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(54) **Title**: METHOD FOR MEASURING A DEPOSITION RATE AND DEPOSITION RATE CONTROL SYSTEM

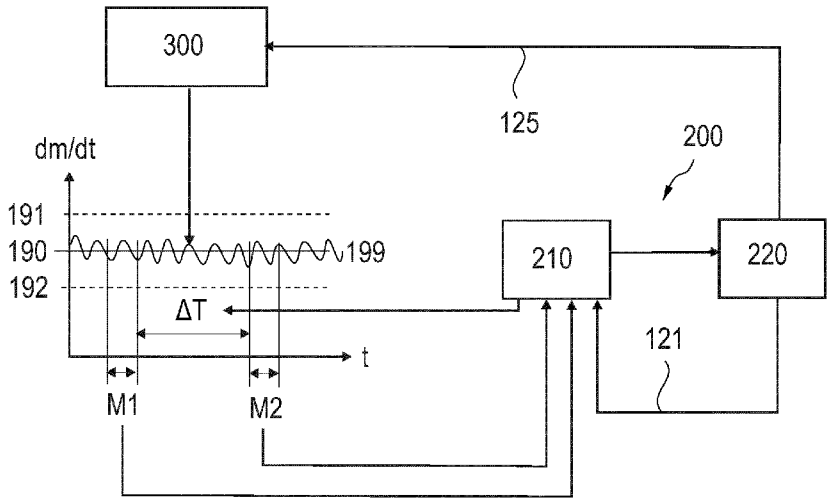


FIG. 4

(57) **Abstract**: A method (100) for measuring a deposition rate of evaporated material is described. The method includes measuring (110) the deposition rate with a time interval ΔT between a first measurement M1 and a second measurement M2, and adjusting (120) the time interval ΔT dependent on the measured deposition rate. Further, a deposition rate control system (200) is described. The deposition rate control system includes a deposition rate measurement assembly (210) for measuring a deposition rate of the evaporated material, and a controller (220) connected to the deposition rate measurement assembly (210) and to an evaporation source (300), wherein the controller is configured to provide a control signal to the deposition rate measurement assembly (210).

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METHOD FOR MEASURING A DEPOSITION RATE AND DEPOSITION RATE CONTROL SYSTEM

TECHNICAL FIELD

[0001] The present disclosure relates to a method for controlling a deposition rate of evaporated material, a deposition rate control system and an evaporation source for evaporation of material. The present disclosure particularly relates to a method and a control system for controlling the deposition rate of evaporated organic material.

BACKGROUND

[0002] Organic evaporators are a tool for the production of organic light-emitting diodes (OLED). OLEDs are a special type of light-emitting diode in which the emissive layer comprises a thin-film of certain organic compounds. Organic light emitting diodes (OLEDs) are used in the manufacture of television screens, computer monitors, mobile phones, other hand-held devices, etc., for displaying information. OLEDs can also be used for general space illumination. The range of colors, brightness, and viewing angle possible with OLED displays is greater than that of traditional LCD displays because OLED pixels directly emit light and do not involve a back light. Therefore, the energy consumption of OLED displays is considerably less than that of traditional LCD displays. Further, the fact that OLEDs can be manufactured onto flexible substrates results in further applications.

[0003] The functionality of an OLED depends on the coating thickness of the organic material. This thickness has to be within a predetermined range. In the production of OLEDs, therefore the deposition rate at which the coating with organic material is effected is controlled to lie within a predetermined tolerance range. In other words, the deposition rate of an organic evaporator has to be controlled thoroughly in the production process.

[0004] Accordingly, for OLED applications but also for other evaporation processes, a high accuracy of the deposition rate over a comparably long time is needed. There is a plurality of measurement systems for measuring the deposition rate of evaporators available. However, these measurement systems suffer from either insufficient accuracy and/or insufficient stability over the desired time period.

[0005] Accordingly, there is a continuing demand for providing improved deposition rate measurement methods, deposition rate control systems, evaporators and deposition apparatuses.

SUMMARY

[0006] In view of the above, a method for measuring a deposition rate of evaporated material, a deposition rate control system, an evaporation source, and a deposition apparatus according to the independent claims are provided. Further advantages, features, aspects and details are apparent from the dependent claims, the description and drawings.

[0007] According to one aspect of the present disclosure, a method for measuring a deposition rate of evaporated material is provided. The method includes measuring the deposition rate with a time interval between a first measurement and a second measurement and adjusting the time interval in dependence of the measured deposition rate.

[0008] According to another aspect of the present disclosure, a deposition rate control system is provided. The deposition rate control system includes a deposition rate measurement assembly for measuring the deposition rate of the evaporated material, a controller connected to the deposition rate measurement assembly, and an evaporation source, wherein the controller is configured to provide a control signal to the deposition rate measurement assembly. In particular, the controller is configured to execute a program code, wherein upon execution of the program code a method for measuring a deposition rate of evaporated material according to embodiments described herein is conducted.

[0009] According to a further aspect of the present disclosure, an evaporation source for evaporation of material is provided. The evaporation source includes an evaporation crucible, wherein the evaporation crucible is configured to evaporate the material; a distribution pipe with one or more outlets provided along the length of the distribution pipe for providing evaporated material at a deposition rate to a substrate, wherein the distribution pipe is in fluid communication with the evaporation crucible; and a deposition rate control system according to embodiments described herein.

[0010] According to yet another aspect of the present disclosure, a deposition apparatus for applying material to a substrate in a vacuum chamber at a deposition rate is provided.

The deposition apparatus includes at least one evaporation source according to embodiments described herein.

[0011] The disclosure is also directed to an apparatus for carrying out the disclosed methods including apparatus parts for performing the methods. The method may be performed by way of hardware components, a computer programmed by appropriate software, by any combination of the two or in any other manner. Furthermore, the disclosure is also directed to operating methods of the described apparatus. It includes a method for carrying out every function of the apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] So that the manner in which the above recited features of the disclosure described herein can be understood in detail, a more particular description, briefly summarized above, may be had by reference to embodiments. The accompanying drawings relate to embodiments of the disclosure and are described in the following:

FIG. 1 shows a block diagram illustrating a method for measuring a deposition rate of evaporated material according to embodiments described herein;

FIG. 2 shows a schematic illustration of a deposition rate control system according to embodiments described herein;

FIG. 3 shows a schematic illustration of a deposition rate control system according to embodiments described herein;

FIG. 4 shows a schematic illustration of a deposition rate control system according to embodiments described herein;

FIG. 5 shows a schematic illustration of measuring a deposition rate according to embodiments of the method for measuring a deposition rate as described herein;

FIGS. 6A and 6B each show a block diagram illustrating embodiments of the method for measuring a deposition rate of evaporated material as described herein;

FIG. 7A shows a schematic view of a measurement assembly in a first state according to embodiments described herein;

FIG. 7B shows a schematic side view of a measurement assembly in a second state according to embodiments described herein;

FIGS. 8A and 8B show schematic side views of an evaporation source according to embodiments described herein; and

FIG. 9 shows a schematic top view of a deposition apparatus for applying material to a substrate in a vacuum chamber according to embodiments described herein.

DETAILED DESCRIPTION OF EMBODIMENTS

[0013] Reference will now be made in detail to the various embodiments of the disclosure, one or more examples of which are illustrated in the figures. Within the following description of the drawings, the same reference numbers refer to same components. In the following, only the differences with respect to individual embodiments are described. Each example is provided by way of explanation of the disclosure and is not meant as a limitation of the disclosure. Further, features illustrated or described as part of one embodiment can be used on or in conjunction with other embodiments to yield yet a further embodiment. It is intended that the description includes such modifications and variations.

[0014] In the present disclosure, the expression "oscillation crystal for measuring the deposition rate" may be understood as an oscillation crystal for measuring a mass variation of deposited material on the oscillation crystal per unit area by measuring the change in frequency an oscillation crystal resonator. In particular, in the present disclosure an oscillation crystal may be understood as a quartz crystal resonator. More particularly, an "oscillation crystal for measuring the deposition rate" may be understood as a quartz crystal microbalance (QCM).

[0015] In the present disclosure, the expression "accuracy of a deposition rate" relates to the deviation of the actual deposition rate, e.g. the measured deposition rate, from a preselected target deposition rate. For example, the smaller the deviation of the measured actual deposition rate from the preselected target deposition rate, the higher the accuracy of the deposition rate.

[0016] With exemplarily reference to FIG. 1, a method 100 for measuring a deposition rate of evaporated material according to embodiments described herein includes measuring 110 the deposition rate with a time interval ΔT between a first measurement and a second measurement, and adjusting 120 the time interval in dependence of the measured deposition rate. In particular, the dependence of the measured deposition rate may be a function of the deposition rate. For example, the first measurement and/or the second measurement may be carried out for 5 minutes or less, particularly for 3 minutes or less, more particularly for 1 minute or less. According to embodiments which can be combined with other embodiments described herein time interval ΔT between a first measurement and a second measurement may be adjusted to be 50 minutes or less, particularly to be 35 minutes or less, more particularly to be 20 minutes or less. Accordingly, by adjusting the time interval between two measurements dependent on a function of the deposition rate, the measurement accuracy of the deposition rate may be increased. In particular, by adjusting the time interval between two measurements in dependence of a function of the deposition rate, the lifetime of a deposition measurement device may be prolonged. In particular, the exposure of the measurement device to evaporated material for measuring the deposition rate of the evaporated material may be reduced to a minimum which can be beneficial for the overall lifetime of the measurement device.

[0017] According to embodiments which can be combined with other embodiments described herein, during an initial adjustment of the preselected target deposition rate the time interval ΔT between a first measurement and a second measurement may be shorter compared to the time interval ΔT between a first measurement and a second measurement when the preselected target deposition rate has been reached. For example, during the initial adjustment of the preselected target deposition rate the time interval ΔT between a first measurement and a second measurement may be 10 minutes or less, particularly to be 5 minutes or less, more particularly to be 3 minutes or less. When the preselected target deposition rate has been reached, the time interval ΔT between a first measurement and a second measurement may be selected from a range between a lower limit of 10 minutes, particularly a lower limit of 20 minutes, more particularly a lower limit of 30 minutes and an upper limit of 35 minutes, particularly an upper limit of 45 minutes, more particularly an upper limit of 50 minutes. In particular, when the preselected target deposition rate has been reached, the time interval ΔT between a first measurement and a second measurement may be 40 minutes.

[0018] According to embodiments which can be combined with other embodiments described herein, the function of the measured deposition rate is selected from the group consisting of: a slope of the deposition rate, a Boolean decision of the deposition rate being in a predetermined range, a polynomial function of the difference of the measured deposition rate to a nominal/set value of a predetermined deposition rate, and an oscillation function of the measured deposition rate. Accordingly, by adjusting the time interval ΔT between two measurements based on a function of the deposition rate the measurement accuracy of the deposition rate may be increased. Further, the exposure of the measurement device to evaporated material for measuring the deposition rate of the evaporated material may be reduced to a minimum which can be beneficial for the overall lifetime of the measurement device.

[0019] According to embodiments which can be combined with other embodiments described herein, the time interval between a first measurement and a second measurement may be adjusted dependent on a deviation of a measured slope of the deposition rate from a preselected slope of the deposition rate. In particular, in the case of a deviation of the measured slope from the preselected slope of the deposition rate of less than 5%, particularly less than 3%, more particularly less than 1.5%, for example 1% or less, is detected, the time interval between a first measurement and a second measurement may be increased. Accordingly, in the case that a deviation of the measured slope from the preselected slope of the deposition rate above 5%, particularly above 3%, more particularly above 1%, for example 1.5%, is detected, the time interval between a first measurement and a second measurement may be decreased.

[0020] According to embodiments which can be combined with other embodiments described herein, the time interval between a first measurement and a second measurement may be adjusted based on a Boolean decision. For example, in the case that a deviation of the measured deposition rate from a preselected target deposition rate is above a preselected upper deposition rate limit or below a preselected lower deposition rate limit, the time interval between a first measurement and a second measurement may be decreased. For example, the preselected upper deposition rate limit may be +3% or below, particularly +2% or below, more particularly +1% or below of the target deposition rate 190. In particular, the preselected upper deposition rate limit may be 1.5%. The lower deposition rate limit may be -3% or below (e.g. -2.5%), particularly -2% or below (e.g. -

1.5%), more particularly -1% or below (e.g. 0.75%) of the target deposition rate 190. In particular, the preselected lower deposition rate limit may be -1.5%.

[0021] According to embodiments which can be combined with other embodiments described herein, the time interval between a first measurement and a second measurement may be adjusted based on a polynomial function of the difference of the measured deposition rate to a nominal/set value of a preselected deposition rate. For example, in the case that a deviation of a polynomial function for the measured deposition rate from a preselected target deposition rate of less than 5%, particularly less than 3% (e.g. 1.5% or less), more particularly less than 1% is detected, the time interval between a first measurement and a second measurement may be increased. Accordingly, in the case that a deviation of a polynomial function for the measured deposition rate from a preselected target deposition rate of above 5%, particularly above 3%, more particularly above 1% (e.g. 1.5% or more) is detected, the time interval between a first measurement and a second measurement may be decreased.

[0022] According to embodiments which can be combined with other embodiments described herein, the time interval between a first measurement and a second measurement may be adjusted based on an oscillation function of the measured deposition rate. For example, in the case that a deviation of an oscillation function for the measured deposition rate from a preselected target deposition rate of less than 5%, particularly less than 3% (e.g. 1.5% or less), more particularly less than 1% is detected, the time interval between a first measurement and a second measurement may be increased. Accordingly, in the case that a deviation of an oscillation function for the measured deposition rate from a preselected target deposition rate of above 5%, particularly above 3%, more particularly above 1% (e.g. 1.5% or more) is detected, the time interval between a first measurement and a second measurement may be decreased.

[0023] FIG. 2 shows a schematic illustration of a deposition rate control system 200 according to embodiments described herein. The deposition rate control system 200 includes a deposition rate measurement assembly 210 for measuring a deposition rate of the evaporated material and a controller 220 connected to the deposition rate measurement assembly 210 and to an evaporation source 300. According to embodiments described herein, the controller 220 may be configured to provide a control signal to the deposition rate measurement assembly 210. In particular, the controller 220 may be configured to

execute a program code, wherein upon execution of the program code a method for measuring a deposition rate according to embodiments described herein is conducted.

[0024] For example, the control signal provided from the controller 220 to the deposition rate measurement assembly 210 may be for adjusting the time interval between a first measurement and a second measurement of the deposition rate. In particular, dependent on the measured deposition rate the time interval between a first measurement and a second measurement may be increased or decreased. For example, in the case that the measured deposition rate is determined to fulfill a preselected criterion, e.g. a stability criterion, the time interval between a first measurement and a second measurement may be increased. Accordingly, in the case that the measured deposition rate is determined not to fulfill a preselected criterion e.g. a stability criterion, the time interval between a first measurement and a second measurement may be increased.

[0025] With exemplary reference to FIG. 2, according to embodiments which can be combined with other embodiments described herein, the deposition rate measurement assembly 210 may measure the actual deposition rate 199. The data of the measured actual deposition rate 199 is transmitted from the deposition rate measurement assembly 210 to the controller 220. Dependent on the measured actual deposition rate 199 the controller 220 may provide a first control signal 125 for controlling the evaporation source 300 for adjusting the deposition rate, e.g. a signal for heating heating-elements provided at the deposition source and/or a signal for cooling cooling-elements provided at the deposition source. According to embodiments which can be combined with other embodiments described herein, the controller 220 may include a closed-loop control including at least one proportional-integral-derivative (PID) controller for controlling the deposition rate. Further, dependent on the measured actual deposition rate 199 the controller 220 may provide a second control signal 121 to the deposition rate measurement assembly 210 for adjusting the time interval ΔT between two measurements, e.g. between a first measurement M1 and a second measurement M2 of the deposition rate, as exemplarily shown in FIG. 4. Accordingly, by providing a deposition rate control system including a controller which is configured for providing a control signal to the deposition rate measurement assembly, the exposure of the measurement device to evaporated material for measuring the deposition rate of the evaporated material may be reduced to a minimum. This can be beneficial for the overall lifetime of the measurement device.

[0026] As exemplary shown in FIG. 3, according to embodiments which can be combined with other embodiments described herein, preselected values for the deposition rate dm/dt may be defined for the deposition rate control system 200. In particular, a target deposition rate 190, an upper deposition rate limit 191, and a lower deposition rate limit 192 may be selected. For example, a measured actual deposition rate 199 may be determined to fulfill a selected deposition rate accuracy criterion in the case that the measured actual deposition rate 199 is within the upper deposition rate limit 191 and the lower deposition rate limit 192, as exemplarily shown in FIG. 3. According to embodiments which can be combined with other embodiments described herein, the upper deposition rate limit 191 may be +3% or below of the target deposition rate 190, particularly +2% or below (e.g. 1.5% or less) of the target deposition rate 190, more particularly +1% or below of the target deposition rate 190. The lower deposition rate limit 192 may be -3% or below (e.g. -2.5%) of the target deposition rate 190, particularly -2% or below (e.g. -1.5%) of the target deposition rate 190, more particularly -1% or below (e.g. -0.75%) of the target deposition rate 190.

[0027] With exemplary reference to FIG. 4, according to embodiments which can be combined with other embodiments described herein, the control signal provided by the controller 220 to the deposition rate measurement assembly 210, e.g. the second control signal 121, may be for adjusting the time interval ΔT between a first measurement M1 and a second measurement M2 of the deposition rate. As exemplarily shown in FIG. 4, the first measurement M1 may be carried out for a first period of time. The deposition rate measurement data of the actual deposition rate 199 may be transmitted from the deposition rate measurement assembly 210 to the controller 220. Depending on the measured actual deposition rate 199 in the first measurement M1, the time interval ΔT between the first measurement M1 and a following measurement, e.g. the second measurement M2, may be determined. For example, in the case that the measured deposition rate is determined to fulfill a selected deposition rate accuracy criterion, the time interval ΔT between the first measurement M1 and the following measurement, e.g. the second measurement M2, may be increased. For example, time interval ΔT between the first measurement M1 and the following measurement may be increased compared to a preset value of the time interval between two measurements, particularly between two subsequent measurements.

[0028] Accordingly, according to embodiments which can be combined with other embodiments described herein, the time interval between the second measurement M2 and a following measurement, e.g. a third measurement, may be determined depending on the measured actual deposition rate 199 in the second measurement M2. For example, in the case that the measured deposition rate of the second measurement M2 is determined to be more accurate than the measured deposition rate of the first measurement M1, the time interval between the second measurement M2 and the following measurement may be increased. Conversely, in the case that the measured deposition rate of the second measurement M2 is determined to be less accurate than the measured deposition rate of the first measurement M1, the time interval between the second measurement M2 and the following measurement may be decreased.

[0029] In FIG. 5 an exemplary schematic illustration of measuring a deposition rate using a method for measuring a deposition rate according to embodiments described herein is shown. In particular, in FIG. 5 an exemplary actual deposition rate 199 [dm/dt] is plotted over time t. Further, FIG. 5 shows an exemplary target deposition rate 190, an exemplary upper deposition rate limit 191, and an exemplary lower deposition rate limit 192. As exemplarily shown in FIG. 5 the exemplary actual deposition rate 199 may vary over time t. In an ideal case, the actual deposition rate 199 is constant over time and corresponds to the preselected target deposition rate 190. However, in reality the actual deposition rate 199 may oscillate around the preselected target deposition rate 190, as exemplarily shown in FIG. 5. Accordingly, the time interval between a first measurement and a second measurement may be adjusted dependent on the measured deposition rate.

[0030] For example, the measured deposition rate may be characterized with respect to a preselected criterion, e.g. a stability criterion, and the time interval between the measurement for which the preselected criterion has to be evaluated and a following measurement may be adjusted depending on the result of the evaluation. For example, in the case that the measured actual deposition rate 199 of a measurement is evaluated to be more accurate than that of a previous measurement, the time interval at which a following measurement is carried out may be increased. In particular, as exemplarily shown in FIG. 5, the measured deposition rate of the second measurement M2 is determined to be more accurate as compared to the first measurement M1, such that the following third measurement is carried out with an increased second time interval $\Delta T2$ in comparison to

the first time interval ΔT1. Accordingly, as exemplarily shown in FIG. 5, in the case that the measured actual deposition rate 199 of a measurement is evaluated to be less accurate than in a previous measurement, the time interval at which a following measurement is carried out may be decreased. In particular, as exemplarily shown in FIG. 5, the measured deposition rate of the fourth measurement M4 is determined to be less accurate as compared to the third measurement M3, such that the following fifth measurement M5 is carried out with a decreased fourth time interval ΔT4 in comparison to the third time interval ΔT3.

[0031] According to embodiments of the method 100 for measuring a deposition rate of evaporated material which can be combined with other embodiments described herein, the method 100 may include shielding 130 a deposition rate measurement device from evaporated material in between the first measurement and the second measurement, as exemplarily shown in the block diagram of FIG. 6A. For example, shielding 130 may include moving a shutter 213 between the deposition rate measurement device 211 and a measurement outlet 230 for providing evaporated material to the deposition rate measurement device 211, as exemplarily shown in FIGS. 7A and 7B. Accordingly, the deposition rate measurement device may be protected from the evaporated material in between measurements, which may be beneficial for the overall lifetime of the deposition rate measurement device.

[0032] According to embodiments of the method 100 for measuring a deposition rate of evaporated material which can be combined with other embodiments described herein, the method 100 may include cleaning 140 the deposition rate measurement device 211 of deposited material in between the first measurement and the second measurement. In particular, cleaning 140 may include evaporating the material deposited on the deposition rate measurement device 211. For example, evaporating the material deposited on the deposition rate measurement device 211 may be performed by heating the deposition rate measurement device. Accordingly, by cleaning the deposition rate measurement device in between measurements the overall lifetime of the deposition rate measurement device may be prolonged.

[0033] In FIGS. 7A and 7B schematic views of a measurement assembly of deposition rate control system according to embodiments described herein are shown. In particular, the deposition rate measurement assembly 210 for measuring a deposition rate of an

evaporated material according to embodiments described herein may include a deposition rate measurement device 211 including an oscillation crystal 212 for measuring the deposition rate. As exemplarily shown in FIGS. 7A and 7B, the deposition rate measurement device 211 may include a holder 250 in which the oscillation crystal 212 may be arranged. The holder 250 may include a measurement opening 122, which can be configured and arranged such that evaporated material may be deposited on the oscillation crystal 212 for measuring the deposition rate of the evaporated material.

[0034] According to embodiments which can be combined with other embodiments described herein, the deposition rate measurement assembly 210 may include a shutter 213 for blocking the evaporated material provided from a measurement outlet 230 for providing evaporated material to the deposition rate measurement device 211, particularly to the oscillation crystal 212. With exemplary reference to FIGS. 7A and 7B, the shutter 213 may be configured to be movable, for example linearly movable, from a first state of the shutter into a second state of the shutter, i.e. the shutter can be a movable shutter. Alternatively the shutter may be configured to be pivotable from a first state into a second state. For example, the first state of the shutter may be an open state in which the shutter 213 does not block the measurement outlet 230 for providing evaporated material to the oscillation crystal 212, as exemplarily shown in FIG. 7A. Accordingly, the second state of the shutter 213 may be a state in which the shutter 213 blocks the measurement outlet 230 such that the oscillation crystal 212 is protected from evaporated material provided through the measurement outlet 230, as exemplarily shown in FIG. 7B.

[0035] By providing the measurement assembly with a shutter the measurement device, particularly the oscillation crystal, may be protected from the evaporated material in between deposition rate measurements which may be beneficial for the overall lifetime of the deposition rate measurement device. Further, by shielding the deposition rate measurement device from evaporated material in between the first measurement and the second measurement using a shutter, negative effects of the heat provided by the evaporated material on the measurement device may be reduced or even eliminated. For example, the quality, accuracy and stability of the deposition rate measurement may be increased by shielding the deposition rate measurement device with a shutter according to embodiments described herein.

[0036] With exemplarily reference to FIG. 7B, according to embodiments which can be combined with other embodiments described herein, the shutter 213 may include a thermal protection shield 216 for protecting the oscillation crystal 212 from the evaporated material. As exemplarily shown in FIG. 7B, the thermal protection shield 216 may be arranged on a side of the shutter 213 which faces the measurement outlet 230. In particular, the thermal protection shield 216 may be configured for reflecting heat energy provided by evaporated material provided through the measurement outlet 230. According to embodiments which can be combined with other embodiments described herein, the thermal protection shield 216 may be a plate, for example a sheet metal. Alternatively, the thermal protection shield 216 may include two of more plates, e.g. sheet metals, which may be spaced with respect to each other, for example by a gap of 0.1 mm or more. For example the sheet metal may have a thickness of 0.1 mm to 3.0 mm. In particular, the thermal protection shield includes a ferrous or non-ferrous material, for example at least one material selected from the group consisting of copper (Cu), aluminum (Al), copper alloy, aluminum alloy, brass, iron, titanium (Ti), ceramic and other suitable materials.

[0037] Accordingly, a measurement assembly including a thermal protection shield according to embodiments described herein may be beneficial for protecting the oscillation crystal from the temperature, e.g. heat, of the evaporated material, in particular when the shutter is in a closed state. In particular, the deposition rate measurements device may cool down when the deposition rate measurement device is shielded from evaporated material in between two measurements. Accordingly, the overall lifetime of the deposition rate measurement device may be prolonged.

[0038] According to embodiments which can be combined with other embodiments described herein, the deposition rate measurement assembly 210 may include at least one heating element 214 for heating the deposition rate measurement device 211 to a temperature at which material deposited on the deposition rate measurement device 211 is evaporated, as exemplary shown in FIGS. 7A and 7B. In particular, the heating element 214 may be arranged in the holder 250, for example next to or adjacent to the oscillation crystal 212. The heating element 214 may be configured to heat the oscillation crystal and/or the holder. Accordingly, the deposition rate measurement device may be cleaned in situ in between two measurements. This can be beneficial, for the overall

lifetime of the deposition rate measurement device and the achievable measurement accuracy.

[0039] According to embodiments which can be combined with other embodiments described herein, the deposition rate measurement assembly 210 may include a heat exchanger 232. In particular, the heat exchanger may be arranged in the holder, for example next to or adjacent to the oscillation crystal and/or next to or adjacent to the heating element 214. The heat exchanger 232 may be configured to exchange heat with the oscillation crystal and/or with the holder 120 and/or with the heating element 214. For example, the heat exchanger may include tubes through which a cooling fluid may be provided. The cooling fluid may be a liquid, e.g. water, or a gas, e.g. air. Additionally or alternatively the heat exchanger may include one or more Peltier element(s). Accordingly, by providing the measurement assembly with a heat exchanger 232 negative effects of high temperature on the quality, accuracy and stability of the deposition rate measurement may be reduced or even eliminated. In particular, providing the measurement assembly with a heat exchanger may be beneficial for cooling the measurement device after the measurement device has been cleaned by heating in order to evaporate deposited material from the deposition rate measurement device, for example in between a first measurement and second measurement.

[0040] With exemplarily reference to FIG. 7B, according to embodiments which can be combined with other embodiments described herein, the deposition rate measurement assembly 210 may include a temperature sensor 217 for measuring the temperature of the deposition rate measurement device 211, particularly the temperature of the oscillation crystal 212 and/or the holder 250. By providing the deposition rate measurement assembly 210 with a temperature sensor 217, information about the temperature of the measurement assembly may be obtained such that a critical temperature at which the oscillation crystal tends to measure inaccurately may be detected. Accordingly, in the case that a critical temperature of the deposition rate measurement device 211 is detected by the temperature sensor an adequate reaction may be initiated, for example a cooling by employing the heat exchanger may be initiated.

[0041] According to embodiments which can be combined with other embodiments described herein, the deposition rate measurement assembly 210 may include a temperature control systemfor controlling the temperature of the oscillation crystal 212

and/or the temperature of the holder 250. In particular, the temperature control system may include one or more of a temperature sensor 217, a heat exchanger 232, a heating element 214 and a sensor controller 233. As exemplarily shown in FIG. 7B, the sensor controller 233 may be connected to the temperature sensor 217 for receiving data measured by the temperature sensor 217. Further, the sensor controller 233 may be connected to the heat exchanger 232 for controlling the temperature of the holder 250 and/or oscillation crystal 212. Further, the sensor controller 233 may be connected to the heating element 214 in order to control the heating temperature of the holder 250 and/or the oscillation crystal 212, e.g. during cleaning as described herein.

[0042] FIGS. 8A and 8B show schematic side views of an evaporation source 300 according to embodiments as described herein. According to embodiments, the evaporation source 300 includes an evaporation crucible 310, wherein the evaporation crucible is configured to evaporate a material, for example an organic material. Further, the evaporation source 300 includes a distribution pipe 320 with one or more outlets 322 provided along the length of the distribution pipe for providing evaporated material, as exemplarily shown in FIG. 8B. According to embodiments, the distribution pipe 320 is in fluid communication with the evaporation crucible 310, for example via a vapor conduit 332, as exemplarily shown in FIG. 8B. The vapor conduit 332 can be provided to the distribution pipe 320 at the central portion of the distribution pipe or at another position between the lower end of the distribution pipe and the upper end of the distribution pipe. Further, the evaporation source 300 according to embodiments described herein includes a deposition rate measurement assembly 210 according to embodiments described herein. As exemplarily shown in FIGS. 8A and 8B, according to embodiments which can be combined with other embodiments described herein, the evaporation source 300 may include a controller 220 connected to the deposition rate measurement assembly 210 and to the evaporation source 300. As described herein, the controller 220 may provide a first control signal 125 to the evaporation source 300 for adjusting the deposition rate. Further, the controller may provide a second control signal 121 to the deposition rate measurement assembly 210 for adjusting the time interval ΔT between two measurements. Accordingly, an evaporation source 300 is provided for which the deposition rate can be measured and controlled with high accuracy.

[0043] As exemplarily shown in FIG. 8A, according to embodiments which can be combined with other embodiments described herein, the distribution pipe 320 may be an elongated cube including a heating element 315. The evaporation crucible 310 can be a reservoir for material, e.g. organic material, to be evaporated with a heating unit 325. For example, the heating unit 325 may be provided within the enclosure of the evaporation crucible 310. According to embodiments, which can be combined with other embodiments described herein, the distribution pipe 320 may provide a line source. For example, as exemplarily shown in FIG. 8B, a plurality of outlets 322, such as nozzles, can be arranged along at least one line. According to an alternative embodiment (not shown), one elongated opening, e.g. a slit, extending along the at least one line may be provided. According to some embodiments, which can be combined with other embodiments described herein, the line source may extend essentially vertically.

[0044] According to some embodiments, which can be combined with other embodiments described herein, the length of the distribution pipe 320 may correspond to a height of a substrate onto which material is to be deposited in a deposition apparatus. Alternatively, the length of the distribution pipe 320 may be longer than the height of the substrate onto which material is to be deposited, for example at least by 10% or even 20%. Accordingly, a uniform deposition at the upper end of the substrate and/or the lower end of the substrate can be provided. For example, the length of the distribution pipe 320 can be 1.3 m or above, for example 2.5 m or above.

[0045] According to embodiments, which can be combined with other embodiments described herein, the evaporation crucible 310 may be provided at the lower end of the distribution pipe 320, as exemplarily shown in FIG. 8A. The material, e.g. organic material, can be evaporated in the evaporation crucible 310. The evaporated material may enter the distribution pipe 320 at the bottom of the distribution pipe and may be guided essentially sideways through the plurality of outlets 322 in the distribution pipe 320, e.g. towards an essentially vertical substrate. With exemplary reference to FIG. 8B, the deposition rate measurement assembly 210 according to embodiments described herein may be provided at an upper portion of the distribution pipe 320, e.g. at the upper end of the distribution pipe 320.

[0046] With exemplarily reference to FIG. 8B, according to embodiments which can be combined with other embodiments described herein, the measurement outlet 230 may be

provided in a wall of the distribution pipe 320, for example in a wall at the backside 224A of the distribution pipe. Alternatively, the measurement outlet 230 may be provided in a top wall 224C of the distribution pipe 320. As exemplarily indicated by the arrow 231 in FIG. 8B the evaporated material may be provided form the inside of the distribution pipe 320 through the measurement outlet 230 to the deposition rate measurement assembly 210. According to embodiments which can be combined with other embodiments described herein, the measurement outlet 230 may have an opening from 0.5 mm to 4 mm. The measurement outlet 230 may include a nozzle. For example, the nozzle may include an adjustable opening for adjusting the flow of evaporated material provided to the deposition rate measurement assembly 210. In particular, the nozzle may be configured to provide a measurement flow selected form a range between a lower limit of 1/70 of the total flow provided by the evaporation source, particularly a lower limit of 1/60 of the total flow provided by the evaporation source, more particularly a lower limit of 1/50 of the total flow provided by the evaporation source and an upper limit of 1/40 of the total flow provided by the evaporation source, particularly an upper limit of 1/30 of the total flow provided by the evaporation source, more particularly an upper limit of 1/25 of the total flow provided by the evaporation source. For example, the nozzle may be configured to provide a measurement flow of 1/54 of the total flow provided by the evaporation source.

[0047] FIG. 9 shows a schematic top view of a deposition apparatus 400 for applying material to a substrate 444 in a vacuum chamber 410 according to embodiments as described herein. According to embodiments which can be combined with other embodiments described herein, the evaporation source 300 may be provided in the vacuum chamber 410, for example on a track, e.g. linear guide 420 or a looped track. The track or the linear guide 420 may be configured for a translational movement of the evaporation source 300. Accordingly, according to embodiments which can be combined with other embodiments described herein, a drive for the translational movement can be provided for the evaporation source 300 at the track and/or the linear guide 420, within the vacuum chamber 410. A first valve 405, for example a gate valve, may be provided which allows for a vacuum seal to an adjacent vacuum chamber (not shown in FIG. 9). The first valve can be opened for transport of the substrate 444 or a mask 432 into the vacuum chamber 410 or out of the vacuum chamber 410.

[0048] According to some embodiments, which can be combined with other embodiments described herein, a further vacuum chamber, such as maintenance vacuum chamber 411 may be provided adjacent to the vacuum chamber 410, as exemplarily shown in FIG. 9. Accordingly, the vacuum chamber 410 and the maintenance vacuum chamber 411 may be connected with a second valve 407. The second valve 407 may be configured for opening and closing a vacuum seal between the vacuum chamber 410 and the maintenance vacuum chamber 411. The evaporation source 300 can be transferred to the maintenance vacuum chamber 411 while the second valve 407 is in an open state. Thereafter, the second valve 407 can be closed to provide a vacuum seal between the vacuum chamber 410 and the maintenance vacuum chamber 411. If the second valve 407 is closed, the maintenance vacuum chamber 411 can be vented and opened for maintenance of the evaporation source 300 without breaking the vacuum in the vacuum chamber 410.

[0049] As exemplarily sown in FIG. 9, two substrates may be supported on respective transportation tracks within the vacuum chamber 410. Further, two tracks for providing masks thereon can be provided. Accordingly, during coating the substrate 444 can be masked by respective masks. For example, the mask may be provided in a mask frame 431 to hold the mask 432 in a predetermined position.

[0050] According to some embodiments, which can be combined with other embodiments described herein, the substrate 444 may be supported by a substrate support 426, which can be connected to an alignment unit 412. The alignment unit 412 may adjust the position of the substrate 444 with respect to the mask 432. As exemplarily shown in FIG. 9 the substrate support4 may be connected to the alignment unit 412. Accordingly, the substrate may be moved relative to the mask 432 in order to provide for a proper alignment between the substrate and the mask during deposition of the material which may be beneficial for high quality display manufacturing. Alternatively or additionally the mask 432 and/or the mask frame 431 holding the mask 432 can be connected to the alignment unit 412. Accordingly, either the mask 432 can be positioned relative to the substrate 444 or the mask 432 and the substrate 444 can both be positioned relative to each other.

[0051] As shown in FIG. 9, the linear guide 420 may provide a direction of the translational movement of the evaporation source 300. On both sides of the evaporation source 300 a mask 432 may be provided. The masks may extend essentially parallel to the

direction of the translational movement. Further, the substrates at the opposing sides of the evaporation source 300 can also extend essentially parallel to the direction of the translational movement. As exemplarily shown in FIG. 9 the evaporation source 300 provided in the vacuum chamber 410 of the deposition apparatus 400 may include a support 302 which may be configured for the translational movement along the linear guide 420. For example, the support 302 may support two evaporation crucibles and two distribution pipes 320 provided over the evaporation crucible 310. Accordingly, the vapor generated in the evaporation crucible can move upwardly and out of the one or more outlets of the distribution pipe.

[0052] As exemplarily shown in FIG. 9, the deposition source may be provided with two or more distribution pipes. For example, two or more distribution pipes may be designed in a triangular shape. A triangular shape of the distribution pipe 320 may be beneficial in the case that two or more distribution pipes are arranged next to each other. In particular, a triangular shape of the distribution pipe 320 makes it possible to bring the outlets for the evaporated material of neighboring distribution pipes as close as possible to each other. This allows for achieving an improved mixture of different materials from different distribution pipes, e.g. for the case of the co-evaporation of two, three or even more different materials.

[0053] Accordingly, the method for measuring a deposition rate of evaporated material, the deposition rate control system, the evaporation source, and the deposition apparatus according to the embodiments described herein provide for improved deposition rate measurement and/or improved deposition rate control. This may be beneficial for high quality display manufacturing, e.g high quality OLED manufacturing.

CLAIMS

1. A method (100) for measuring a deposition rate of evaporated material, comprising
- measuring (110) the deposition rate with a time interval between a first measurement and a second measurement, and
- adjusting (120) the time interval dependent on the measured deposition rate.

2. The method (100) according to claim 1, wherein the dependency of the measured deposition rate is a function of the deposition rate.

3. The method (100) according to claim 1 or 2, wherein the function of the measured deposition rate is selected from the group consisting of: a slope of the deposition rate, a Boolean decision of the deposition rate being in a predetermined range, a polynomial function of the difference of the measured deposition rate to a nominal/set value of a predetermined deposition rate, and an oscillation function of the measured deposition rate.

4. The method (100) according to any of claims 1 to 3, further comprising shielding (130) a deposition rate measurement device from evaporated material in between the first measurement and the second measurement.

5. The method (100) according to claim 4, wherein shielding (130) comprises moving a shutter (213) between the deposition rate measurement device (211) and a measurement outlet (230) for providing evaporated material to the deposition rate measurement device (211).

6. The method (100) according to any of claims 1 to 5, further comprising cleaning (140) the deposition rate measurement device (211) from deposited material in between the first measurement and the second measurement.

7. The method (100) according to claim 6, wherein cleaning (140) comprises evaporating the deposited material from the deposition rate measurement device (211).

8. The method (100) according to claim 7, wherein evaporating the deposited material from the deposition rate measurement device (211) is performed by heating the deposition rate measurement device.

9. A deposition rate control system (200) comprising:
- a deposition rate measurement assembly (210) for measuring a deposition rate of the evaporated material, and
- a controller (220) connected to the deposition rate measurement assembly (210) and to an evaporation source (300), wherein the controller is configured to provide a control signal to the deposition rate measurement assembly (210), particularly wherein the controller is configured to execute a program code, wherein upon execution of the program code a method according to claims 1 to 8 is conducted.

10. The deposition rate control system (200) according to claim 9, wherein the controller (220) comprises a closed-loop control comprising at least one proportional-integral-derivative (PID) controller for controlling the deposition rate.

11. The deposition rate control system (200) according to claim 9 or 10, wherein the deposition rate measurement assembly (210) comprises a deposition rate measurement device (211) comprising an oscillation crystal (212) for measuring the deposition rate.

12. The deposition rate control system (200) according to any of claims 9 to 11, wherein the deposition rate measurement assembly (210) comprises a shutter (213), particularly a movable shutter, for shielding the deposition rate measurement device (211) from evaporated material provided from a measurement outlet (230) for providing evaporated material to the deposition rate measurement device (211).

13. The deposition rate control system (200) according to any of claims 9 to 12, wherein the deposition rate measurement assembly (210) comprises at least one heating element (214) for heating the deposition rate measurement device (211) to a temperature at which material deposited on the deposition rate measurement device (211) is evaporated.

14. An evaporation source (300) for evaporation of material, comprising:
- an evaporation crucible (310), wherein the evaporation crucible is configured to evaporate the material;
- a distribution pipe (320) with one or more outlets provided along the length of the distribution pipe for providing evaporated material at a deposition rate to a substrate, wherein the distribution pipe (320) is in fluid communication with the evaporation crucible (310); and
- a deposition rate control system (200) according to any of claims 9 to 13.

15. A deposition apparatus (400) for applying material to a substrate (444) in a vacuum chamber (410) at deposition rate, comprising at least one evaporation source (300) according to claim 14.

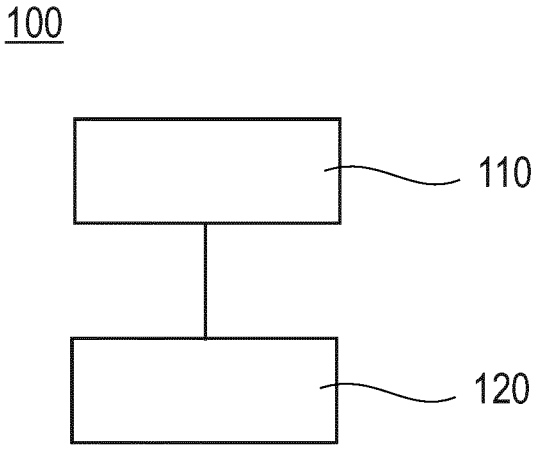


FIG. 1

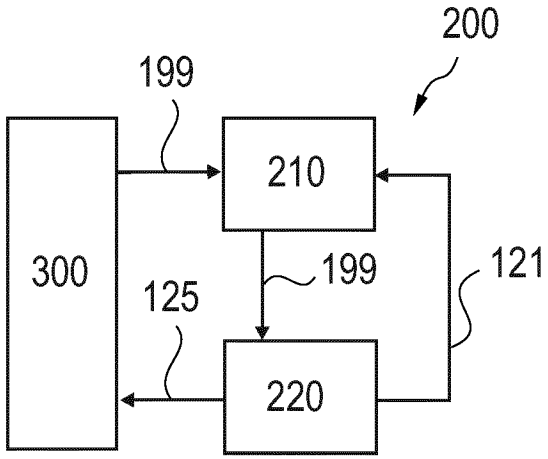


FIG. 2

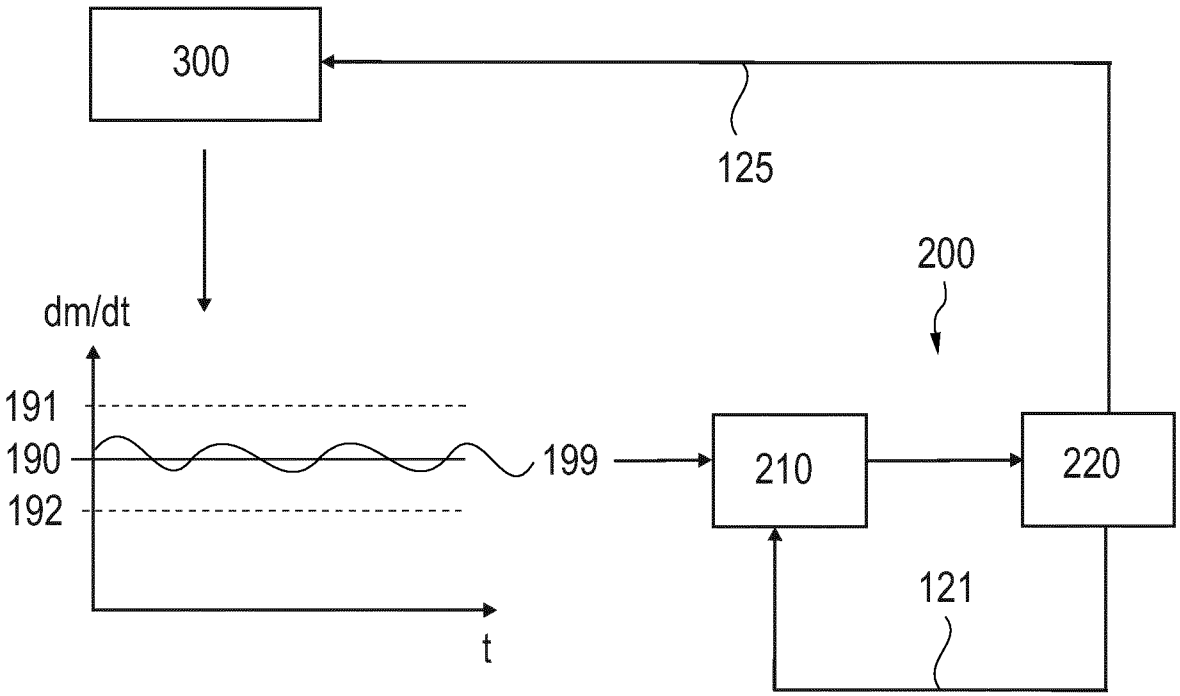


FIG. 3

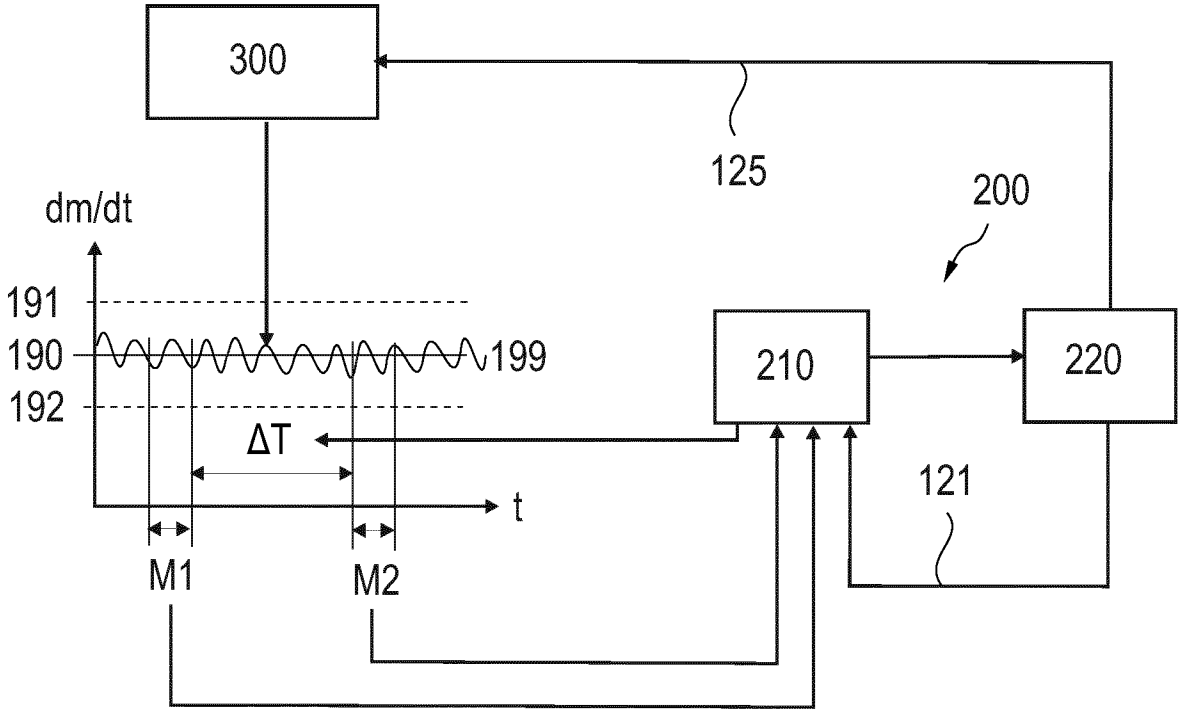

300
125
200
dm/dt
191
190
192
199
210
220
ΔT
121
t
M1
M2

FIG. 4

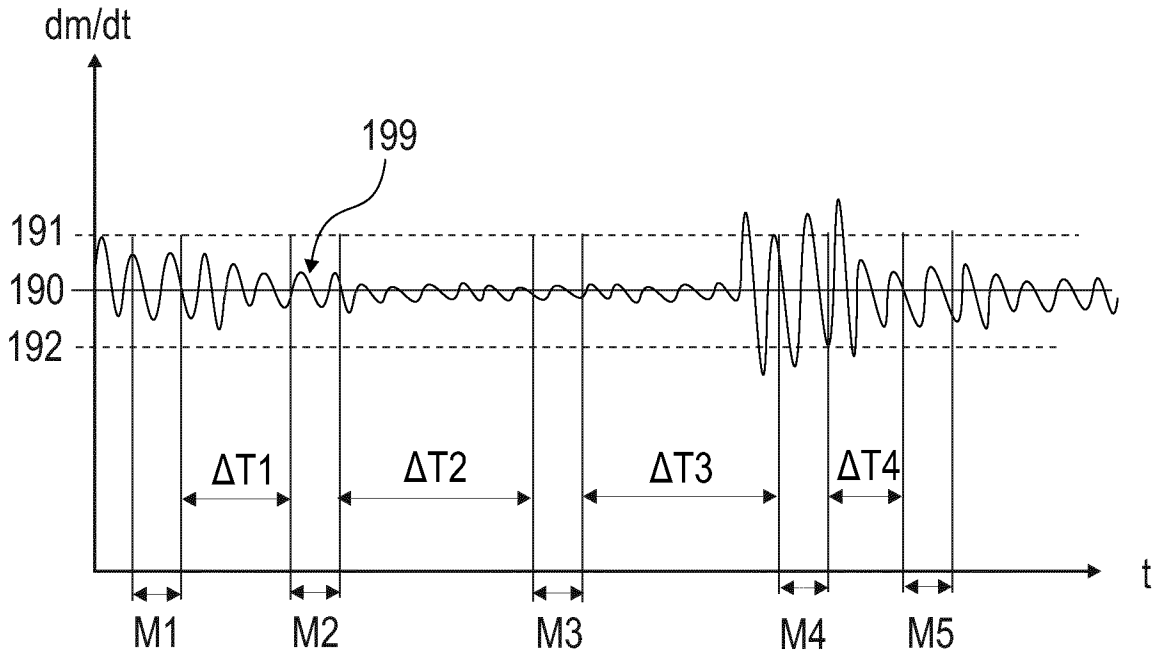

dm/dt
199
191
190
192
ΔT1
ΔT2
ΔT3
ΔT4
t
M1
M2
M3
M4
M5

FIG. 5

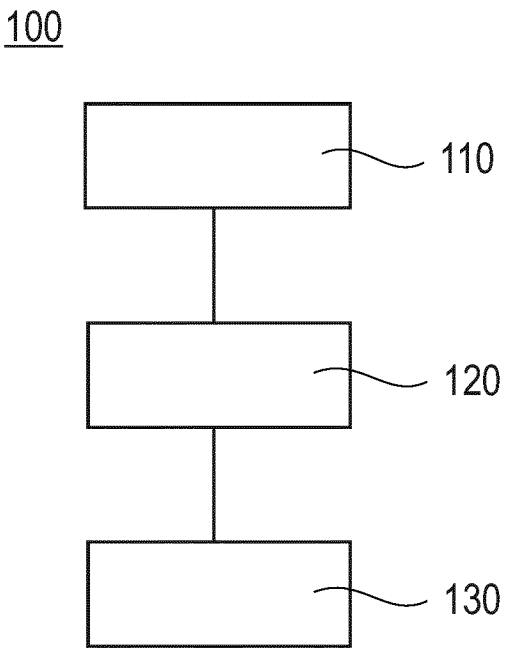


FIG. 6A

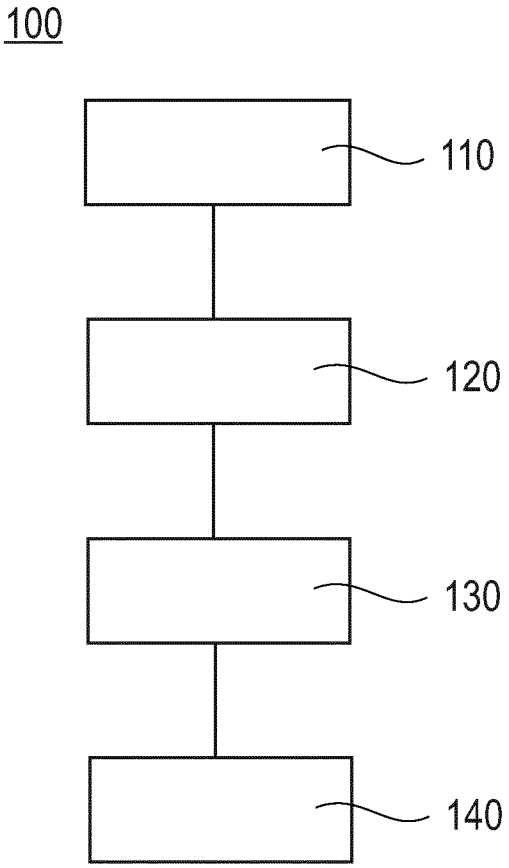


FIG. 6B

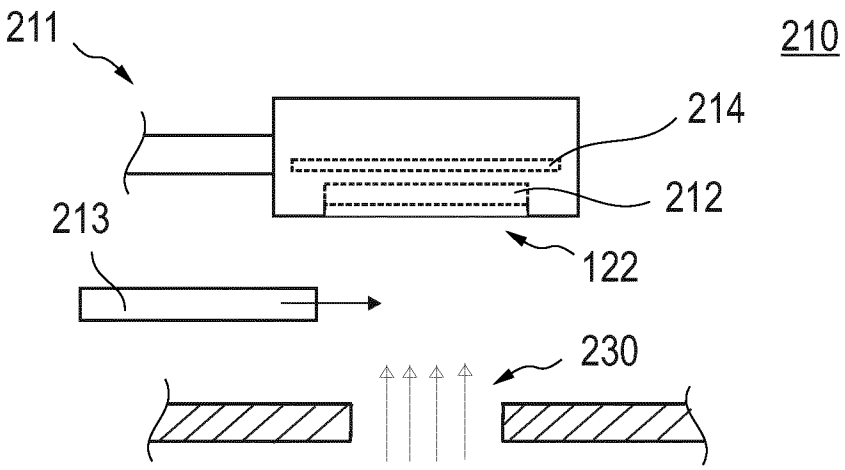


FIG. 7A

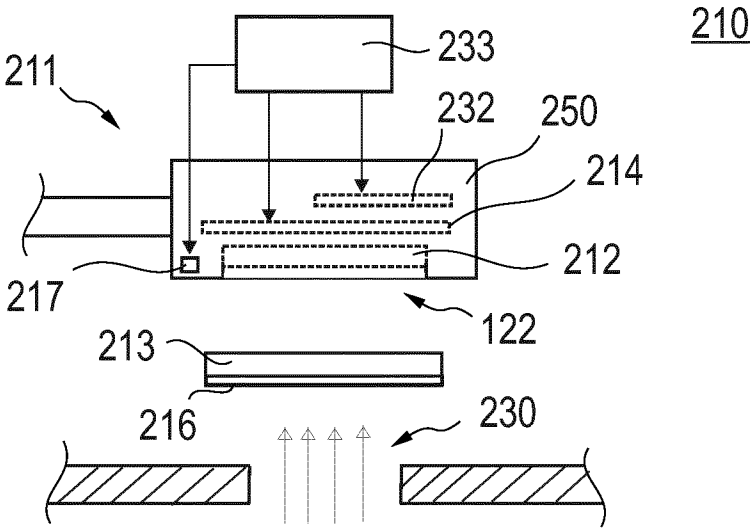


FIG. 7B

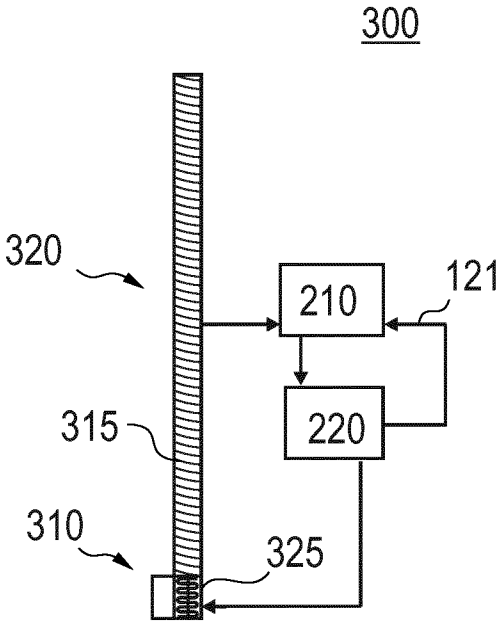


FIG. 8A

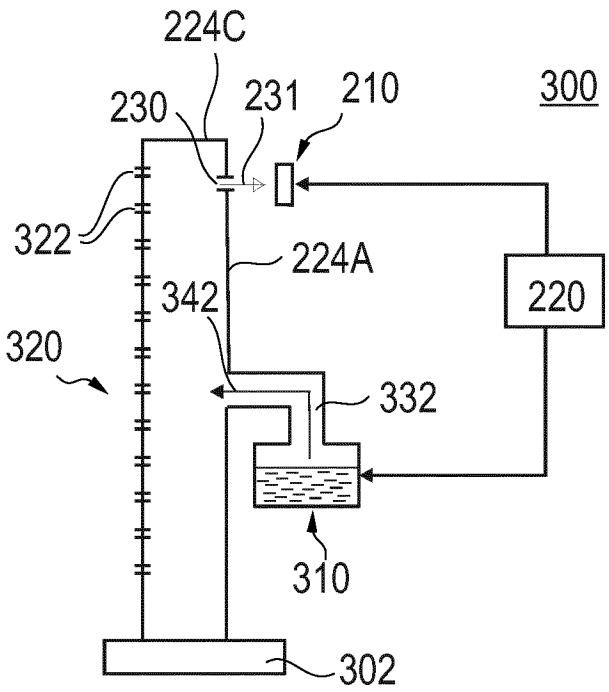


FIG. 8B

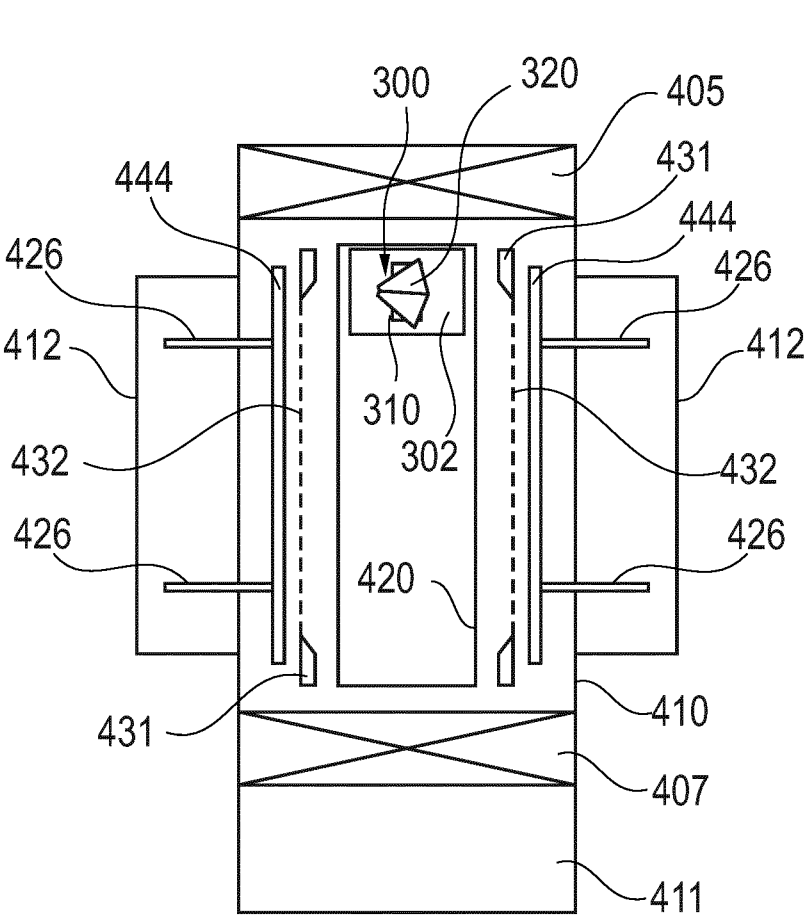

400
300
320
405
431
444
444
426
426
412
412
310
302
432
432
426
426
420
410
431
407
411

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/063636

A. CLASSIFICATION OF SUBJECT MATTER
INV. C23C14/24 C23C14/54 G05B21/02
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)
C23C G05B

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2010/316788 A1 (DIEGUEZ-CAMPO MANUEL [DE] ET AL) 16 December 2010 (2010-12-16) paragraphs [0025], [0033], [0038]; figure 1B	1-15 4-8
X Y	US 2003/140858 A1 (MARCUS MICHAEL A [US] ET AL) 31 July 2003 (2003-07-31) paragraphs [0043], [0044], [0055], [0061]; figures 7,8	1-3,9-15 4-8
X	US 2010/086681 A1 (IKUTA HIROYUKI [JP] ET AL) 8 April 2010 (2010-04-08) paragraphs [0071] - [0085], [0139]; figure 1	1-5, 9-12,14, 15

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

[X] See patent family annex.

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

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 November 2015	19/11/2015

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

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Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/063636

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 2009/306803 A1 (BEHM GARY W [US] ET AL) 10 December 2009 (2009-12-10) paragraph [0032]; figures 4A, 4B -----	1-3

1

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Information on patent family members

International application No
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