least one internal temperature sensor is above the predetermined upper limit, the computer sends a signal to the cooler, to provide cooling of the cooling fluid.

[0060] As the computer repeatedly, for example every second or every five seconds, receives signals from the at least one internal temperature sensor, the computer will stop signalling the cooler to cool the cooling fluid when the temperature of the UV-LEDs decreases below the predetermined threshold value. If the temperature of one or more UV-LEDs is the same as or within a predetermined distance from the dew point, the signal to the cooler is also stopped.

Housing:

[0061] The present invention may further comprise a housing wherein the cooling wall is arranged, the housing comprising an inlet providing a flow path for the cooling fluid to the first main channel and an outlet, providing a flow path for the cooling fluid from the second main channel out of the housing.

[0062] The inlet and outlet of the housing may preferably be a continuation of the fluid inlet and fluid outlet in the cooling wall.

[0063] The housing and the cooling wall may be made as one piece.

[0064] The housing may comprise a framework for the cooling wall and the plate forming the at least one closed

fluid channel. The function of the housing may be to stabilize the structural elements of the UV-LED lamp.

Outer casing:

[0065] The UV-LEDs, the temperature sensors and or other electronic elements may be sensitive to the external environment and may need protection. The protection may be an outer casing, such as a box, wherein the housing and/or the cooling wall and the plate are positioned.

[0066] Thus, in some embodiments, the UV-LED lamp further comprises an outer casing or outer plate comprising an elongated front with an area through which light from the UV-LEDs can be transmitted.

[0067] The protection may be a single outer plate configured on the cooling wall or on/in the housing to cover the second surface of the cooling wall. However, as the second surface of the cooling wall holds the UV-LEDs, the outer plate is positioned at least 0.2 cm from the UV-LED, such as more than 10 cm from the UV-LEDs. The outer plate or outer casing preferably comprises an area, through which light from the UV-LEDs can be transmitted. The area may be transparent. The area may consist of or comprise glass or plastic. In preferred embodiments, the second surface of the cooling wall face the area of the outer plate or outer casing through which light from the UV-LEDs can be transmitted.

[0068] The housing and the outer casing may be made in one piece.

Method:

[0069] In a third aspect, the present invention relates to a method for curing of a UV curable material with the UV-LED lamp or a UV-LED system as described above. The method comprises:

- arranging at least part of a UV curable material in a light zone of the UV-LED lamp,
- turning on the UV-LED system,
- providing inputs from the at least one internal temperature sensor as well as information on the temperature and humidity of the surroundings to the control system,
- using the control system to calculate the dew point based on the inputs received,
- using the control system to regulate the temperature and/or the flow rate of the cooling fluid based on inputs from the at least one internal temperature sensor as well as information on the temperature and humidity of the surroundings so that the temperature of the UV-LEDs as measured by the at least one internal temperature sensor, is always above the dew point and below a predetermined threshold value, when the UV-LED lamp is in use, and
- curing the UV-curable material for a predetermined period of time.

[0070] In some embodiments, the curable material or product may be positioned on a conveyer belt and moved past or under the UV-LED lamp at a predetermined speed. The length of the UV-LED lamp determines the size of curable materials that can be cured by the UV-LED lamp. Thus, the length of the UV-LED lamp may vary, depending on the size and shape of the curable products the lamp are intended to cure.

[0071] In some embodiments, the UV-LED lamp may be able to move along one or more axes in a way so that a curable object larger than the span of the UV-LEDs in the UV-LED lamp can be cured by moving the UV-LED lamp over or along the object.

[0072] The different aspects of the present invention as described above may each be combined with any of the other aspects as long as it is physically possible. These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE FIGURES

[0073] The UV-LED lamp and UV-LED system according to the present invention will now be described in more detail with regard to the accompanying figures. The figures show one way of implementing the present invention and is not to be construed as being limiting to other possible embodiments falling within the scope of the attached claim set.

Figure 1 schematically illustrates a cooling wall of a UV-LED lamp according to an embodiment of the present invention, where the first surface can be viewed.

Figure 2 schematically illustrates the arrangement of a cooling wall and a plate of the UV-LED system according to an embodiment of the present invention.

Figure 3A and 3B schematically illustrate a cooling wall of a UV-LED lamp according to embodiments of the present invention, where the arrangement of UV-LEDs and internal temperature sensors on the second surface can be viewed.

Fig. 3A is an embodiment where the UV-LEDs and internal temperature sensors are arranged on the second surface of the cooling wall.

Fig. 3B is an embodiment where the UV-LEDs and internal temperature sensors are arranged adjacent to the second surface of the cooling wall, arranged on a holding element on the cooling wall.

Fig. 3C is an embodiment illustrates a holding element holding UV-LEDs and an internal temperature sensor.

Figure 4 schematically illustrates the mechanisms of a control system according to an embodiment of the UV-LED lamp of the present invention.

Figure 5 schematically illustrates a UV-LED system according to an embodiment of the present invention.

Figure 6 schematically illustrates a closed UV-LED system according to an embodiment of the present invention.

Figure 7 schematically illustrates a UV-LED lamp comprising an outer plate with an area through which light from the UV-LEDs can be transmitted according to an embodiment of the present invention.

Figure 8 schematically illustrates an embodiment a UV-LED lamp wherein the cooling wall is arranged in a housing. Fig. 8A shows the housing without an outer plate, whereas fig. 8B shows an embodiment comprising an outer plate with an area through which light from the UV-LEDs can be transmitted.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0074] The present invention relates to a UV-LED lamp and a UV-LED system comprising the UV-LED lamp as well as a cooling system. The UV-LED lamp of the present invention comprises a cooling wall, a plate, a plurality of UV-LEDs and at least one internal temperature sensor, as well as a connection to a control system. The UV-LED lamp is configured for cooling the plurality of UV-LEDs in the UV-LED lamp when the lamp is in use. In use, the UV-LED lamp is connected to a fluid based cooling system comprising a fluid source, a fluid drain, a cooler and a pump.

[0075] Fig. 1 schematically illustrates an embodiment of a cooling wall 11 of a UV-LED lamp of the present invention, showing a possible design of the first surface of the cooling wall 11. The cooling wall 11 has a first surface 19 and an opposite second surface 20.

[0076] The first surface 19 of the cooling wall comprises recesses forming a fluid channel being an integrated part of the first surface 19. The open fluid channel 8 comprises a first main channel 16 being fluidly connected to four sub-channels 17, each sub-channel 17 being fluidly connected to a second main channel 18. The first and second main channels 16, 18 are parallel and extend in a longitudinal direction in the first surface 19 of the cooling wall 11. The sub-channels 17 extend between the first and second main channels 16, 18 in a transverse direction in the first surface 19 of the cooling wall 11. The sub-channels 17 are shaped and dimensioned so as to provide a turbulent flow for a cooling fluid flowing in the sub-channels 17, when the UV-LED lamp is in use. Corners, forcing the cooling fluid flowing within the sub-channels

to change direction to such an extent that a turbulent flow is provided within the sub-channels, when the UV-LED lamp is in use, may provide the turbulent flow. It is advantageous to have a turbulent flow in the sub-channels, as it ensures a constant mixing of most fluid in the sub-channels as well as a homogenous temperature in the sub-channels. Hereby a more efficient heat transfer is obtained.

[0077] The cooling wall 11 further comprises a fluid inlet 9 providing a flow path for a cooling fluid to the first main channel 16 as well as a fluid outlet 10 providing a flow path for the cooling fluid from the second main channel 18 out of the at least one fluid channel.

The arrangement of the fluid inlet 9 and fluid outlet 10 as well as the shape and dimensions of the at least one fluid channel 8 are typically so that a laminar flow is established in the cooling fluid flowing in the first and second main channels 16, 18, when the UV-LED lamp is in use.

[0078] Reference is made to fig. 2 illustrating a cooling wall 11 and a plate 25 which are joined, so that at least one closed fluid channel 8 is formed and the cooling fluid can flow in the at least one fluid channel 8 without leaking cooling fluid to the surroundings, when the UV-LED lamp is in use. The cooling wall 11 and the plate 25 may e.g. be screwed or bolted together.

[0079] Reference is made to fig. 3 illustrating different embodiments of the arrangement of the UV-LEDs and temperature sensors 12 on or adjacent to the second surface 19 of the cooling wall 11.

[0080] The second surface 20 of the cooling wall 11 holds a plurality of UV-LEDs 3 and internal temperature sensors 12 being arranged on or adjacent to the cooling wall 11. The sub-channels 17 on the first surface 19 of the cooling wall 11 are configured for cooling the UV-LEDs 3 by means of heat transfer from the UV-LEDs 3 through the cooling wall 11 to the cooling fluid flowing in the sub-channels 17, when the UV-LED lamp is in use.

[0081] The plurality of UV-LEDs 3 may be arranged in UV-LED units 1 along the cooling wall 11. Each UV-LED unit 1 comprises at least one UV-LED 3, preferably more than one UV-LED 3, such as more than six UV-LEDs 3. A plurality of internal temperature sensors 12 arranged and configured for measuring the temperature of the UV-LEDs 3. Fig. 3A illustrates an example of the arrangement of the UV-LEDs 3 and temperature sensors 12 on the second surface 20 of the cooling wall 11. The second surface illustrated in fig. 3A comprises three UV-LED units 1 arranged with a space between them. Each UV-LED unit comprises sixteen UV-LEDs arranged in close proximity in a row. Eight internal temperature sensors are arranged on the cooling wall, arranged to measure the temperature of nearby UV-LEDs.

[0082] Fig. 3B illustrates an embodiment of the UV-LEDs 3 and temperature sensors 12 adjacent to the second surface 20 of the cooling wall 11. The UV-LEDs 3 and temperature sensors 12 are arranged on holding elements 14 arranged on the second surface 20 of the cooling wall 11. In the embodiment shown in fig. 3B, the

holding elements 14 are arranged on the second surface 20 in close proximity to each other to form a light module. Each of the holding elements is screwed or bolted to the second surface in two points, one in the top and one in the bottom of the holding element 14.

In the embodiment shown in fig. 3B, each holding element 14 holds a UV-LED unit 1 comprising nine UV-LEDs 3 arranged in a dense array with three parallel rows, each row comprising three UV-LEDs. Furthermore, each holding element 14 holds one internal temperature sensor 12 configured to measure the temperature of the UV-LEDs 3 in each UV-LED unit 1. The cooling wall 11 and the holding elements 14 may comprise means for fastening the holding elements to the cooling wall. In fig. 3B, the cooling wall and the holding element comprise holes, so that the holding elements can be bolted to the second surface with fastening means (28) through the holes.

[0083] Fig. 3C illustrates a holding element 14 holding a UV-LED unit 1 comprising fifteen UV-LEDs 3 arranged in a dense array with five parallel rows, each row comprising three UV-LEDs. Furthermore, the holding element 14 holds one internal temperature sensor 12 configured to measure the temperature of one or more UV-LEDs in the UV-LED unit.

[0084] Each holding element 14 is arranged on or adjacent to the second surface 20 of the cooling wall 11 in a way so that heat from the UV-LEDs 3 is transferred through the holding element 14 and through the cooling wall 11 to the cooling fluid flowing in the sub-channels 17, when the UV-LED lamp is in use.

[0085] The UV-LED lamp of the present invention further comprises a connection to a control system 13 adapted to control the temperature and/or the flow rate of the cooling fluid flowing in the fluid channels, when the UV-LED lamp is in use. The temperature and/or the flow rate of the cooling fluid is/are regulated based on inputs from the internal temperature sensors 12 as well as information on the temperature and humidity of the surroundings. The control system is programmed, so that the temperature of the UV-LEDs as measured by the internal temperature sensors is always above the dew point and below a predetermined threshold value, when the UV-LED lamp is in use.

[0086] The control system 13 may receive information on the temperature and humidity in the surroundings from at least one external sensor 21 positioned on a surface of the UV-LED lamp or in the external environment.

[0087] Reference is made to fig. 4, schematically illustrating a control system for controlling the UV-LED lamp of the present invention.

In an embodiment, the control system 13 is a computer receiving signals from at least one external sensor 21 on the temperature and humidity of the surroundings, such as every minute, when the UV-LED lamp is in use. The computer 13 then calculates the dew point every time a signal is received from the at least one external sensor, such as every minute, based on the received signals. Simultaneously, the computer 13 receives signals rep-

representative of the temperature of UV-LEDs 1 from the at least one internal temperature sensor 12. The computer receives signals on the temperature of UV-LEDs from the at least one internal temperature sensor 12 at regular intervals, such as every fifth second, when the UV-LED lamp is in use.

If the temperature of one or more UV-LEDs is above a predetermined threshold value, the computer 13 sends a signal to a cooler 7, to decrease the temperature of the cooling fluid. When the computer 13 receives a signal from the at least one internal temperature sensor 12, indicating that the temperature is below the predetermined threshold value again, it stops signalling the cooler 7 to cool the cooling fluid. Thus, the cooler 7 stops cooling the cooling fluid further. In other embodiments, the system may alternatively or in combination with the above be designed to vary the flow rate of the cooling fluid in order to obtain a higher cooling effect in order to provide the necessary cooling.

The temperature of the UV-LEDs is allowed to be within a predetermined range, with a lower limit determined by the dew point and a predetermined upper limit (predetermined threshold value), where overheating of the UV-LEDs is prevented. If the temperature of one or more UV-LEDs falls below the dew point or if one or more UV-LEDs is above the predetermined threshold value, the system may shut down or warns a person responsible for the system. The lower limit may be at least one degree above the dew point, such as at least three degrees above the dew point.

[0088] The present invention further relates to a UV-LED system comprising the UV-LED lamp as described above and further comprising a fluid-based cooling system 5. Reference is made to fig. 5, showing an embodiment of a UV-LED system of the present invention. The cooling system 5 is adapted for cooling the UV-LEDs 3 by pumping a cooling fluid into the UV-LED lamp through the fluid inlet 9 and receiving the cooling fluid at the fluid outlet 10. Thus, the cooling system 5 comprises a cooling fluid source 6 being fluidly connected to the fluid inlet 9 and a cooling fluid drain 15 being fluidly connected to the fluid outlet 10.

The cooling system further comprises a cooler 7, such as a heat exchanger, configured for cooling of the cooling fluid before it enters the fluid channel 8 through the fluid inlet 9. The cooler is configured to receive inputs from the control system connected to the UV-LED lamp, and regulate the temperature and/or the flow rate of the cooling fluid based on these inputs. A pump 24 is also connected to or comprised in the cooling system, adapted to pump the cooling fluid through the UV-LED system.

[0089] Reference is made to fig. 6, showing a closed UV-LED system of the present invention. The closed system at least comprises the fluid channel 8, the fluid inlet 9, the fluid outlet 10, the cooling fluid source 6, the cooling fluid drain 15 and optionally the cooler. In some embodiments, the fluid flow through the cooler. In some embodiments, an external cooler cools the cooling fluid e.g. in

a pipe, without directly being a part of the closed system.

[0090] Reference is made to fig. 7, showing a UV-LED lamp comprising an outer plate 23 with an area 22 through which light from the UV-LEDs 3 can be transmitted.

[0091] Reference is made to fig. 8, showing a UV-LED lamp wherein the cooling wall 11 is arranged in a housing 4. The second surface 20 of the cooling wall can be viewed in fig. 8. Fig. 8A shows the housing without an outer plate with an area 22 through which light from the UV-LEDs 3 can be transmitted, whereas fig. 8B shows the housing comprising an outer plate with an area 22 through which light from the UV-LEDs 3 can be transmitted.

The housing comprises an inlet 26 providing a flow path for the cooling fluid to the first main channel 8 and an outlet 27, providing a flow path for the cooling fluid from the second main channel 18 out of the housing 4.

[0092] The present invention further relates to a method for curing of UV curable material with a UV-LED system as described herein. The method comprise at least the following steps:

- arranging at least part of a UV curable material in a light zone of the UV-LED lamp,
- turning on the UV-LED system,
- providing inputs from the at least one internal temperature sensor 12 as well as information on the temperature and humidity of the surroundings to the control system 13,
- using the control system 13 to calculate the dew point based on the inputs received,
- using the control system 13 to regulate the temperature and/or the flow rate of the cooling fluid based on inputs from the at least one internal temperature sensor 12 as well as information on the temperature and humidity of the surroundings so that the temperature of the UV-LEDs 3 as measured by the at least one internal temperature sensor 12 is always above the dew point and below a predetermined threshold value, when the UV-LED lamp is in use, and
- curing the UV-curable material for a predetermined period of time.

[0093] Although the present invention has been described in connection with the specified embodiments, it should not be construed as being in any way limited to the presented examples. The scope of the present invention is set out by the accompanying claim set. In the context of the claims, the terms "comprising" or "comprises" do not exclude other possible elements or steps. In addition, the mentioning of references such as "a" or "an" etc. should not be construed as excluding a plurality. The use of reference signs in the claims with respect to elements indicated in the figures shall also not be construed as limiting the scope of the invention. Furthermore, individual features mentioned in different claims, may possibly be advantageously combined, and the mention-

ing of these features in different claims does not exclude that a combination of features is not possible and advantageous.

LIST OF REFERENCE NUMBERS USED

[0094]

1 UV-LED unit	
3 UV-LEDs	10
4 housing	
5 cooling system	
6 cooling fluid source	
7 cooler, such as a heat exchanger	
8 fluid channel	15
9 cooling fluid inlet	
10 cooling fluid outlet	
11 cooling wall	
12 internal temperature sensors	
13 control system	20
14 holding element	
15 cooling fluid drain	
16 first main channel	
17 sub-channels	
18 second main channel	25
19 first surface of cooling wall	
20 second surface of cooling wall	
21 external sensor	
22 area in outer casing through which light from the UV-LEDs can be transmitted	30
23 outer casing or outer plate	
24 pump	
25 plate	
26 housing inlet	
27 housing outlet	35
28 fastening means	

ing fluid to the first main channel (8),
 - a fluid outlet (10), providing a flow path for the cooling fluid from the second main channel (18) out of the at least one fluid channel (8),
 - a plurality of UV-LEDs (3) being arranged on or adjacent to the second surface (20) of the cooling wall (11), wherein

- the sub-channels (17) are configured for cooling the UV-LEDs (3) by means of heat transfer from the UV-LEDs (3) through the cooling wall (11) to the cooling fluid flowing in the sub-channels (17), when the UV-LED lamp is in use,

- a plate (25) located adjacent to the first surface of the cooling wall (11), so that the at least one fluid channel (8) is formed as a closed fluid channel (8) and the cooling fluid can flow in the at least one fluid channel (8) without leaking cooling fluid to the surroundings,

- at least one internal temperature sensor (12) arranged and configured for measuring a temperature of the UV-LEDs (3),

- a connection to a control system (13) adapted to control the temperature and/or the flow rate of the cooling fluid, so that the temperature and/or the flow rate of the cooling fluid is/are regulated based on inputs from the at least one internal temperature sensor (12) as well as information on the temperature and humidity of the surroundings, in a way so that the temperature of the UV-LEDs as measured by the at least one internal temperature sensor is always above the dew point and below a predetermined threshold value, when the UV-LED lamp is in use.

Claims

1. A UV-LED lamp comprising:

- a cooling wall (11) having a first surface (19) and an opposite second surface (20),
 - at least one fluid channel (8) being an integrated part of the first surface (19) of the cooling wall (11) and comprising a first main channel (16) being fluidly connected to a plurality of sub-channels (17), each sub-channel (17) being fluidly connected to a second main channel (18), wherein

- the sub-channels (17) are shaped and dimensioned so as to provide a turbulent flow for a cooling fluid flowing in the sub-channels (17), when the UV-LED lamp is in use,

- a fluid inlet (9), providing a flow path for a cool-

2. The UV-LED lamp according to claim 1, wherein the plurality of UV-LEDs (3) are arranged in UV-LED units (1) along the cooling wall (11), wherein each UV-LED unit (1) comprises at least one UV-LED (3), preferably more than one UV-LED (3), such as more than 6 UV-LEDs (3).

3. The UV-LED lamp according to claim 2, wherein each UV-LED unit (1) comprises a plurality of UV-LEDs (3) arranged in an array comprising more than one row of UV-LEDs.

4. The UV-LED lamp according to claim 2 or 3, wherein each UV-LED unit (1) further comprises at least one internal temperature sensor (12) arranged in close proximity to the UV-LEDs (3), the at least one internal temperature sensor (12) being configured to measure the temperature of the at least one UV-LED (3) in the UV-LED unit (1).

5. The UV-LED lamp according to any of claims 2-4, wherein each UV-LED unit (1) is arranged on a holding element (14), and wherein each holding element (14) is arranged on or adjacent to the second surface (20) of the cooling wall (11) in a way so that heat from the UV-LEDs (3) is transferred through the holding element (14) and through the cooling wall (11) to the cooling fluid flowing in the sub-channels (17), when the UV-LED lamp is in use. 5
6. The UV-LED lamp according to any of the preceding claims, further comprising a housing (4) wherein the cooling wall is arranged, the housing comprising a housing inlet (26) providing a flow path for the cooling fluid to the first main channel (8) and a housing outlet (27), providing a flow path for the cooling fluid from the second main channel (18) out of the housing (4). 10
7. The UV-LED lamp according to any of the preceding claims, further comprising an outer casing (23) or outer plate (23) comprising an elongated front (21) with an area (22) through which light from the UV-LEDs (3) can be transmitted. 20
8. The UV-LED lamp according to any of the preceding claims, wherein the first and second main channels (8, 18) are parallel and extend in a longitudinal direction in the first surface (19) of the cooling wall (11), and the sub-channels (17) extend between the first and second main channels (8, 18) in a transverse direction in the first surface (19) of the cooling wall (11). 25
9. The UV-LED lamp according to any of the preceding claims, wherein each sub-channel (17) comprises at least one area, such as a corner, forcing cooling fluid flowing within the sub-channels to change direction to such an extent that a turbulent flow is provided within the sub-channels (17), when the UV-LED lamp is in use. 30
10. The UV-LED lamp according to any of the preceding claims, wherein the control system (13) receives information on the temperature and humidity in the surroundings from at least one external sensor (21) positioned on a surface of the UV-LED lamp or in an external environment. 35
11. The UV-LED lamp according to any of the preceding claims, wherein the arrangement of the fluid inlet (9) and fluid outlet (10) as well as the shape and dimensions of the at least one fluid channel (8) are so that a laminar flow is established in the cooling fluid flowing in the first and second main channel (16, 18), when the UV-LED lamp is in use. 40
12. A UV-LED system comprising a UV-LED lamp according to any of claims 1-11, further comprising a cooling system (5) for cooling the UV-LEDs (3), the cooling system (5), comprising: 45
 - a cooling fluid source (6) being fluidly connected to the fluid inlet (9) and a cooling fluid drain (15) being fluidly connected to the fluid outlet (10),
 - a cooler (7) for cooling of the cooling fluid contained in the cooling fluid source (6), and
 - a pump (24) connected to the system and adapted to pump the cooling fluid through the system.
13. The UV-LED system according to claim 12, wherein the cooling fluid source (6) and the cooling fluid drain (15) are connected so as to provide a closed system where the cooling fluid is recirculated in the closed system comprising the at least one fluid channel (8), the inlet (9), the outlet (10), the cooling fluid source (6) and the cooling fluid drain (15). 50
14. Use of a UV-LED system according to claim 12 or 13 for curing of UV curable material, such as ink, coating, lacquer, adhesive, or polymer resin.
15. A method for curing of UV curable material with a UV-LED system according to any of claims 12-13, the method comprising: 55
 - arranging at least part of a UV curable material in a light zone of the UV-LED lamp,
 - turning on the UV-LED system,
 - providing inputs from the at least one internal temperature sensor (12) as well as information on the temperature and humidity of the surroundings to the control system (13),
 - using the control system (13) to calculate the dew point based on the inputs received,
 - using the control system (13) to regulate the temperature and or the flow rate of the cooling fluid based on inputs from the at least one internal temperature sensor (12) as well as information on the temperature and humidity of the surroundings so that the temperature of the UV-LEDs (3) as measured by the at least one internal temperature sensor (12) is always above the dew point and below a predetermined threshold value, when the UV-LED lamp is in use, and
 - curing the UV-curable material for a predetermined period of time.

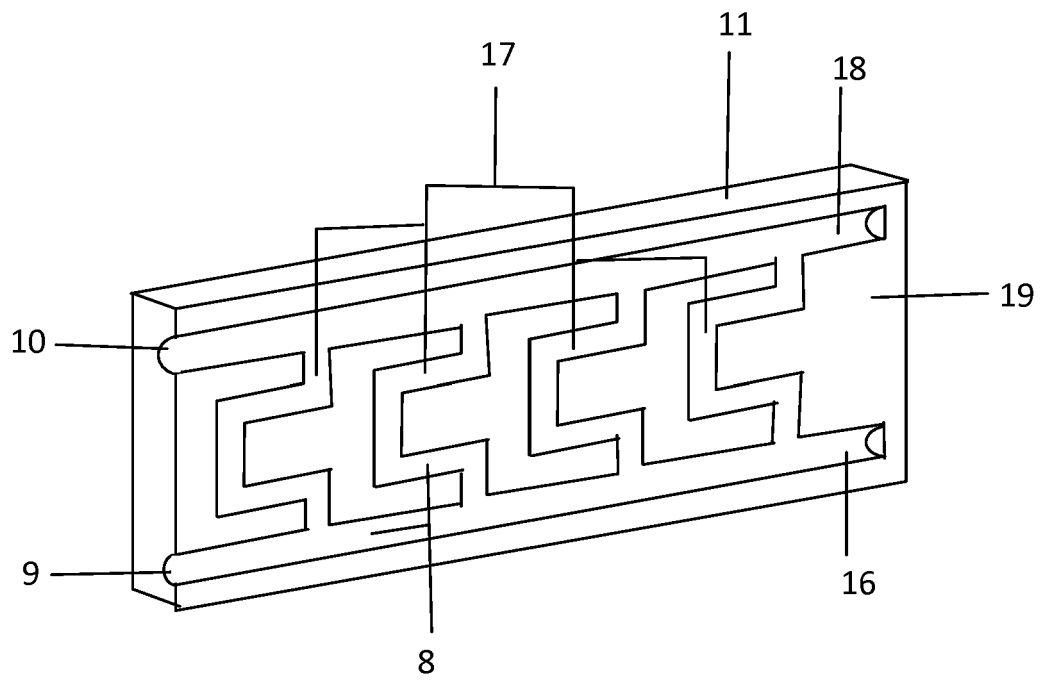


Fig. 1

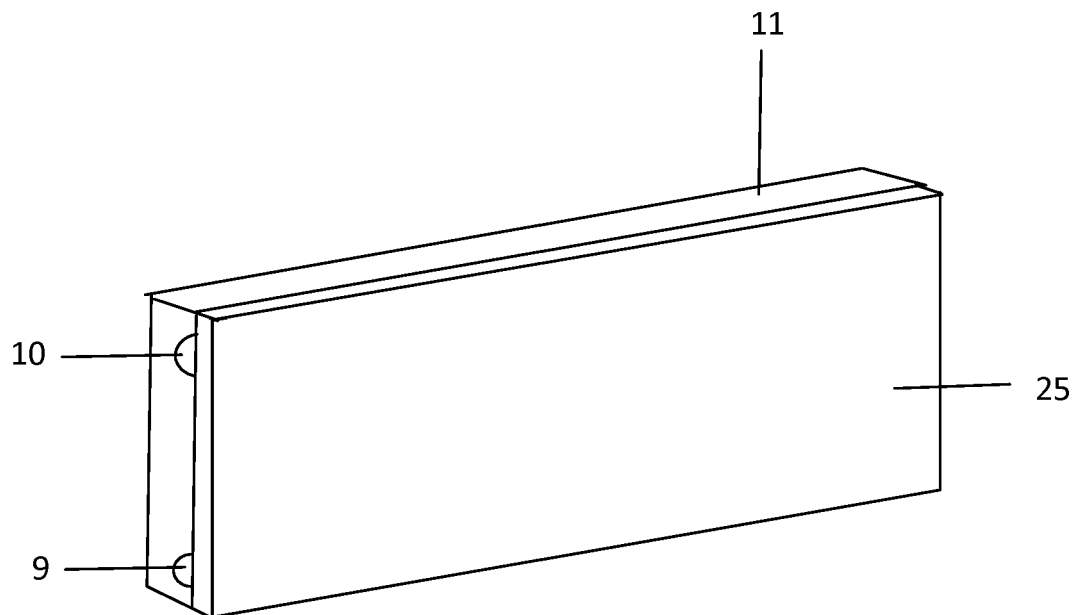


Fig. 2

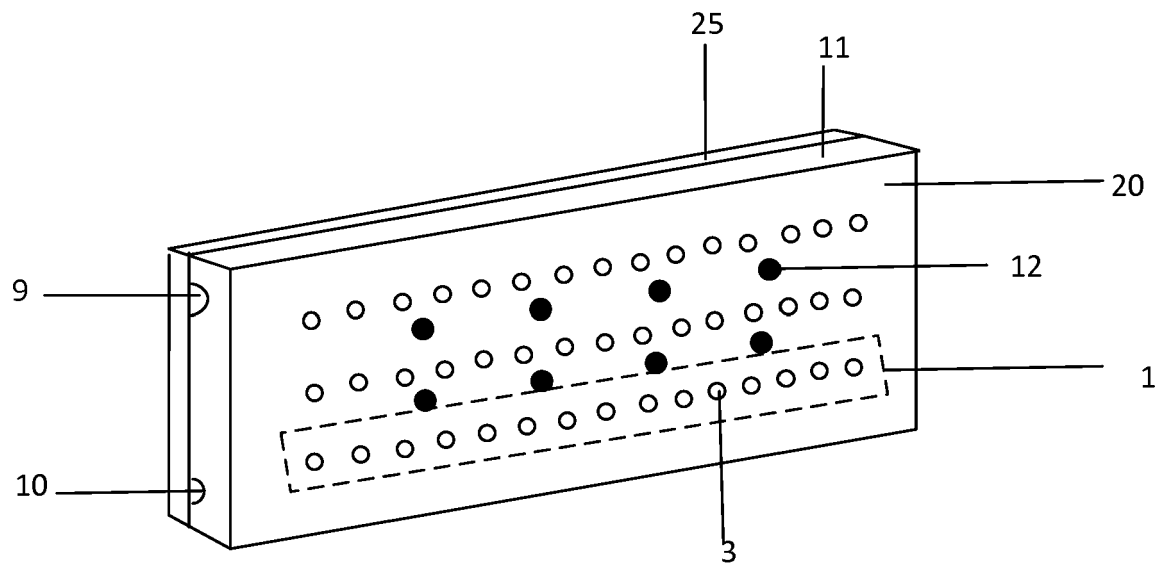


Fig. 3a

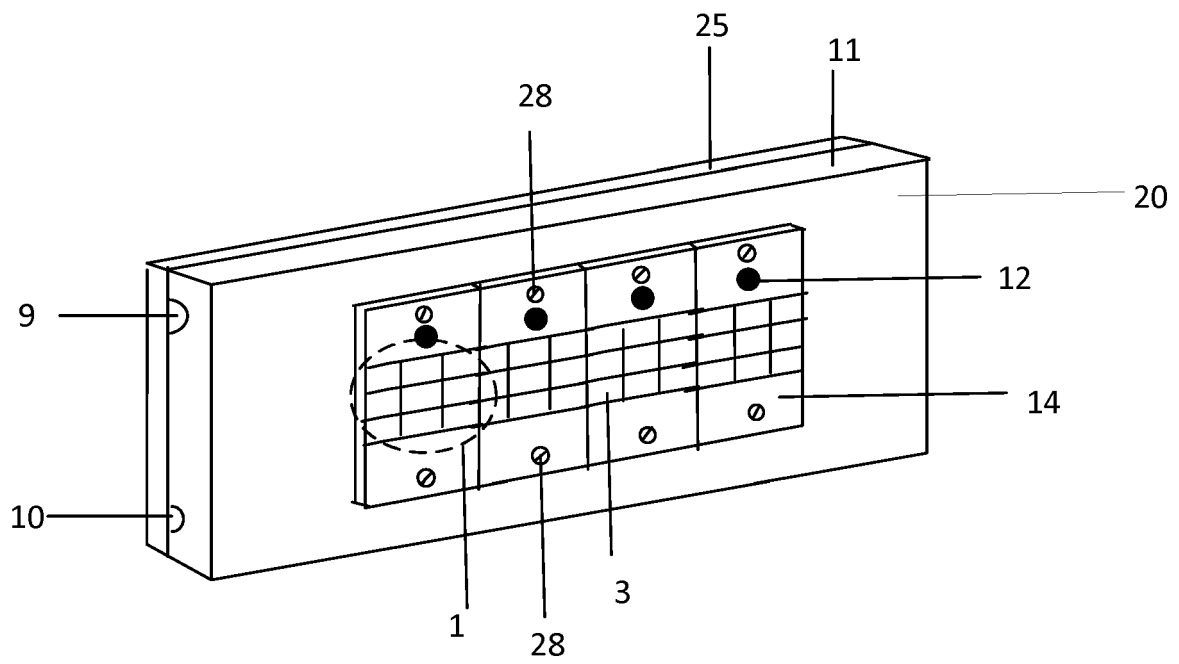


Fig. 3b

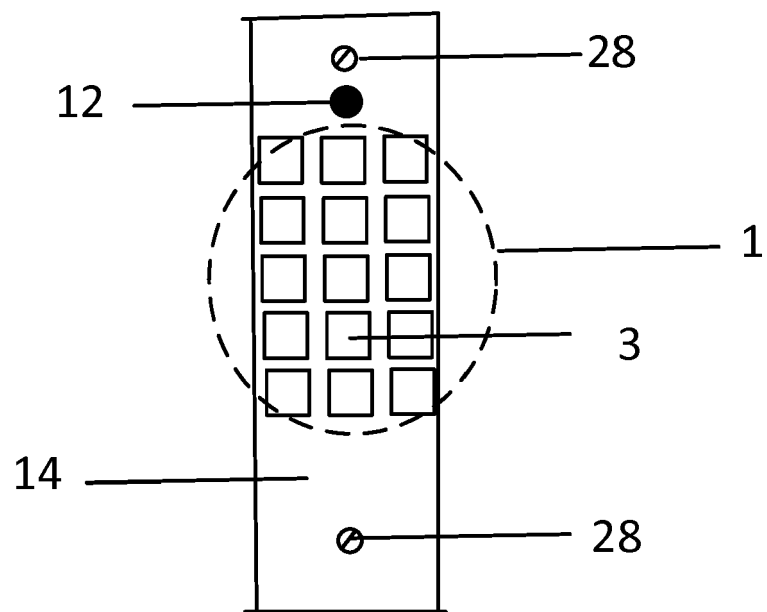


Fig. 3c

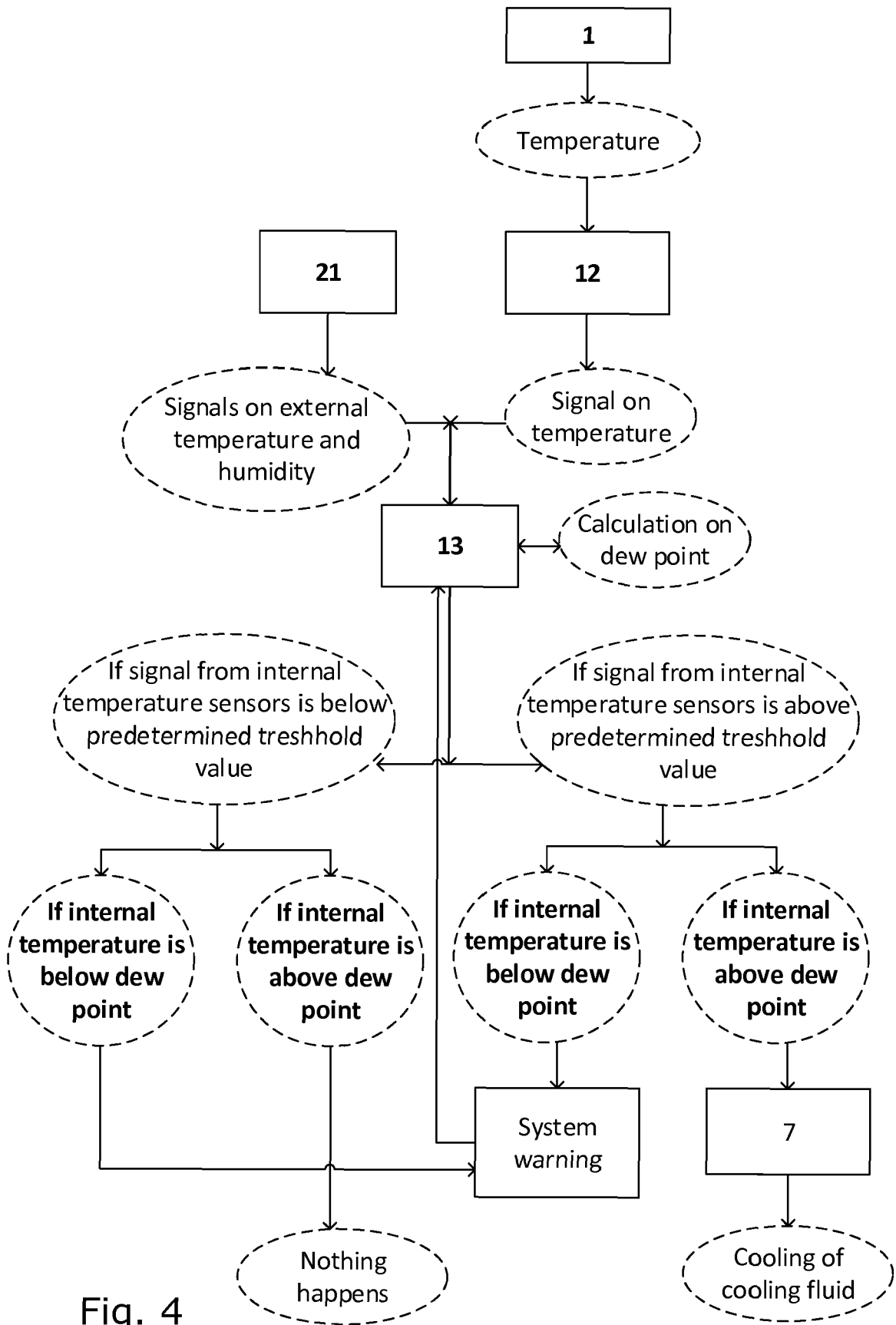


Fig. 4

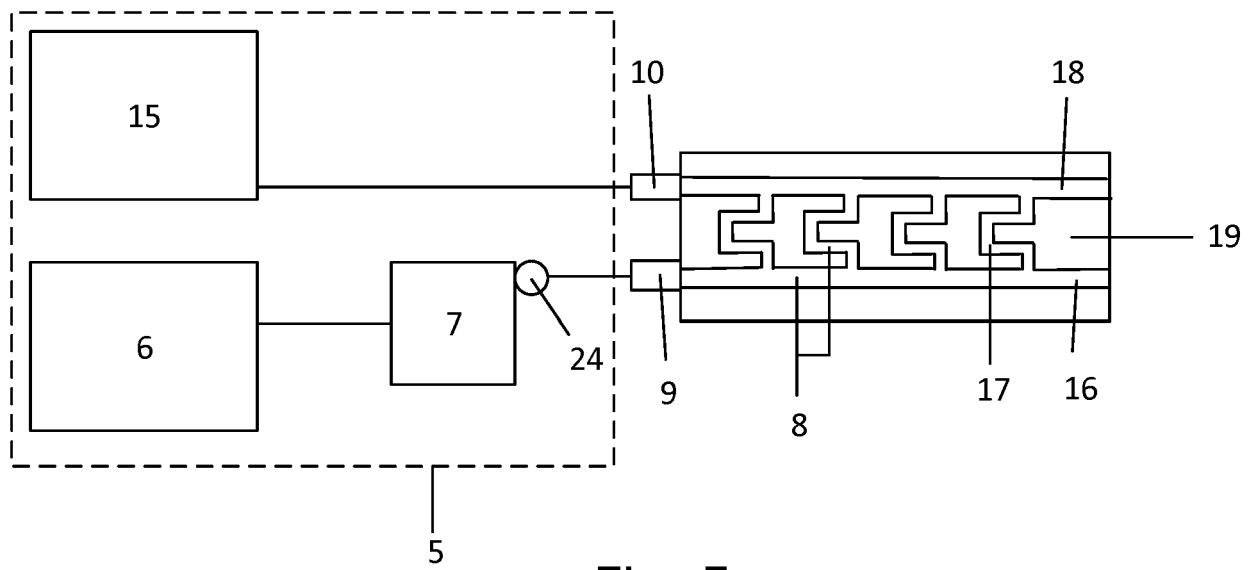


Fig. 5

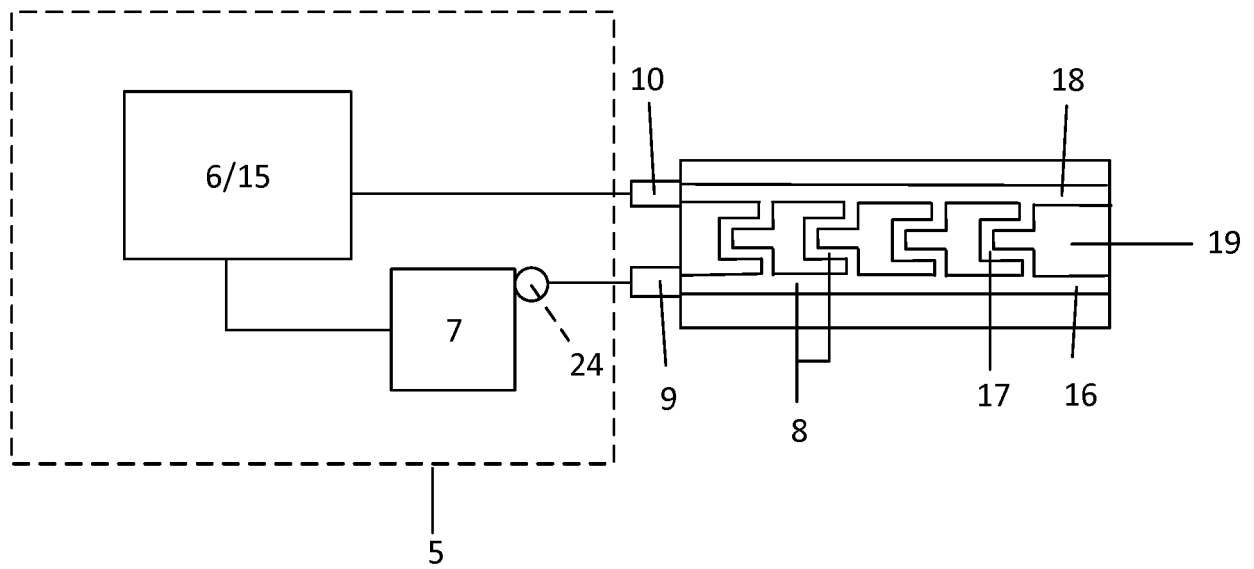


Fig. 6

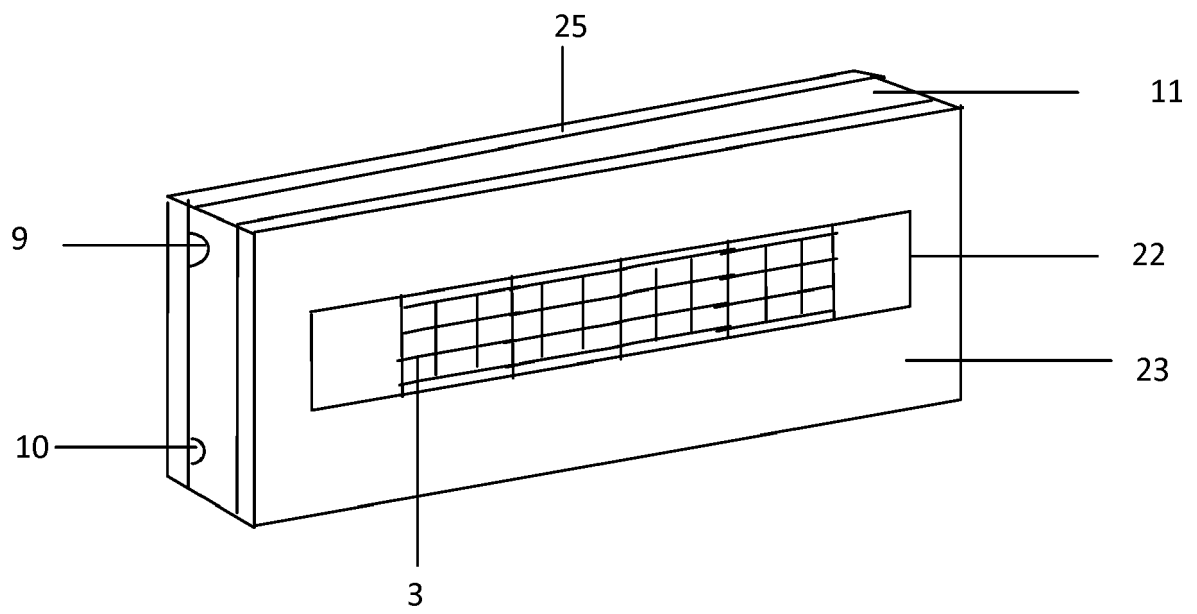


Fig. 7

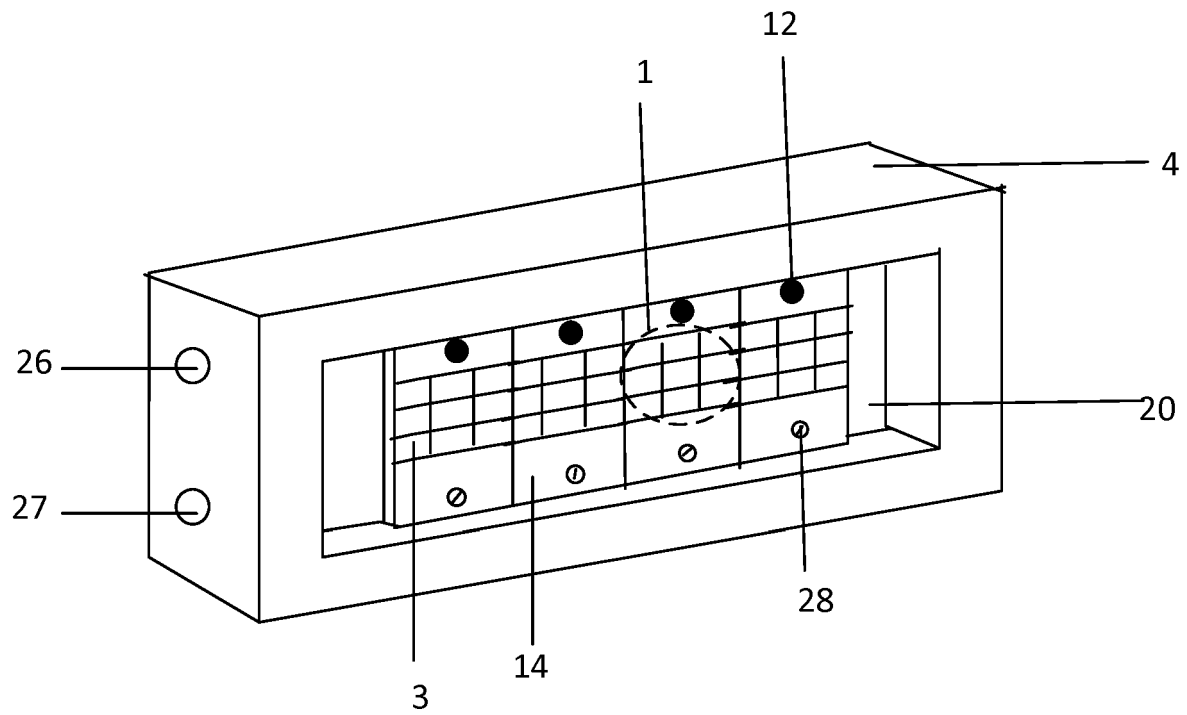


Fig. 8a

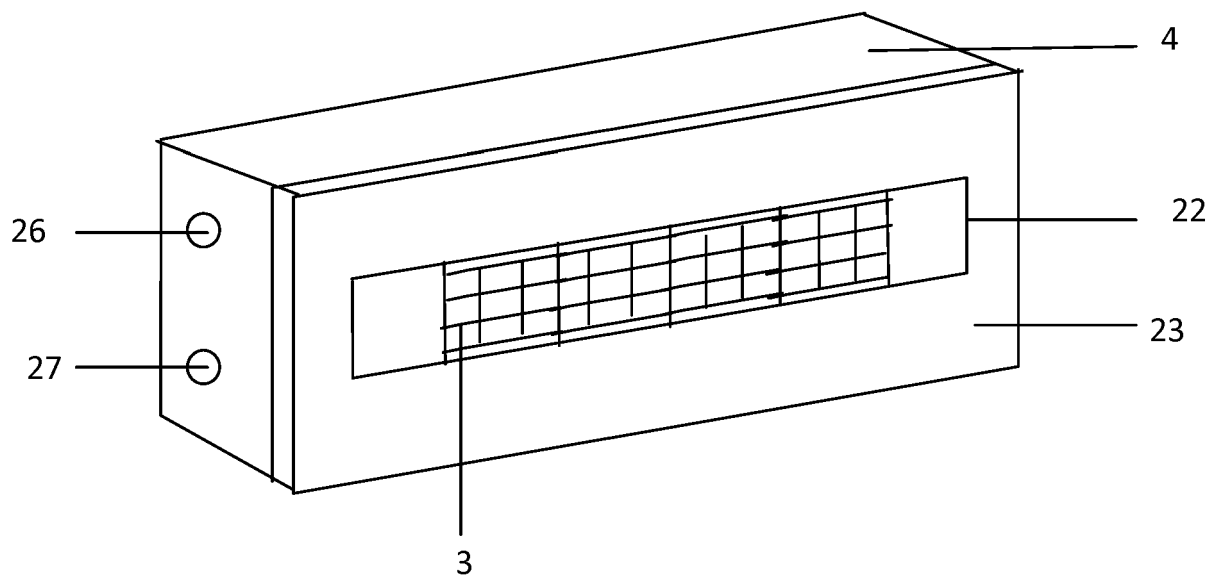


Fig. 8b



EUROPEAN SEARCH REPORT

Application Number
EP 17 20 5879

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Place of search The Hague		Date of completion of the search 9 April 2018	Examiner Blokland, Russell
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