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(54) **Title**: FLUX MONITOR

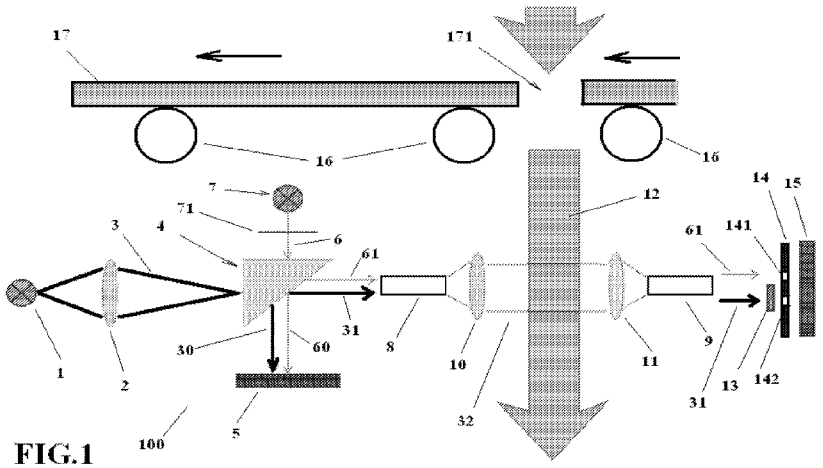


FIG.1

(57) **Abstract**: A flux monitor system includes a light source and a sensor.

WO 2011/082291 A1

Flux Monitor

CLAIM OF PRIORITY

This application claims priority to U.S. Provisional Patent Application No. 61/291,752, filed on December 31, 2009, which is incorporated by reference in its entirety.

TECHNICAL FIELD

This invention relates to a deposition monitoring process, which can include a vapor flux monitor.

BACKGROUND

A photovoltaic device can be manufactured by forming one or more layers of material adjacent to substrate. The materials can include semiconductor materials or metals, for example. Layers can be formed by suitable deposition methods. Past manufacturing processes have been lacking in that they do not include effective means for measuring vapor flux properties of materials being deposited.

DESCRIPTION OF DRAWINGS

FIG. 1 illustrates a configuration of an in-situ flux monitor for in-line deposition process.

FIG. 2 is a perspective view illustrating a measuring light beam split by a plurality of fibers, directed through a vapor flux at different positions, and coupled on the other side of the vapor flux for calibration and measurement.

FIG. 3 is a top view illustrating the measuring light beam split by a plurality of fibers directed through a vapor flux at different positions, coupled on the other side of the vapor flux, and detected by a pixel array sensor.

FIG. 4 is a close-in view of a pixel array sensor, a mask, and a monochromatic filter.

FIG. 5 is a top view of a shield with an aperture and windows transparent in the measurement wavelength.

FIG. 6 illustrates a schematic setup of optical elements of the system.

FIG. 7 illustrates a setup to couple the light through the chamber wall from th side to the vacuum side.

FIG. 8 illustrates a setup to couple the light in and out of the shield.

FIG. 9 is a perspective view illustrating that a UV bandpass filter can be positioned in front of the detector.

FIG. 10 is a diagram of a photodiode output waveform.

FIG. 11 is a diagram of a photodiode output waveform.

DETAILED DESCRIPTION

Photovoltaic devices can include multiple layers formed on a substrate. For example, a photovoltaic device can include layers of semiconductor, metal, and/or ot suitable materials created (e.g., formed or deposited) adjacent to a substrate. Each la may include more than one layer or film. Each layer can cover all or a portion of the device and/or all or a portion of the layer or substrate underlying the layer. For exan a "layer" can mean any amount of any material that contacts all or a portion of a surf The process can be monitored in one aspect by observing and/or measuring informat relating to the flux of the vapor being deposited, such as the vapor flux density. The can include vapor including atoms or other particles of a material being deposited on surface of a substrate. For example, if vaporized material is being deposited in an in deposition process on the top surfaces of a plurality of in-line substrates, vapor that c not contact a substrate surface can flow as vapor flux through gaps between substrate beneath the substrates. Information relating to vapor flux can be measured. For exa the density of the vapor flux, or vapor flux density (e.g., in terms of number of atom particles per unit volume of space) can be measured. Vapor flux density can be measuring using atomic absorption.

When a beam of light passes through a cloud of atoms (e.g., vapor flux) with given density across the light beam diameter, photons at the characteristic wavelengt be absorbed by particular atoms. The amount of absorption depends on the number particular atoms in the light path. Therefore, atomic absorption can be used to monit the metal vapor flux. When an excited atom de-excites, it emits a photon of characte wavelength. Atomic absorption (AA) is the reverse of this process. When a beam o light at the characteristic wavelength passes through a cloud of atoms with certain de across the light beam diameter, photons are absorbed by the atoms. The amount of

absorption depends on the number of atoms in the light path. Therefore, atomic absorption can be used to monitor the vapor flux of metal evaporation, chemical vap deposition (CVD), or other vapor transition deposition process.

To measure the position-sensitive vapor flux density and deposition rate, a spatially dependent sensor of compact dimensions is developed with an in-situ flux monitor configuration for in-line deposition processes. By splitting and directing the measuring light beam through the vapor flux at different locations, position-sensitive information can be obtained. A pixel array sensor is used to measure the absorptions the split measuring light beam. The pixel array sensor can be a 1D detector array (e. line of photodiodes or an integrated line sensor) for a position-sensitive detection. T pixel array sensor can be a 2D detector array. A calibration light can be used. Correlating the absorptions to the flux density from calibration, the position-sensitiv information can be extracted. Spectroscopy can also be used in conjunction with the vapor flux density measurement system.

In one aspect, a method of measuring position-sensitive vapor flux density ca include directing a measuring light beam through a vapor flux of deposition to a pixe array sensor. The measuring light beam can include a wavelength capable of being absorbed by the vapor flux of deposition. The measuring light beam can be generate a light source. The method can include measuring attenuation of the measuring light beam by the pixel array sensor. The method can include determining vapor flux den by calculating the absorption from the attenuation of the measuring light beam and correlating the absorption to vapor flux density.

The method can further include splitting the measuring light beam. The split portions of the measuring light beam can be directed through the vapor flux at differ positions and detected by different segments of the pixel array sensor respectively. T method can include correlating the absorption to vapor flux density at different posit to obtain position-sensitive vapor flux density.

The method can further include generating a calibration light beam. The calibration light beam can be split and directed along the same measuring channel an through the vapor flux, and its attenuation can be detected by the same pixel array se The method can include splitting the calibration light and the measuring light by a pi array sensor mask including a top slit and bottom slit. One of the slits can be used fc calibration light, and the other one of the slits can be used for the measuring light,

shuttering the calibration light beam during measurement. The method can include reading the pixel array sensor, subtracting a contribution from optical coating via the calibration light beam in the measuring channel and correlating absorption to vapor f density after calibration.

The calibration light beam can be white light. The calibration light beam car generated by a monochromatic light source. The calibration light can be designed to absorbed by undesired optical coating, not the vapor flux. The pixel array sensor car include a charge-coupled device (CCD) detector. The pixel array sensor can include complementary metal-oxide-semiconductor (CMOS) detector. The pixel array sensc have a wavelength measurement range of about 100 to about 2000 nm, or about 100 about 1000 nm, or about 200 to about 500 nm.

The method can further include directing a reference light beam to a second sensor without passing through the vapor flux. The reference light beam and the measuring light beam can be generated by the same light source. The method can in measuring attenuation of the reference light beam by the second sensor. The method include calculating vapor flux density by comparing the attenuation of the measuring beam and the attenuation of the reference light beam to eliminate the effect of fluctu of the light source.

The measuring light beam and the reference light beam can be generated by a light source including a hollow cathode lamp. The measuring light beam and the reference light beam can be generated by a light source including a monochromatic l source.

In one aspect, a method to build an in-situ position-sensitive flux monitor sys for in-line deposition process with plurality of separate rollers and plurality of movir substrates can include directing a measuring light beam along a measuring channel through a vapor flux of deposition to a pixel array sensor. The measuring light beam include a wavelength capable of being absorbed by the vapor flux of deposition. The method can include directing a reference light beam to a second sensor without passi through the vapor flux. The method can include positioning the measuring channel u plurality of separate rollers and plurality of moving substrates. The method can incl using the gap between the rollers to pass flux to the measuring channel. The method include mounting the entire system on a backbone made from material with a substantially small coefficient of thermal expansion to minimize the possible

misalignment due to thermal expansion. The method can include measuring attenuat of the measuring light beam by the pixel array sensor, measuring attenuation of the reference light beam by the second sensor. The method can include using the movin substrates and rollers as the flux and radiation shields for the pixel array sensor and second sensor. The method can include calculating vapor flux density by comparing attenuation of the measuring light beam and the attenuation of the reference light bea eliminate the effect of fluctuation of the light source, calculating the absorption from attenuation, and correlating the absorption to vapor flux density.

The method can further include splitting the measuring light beam. The split portions of the measuring light beam can be directed through the vapor flux at differ positions and detected by different segments of the pixel array sensor respectively. T method can include correlating the absorption to vapor flux density at different posit to obtain position-sensitive vapor flux density. The method can further include generating a calibration light beam. The calibration light beam can be split and direc along the same measuring channel and through the vapor flux, and its attenuation car detected by the same pixel array sensor. The method can include splitting the calibra light and the measuring light by a pixel array sensor mask comprising a top slit and bottom slit. One of the slits can be used for the calibration light. The other one of th slits can be used for the measuring light. The method can include using the moving substrates to shutter the flux on and off. The method can include using the shutter-o position to calibrate the measurement. The method can include reading the pixel arra sensor, subtracting a contribution from an undesired optical coating via the calibratic light beam in the measuring channel, and correlating absorption to vapor flux density after calibration.

The method can further include positioning an additional flux and radiation s to protect the pixel array sensor and second sensor. The shield can include a windov transparent in the measuring wavelength range in the measuring channel. The metho can include opening an aperture on the additional flux and radiation shield to allow t vapor flux to pass the measuring channel. The dimension of the aperture can be significantly bigger than the measuring light beam diameter. The pixel array sensor include a charge-coupled device (CCD) detector. The pixel array sensor can include complementary metal-oxide-semiconductor (CMOS) detector. The pixel array sensc

have a wavelength measurement range of about 100 to about 2000 nm, or about 100 about 1000 nm, or about 200 to about 500 nm.

The measuring light beam and the reference light beam can be generated by a light source including a hollow cathode lamp. The measuring light beam and the reference light beam can be generated by a light source including a monochromatic l source. The mounting backbone can include a ceramic material. The mounting back can include graphite. The calibration light beam can be generated by a light source including a monochromatic light source.

A method of manufacturing an in-situ flux monitor system for in-line deposit process using a plurality of separate rollers and plurality of moving substrates can in generating a measuring light beam including a wavelength that can be absorbed by a vapor flux of deposition. The method can include creating a reference signal by spli a portion of the measuring light beam. The portion of the light beam, the reference l beam, is directed along a reference channel without passing through the vapor flux. method can include positioning the measuring channel under plurality of separate rol and plurality of moving substrates. The method can include the substrates being transported on the rollers. The method can include passing flux through the gap betv the rollers to the measuring channel. The method can include mounting the entire sy on a backbone made from material with a very small coefficient of thermal expansio minimize the possible misalignment due to thermal expansion. The method can incl measuring the attenuation of the measuring light beam by a first sensor. The method include measuring the attenuation of the reference light beam by a second sensor. Tl method can include calculating vapor flux density by comparing the attenuation of th measuring light beam and the attenuation of the reference light beam to eliminate the effect of fluctuation of the light source, calculating the absorption from the attenuatic and correlating the absorption to vapor flux density.

The method can further include generating a calibration light beam. The calibration light beam can be directed along the same measuring channel and throug vapor flux. The attenuation of the light beam can be detected by the same first sensc The method can include splitting the calibration light and the measuring light by a fi sensor mask comprising a top slit and bottom slit. One of the slits can be used for th calibration light. The other one of the slits can be used for the measuring light. The method can include using the moving substrates to shutter the flux on and off. The

method can include using the shutter-off position to calibrate the measurement. The method can include reading the first sensor, subtracting the contribution from optical coating via the calibration light beam in the measuring channel, and correlating absorption to vapor flux density from calibration.

The method can further include positioning an additional flux and radiation s to protect the first sensor and second sensor. The shield can include a window transp in the measuring wavelength range in the measuring channel. The method can inclu opening an aperture on the additional flux and radiation shield to allow the vapor flu pass the measuring channel. The dimension of the aperture can be significantly bigg than the measuring light beam diameter. The measuring light beam and the referenc light beam can be generated by a light source including a hollow cathode lamp or monochromatic light source. The mounting backbone can include ceramics or graph The calibration light beam can be generated by a monochromatic light source. The method can further include using the signal change caused by the moving substrates count the number of substrates, check distances between the substrates, and compute moving speed of substrates. The moving substrates shutter the flux on and off and th spacing between the moving substrates determines the length of signal change cycle.

In one aspect, an in-situ flux monitor system for in-line deposition process wi plurality of separate rollers and plurality of moving substrates can include a first ligh source to generate a measuring light beam including a wavelength that can be absorb by a vapor flux of deposition along a measuring channel. The system can include an optic device to create a reference signal by splitting a portion of the measuring light beam. The portion of the light beam, the reference light beam, can be directed along reference channel without passing through the vapor flux. The system can include a plurality of optic fibers to direct the measuring channel under a plurality of separate rollers and plurality of moving substrates, which can be transported on the rollers. T flux can pass through the gap between the rollers to the measuring channel. The syst can include a mounting backbone. The entire system can be mounted on the backbo and the backbone can be made from material with a substantially small coefficient of thermal expansion to minimize the possible misalignment due to thermal expansion. example, the backbone can be made from a material having a smaller coefficient of thermal friction than a metal. The system can include a first sensor to measure the attenuation of the measuring light beam and a second sensor to measure the attenuati

the reference light beam. The system can include a measurement module to calculat vapor flux density by comparing the attenuation of the measuring light beam and the attenuation of the reference light beam to eliminate the effect of fluctuation of the lig source, calculating the absorption from the attenuation, and correlating the absorptio vapor flux density.

The system can include a second light source to generate a calibration light b The calibration light beam can be directed along the same measuring channel and thr the vapor flux, and its attenuation can be detected by the same first sensor. The syst can include a first sensor mask comprising a top slit and bottom slit to split the calib light and the measuring light. One of the slits can be used for the calibration light. other one of the slits can be used for the measuring light. The system can include a configuration to use the moving substrates to shutter the flux on and off. The shutter position can be used to calibrate the measurement. The system can include a calibra module to read the first sensor, subtract the contribution from optical coating via the calibration light beam in the measuring channel, and correlate absorption to vapor flu density from calibration. The configuration can include an additional flux and radiat shield to protect the first sensor and second sensor. The shield can include a windov transparent in the measuring wavelength range in the measuring channel. The syster include an aperture on the additional flux and radiation shield to allow the vapor flux pass the measuring channel. The dimension of the aperture can be significantly bigg than the measuring light beam diameter. The first light source can include a hollow cathode lamp. The first light source can include a monochromatic light source. The mounting backbone can include ceramics. The mounting backbone can include grap The second light source can include a monochromatic light source.

The measurement module can further use the signal change caused by the mc substrates to count the number of substrates, check distances between the substrates, compute the moving speed of substrates. The moving substrates can shutter the flux and off. The spacing between the moving substrates can determine the length of sig change cycle. The optic fiber can include sapphire. The optic fiber can include quar

As described above, when a beam of light at the characteristic wavelength pa through a cloud of atoms with a given density across the light beam diameter, photor absorbed by the atoms. The amount of absorption depends on the number of atoms i light path.

For example, let

I_{in} = incident light intensity

I_{out} = transmitted light intensity

N = number of atoms the beam interacts.

Beer's law states that

$I_{out} = I_{in} \exp(- N/\alpha)$

α is a constant that is related to the cross-section of optical absorption.

$N = \alpha \ln(I_{in}/I_{out})$.

The ratio I_{out}/I_{in} is directly related N. Therefore AA can be used as a monitor metal flux. Note that

$dI_{out}/dN = -(I_{out}/\alpha)$.

AA is most sensitive when I_{out} is large, or when N is small. The major characteristic absorption lines of Cu, In, Zn, Mn, Fe, and Ga are shown below:

Copper	324.75(s)/327.40/217.90 nm
Gallium	287.4/294.36(s)/403.3 nm
Zinc	213.9(s) nm
Manganese	279.5(s) nm
Indium	303.94(s)/325.61 nm
Iron	248.3(s) nm

The notation 's' means the strongest. Therefore, the working wavelength of the ligh source can be in the range of some major characteristic absorption lines of the intere elements. For example, the working wavelength of the light source can be in the 20(350 nm range in the UV.

Referring to Fig. 1, position-sensitive flux monitor system 100 can be placed inside the deposition chamber under moving substrates 17 and rollers 16. Moving substrates 17 can be used to shutter vapor flux 12 off during the measurement. Both moving substrates 17 and rollers 16 can be used to shield position-sensitive flux mor system 100 from the vapor and radiation. Light source 1 can generate light beam 3 including a wavelength that can be absorbed by vapor flux 12. Light source 1 can in any suitable light source. In certain circumstances, light source 1 for AA can includ hollow cathode lamp (HCL) where an Ar or Ne plasma excites the atoms of interest emit the characteristic lines. Light source 1 for AA can include a tunable laser, such tunable diode laser (TDL). Light source 1 can include a light emitting diode (LED).

Light source 1 can emit light beam 3 having any suitable wavelength or range of wavelengths.

The intensity ratio I_{out}/I_{in} can be used for the measurement. I_{in} can be measur shuttering off the metal vapor. Another detector can be used to monitor the HCL out Therefore, corrections can be made to the light intensity if necessary. The transmissi the optical system may change due to metal deposition on the optical elements. If th metal vapor can be shuttered off to measure I_{in}, it is equivalent to an intensity change the light source and be used as above. A white light source 7 (e.g., a light source tha not absorbed or scattered by the metal vapor) can also be used to monitor a change ir transmission.

Referring to Fig. 1, light beam 3 can be split into reference beam 30 and measuring beam 31 by splitter 4. Reference beam 30 can be detected by second sens White light source 7 can generate white light beam 6. Shutter 71 can be used to shut white light beam 6. White light beam 6 can be split into reference beam 60 and calibration beam 61 by splitter 4. Optic fiber bundle 8 can be used to transmit measu beam 31 and calibration beam 61. Measuring beam 31 and calibration beam 61 can directed through vapor flux 12 in measuring channel 32. Measuring beam 31 and calibration beam 61 can be transmitted by optic fiber bundle 9 at the other side of va flux 12. Mask 14 having top slit 141 and bottom slit 142 can be used to split measur beam 31 and calibration beam 61. The emission from the light source (e.g., an HCL include other background emission lines. A bandpass filter either at the source or at detector can be used to filter the unwanted emission lines. For example, monochrom filter 13 can be used to filter measuring beam 31. Any other suitable device can be u for example, a spectrometer.

Pixel array sensor 15 can be a 2D sensor and can be used to measure the attenuation of measuring beam 31 and calibration beam 61. Lenses 2, 10, and 11 car used for directing and coupling of light beam. In other circumstances, the location fo sensing the metal flux can be positioned directly at the plume exciting the source. Th width of the plume can be about 10 – 20 cm, for example, at exit of the source and ca expand to about 80 – 120 cm. For example, the distance between the source exit to t plate can be about 50 – 70 cm. In some embodiments, in order not to interrupt the pl the separation between the AA light probe and the detector path can be at least about 50 cm, for example, 10 – 20 cm. For example, the proximity to the exit of the source

means components may be subjected to considerable radiation heating. Deposition c scattered metal atoms on the optics may also occur. Therefore, a shield (50 in Fig.5) be included in the design. All of these optic components can be positioned outside tl deposition chamber on the atmospheric side. Light can be coupled into and out of th chamber. Pixel array sensor 15 can use a first dimension to detect position informati and a second dimension to detect the spectral information using, for example, a spectrometer. A spectrometer can be used to monitor the characteristics of the light, any other characteristic including the identity of the vapor material. The spectromet be positioned and utilized in any manner suitable to take spectroscopic measurement

The pixel array sensor can have a wavelength measurement range from abou to about 2000 nm. The pixel array sensor can have a wavelength measurement rang from about 100 to about 1700 nm. The pixel array sensor can have a wavelength measurement range from about 100 to about 1000 nm. The pixel array sensor can ha wavelength measurement range from about 200 to about 500 nm.

Referring to Fig. 2 and 3, measuring light beam 31 is split by plurality of opt fiber cables 81, directed through vapor flux 12 at different positions, and coupled on other side of vapor flux 12. Since gap 171 between moving substrates 17 can be use pass vapor flux 12 to measuring channel 32, position-sensitive flux density informati can be obtained. Moving substrates 17 can be used as a shutter of vapor flux 12. Therefore, the signal can be used to sense the presence of a substrate and the time stamped information can allow the measurement of the translation speed of the subst on rollers 16 as well as substrate counting. Each split portion of measuring beam 31 calibration beam 61 is transmitted by plurality of optic fiber cables 91 at the other sic vapor flux 12 and illuminates a given segment of pixel array sensor 15. By measurir attenuation of reference light beam 30 by second sensor 5 (Fig.1), position-sensitive vapor flux density can be extracted by comparing the attenuation of each portion of t measuring light beam 31 and reference light beam 30 (Fig.1), calculating the absorpt from the attenuation by applying Beer's law, and correlating the absorption to vapor density at different positions in the flux. The optic fibers can include sapphire, quart any other suitable optically transparent materials. The system can be used to calcula and/or measure any suitable characteristic based on the absorption, including the den of the vapor (e.g., the density of the vapor flux present in measuring light beam 31).

system can calculate and/or measure position-specific vapor and flux data in one or r dimensions and at various times for comparison.

Referring to Fig. 4, mask 14 can include top slit 141 and bottom slit 142. Ma can be positioned in front of pixel array sensor 15 to split measuring beam 31 and calibration beam 61. Top slit 141 can be used for calibration beam 61. Bottom slit 1 can be used for measuring beam 31. Monochromatic filter 13 can be used to filter measuring beam 31.

Referring to Fig. 5, shield 50 can be included to address the protection of pos sensitive flux monitor system 100 (Fig.1). All of these optic components can be positioned outside the deposition chamber on the atmospheric side. Light can be cou into and out of the chamber through window 52 on the side walls of shield 50. Aper 54 can be included on the top of shield 50 to allow flux to pass to measuring channel (Fig.1 and 2). For example, aperture 54 can be a hole through which the flux can pa: To avoid impacts from material build-up on aperture 54 (shrinking of dimensions), optical beam diameter 55 can be significantly smaller than the opening of aperture 5- Windows 52 transparent in the measurement wavelength can be placed in measuring channel 32 between coupling lens 51 and 53 for protection. The diameter of related coupling pipe holding the lenses should be significantly larger than the beam diamet Finally, to avoid misalignment due to thermal expansion, the entire assembly of posi sensitive flux monitor system 100 with an in-situ flux monitor configuration for in-li deposition process can be mounted to a backbone made from material with a very sn coefficient of thermal expansion (CTE) (e.g., ceramics or graphite). In certain circumstances, a sampling hole can be made through the heat shields and the wall of source. The wall of the source can be hotter than the melt and thus there may not be metal deposition there. However, condensation can happen on the cooler heat shield outside. The gas pressure (including Se) can be in the millitorr range, there may be scattering of the metal atoms off the line of sight and be deposited on the edge of the on the shield. The change in the sampling hole-size can change the sampling flux an periodic maintenance may be used to clean out the sampling hole.

Referring to Fig. 6, depicting a setup of optical elements of a flux monitor sy: light source 1 (e.g., HCL) can remain on during the experiment to maintain stability. light beam 3 from light source 1 is coupled through collimating lens 22 to optical fib 24. The light can be split into reference beam 30 and measuring beam 31. A fiber o

attenuator 24 can be used to adjust the light intensity at any appropriate point. Meas beam 31 is transmitted to pixel array sensor 15 and reference beam 30 is transmitted second sensor 5, for example, as described above. White light source 7, (e.g., a whit LED) can be turned on and off by any suitable control system, including, for exampl computer system 22 via, for example a shutter or attenuator. It can be split into also into a reference beam 60 for monitoring at second sensor 5 and calibration beam 61 transmitted to pixel array sensor 15. .

Referring to Fig. 7, depicting a portion of the deposition chamber, the light (e from a measuring beam 31 (Fig. 6)) can be coupled through the chamber wall 46 fro air side to the vacuum side. Because there may be a difference between the temperat on the vacuum side of the chamber (which may be, for example, about 250 degrees C and the chamber wall (which may be, for example, about 50 degrees C), the choice o vacuum feedthrough and the optical fiber can be selected to withstand these tempera and/or difference between these temperatures. The feedthrough can occur through fl 48 adjacent to an opening in chamber wall 46. Optical fibers 40, 42 can be coupled across flange 46 using a suitable optical connector 44, such as an SMA 905 optical connector. There can be two such feedthroughs, one for guiding the light for AA int chamber, and one for guiding the signal light out from the chamber.

In certain circumstances, the location for sensing the metal flux can be under the conveyor system with measurement occurring in the space in between plates. Fo example, there can be 2 – 4 cm in between the plates on the conveyor. The conveyo speed can be 10 – 100 cm/min. Therefore, there can be a 1 – 25 s gap at which the n flux moves through the space between the conveyor rollers. The metal flux can be available for monitoring. The advantages are the following: there is little interferenc the metal plume and the deposition process; the AA optics are not subjected to the radiation heat from the source, however, it may be shielded from the radiation heat fi the heaters at the bottom of the chamber; in addition, the density of the plume is less. signal might be smaller, but metal deposition on the optical and sensor components c be reduced, especially since the flux is shuttered by the plates a portion of the time (a 3 cm/61 cm, meaning about 5% transmission or about 95% blocked). When the met flux is shuttered, a direct measure of I_{in} can be obtained and there may not be a need the monitoring of the light output from the HCL or using a white light source for correction to transmission. Another solution is to install a mechanical shutter. The

introduction of the Se flux may change the shape of the plume and hence affect the f monitored by AA even if the integrated flux for deposition remains the same. The el from the Se can be studied experimentally in a separate test chamber.

Fig. 8 depicts an in-situ vapor flux monitor system having components in a chamber and an inner chamber (e.g. "hot box") to form a functional feedthrough in tl system. The light can be coupled in and out of the inner chamber, in which the temperature can be at 400 – 800 degrees C. The feedthrough can include one or mor segments of conduit 64 or any other material suitable for transversing inner chamber flange 70 in inner chamber wall 72. A portion of the feedthrough can be mounted at bottom of the inner chamber as the sampling location can be underneath conveyor ro 16, as shown in Fig. 8. A light beam can be transmitted through optical fiber 60 and across inner chamber wall 72 via conduit 64. The light beam can pass through collimating lens 62 to convert the light from optical fiber 60 into a parallel beam out the inner chamber, where the temperature can be 200 – 300 degrees C. The parallel l can be transmitted into the feedthrough. Conduit 64 can include any suitable configuration, size, or material. For example, conduit 64 can include tubing. Condu can include stainless steel. Conduit 64 can include a material having a substantially coefficient of thermal expansion (CTE).

Conduit 64 can be attached to inner chamber wall 72 by attaching it to flange for example, by welding. Stainless steel can be selected as a material for use in cond 64 because stainless steel has low thermal conductivity and is resistant to Se. The le and thickness of conduit 64 can be adjusted to bridge the temperature difference betv the inside of the chamber (for example, about: 200 – 300 degrees C) and the inside tl inner chamber (for example, about 500 – 600 degrees C). The light beam from optic fiber 60 can be transmitted through conduit 64 by reflecting it in the suitable directio where there is a turn in conduit 64, for example. Reflector 66 can be used to reflect t light beam. Reflector 66 can include, for example, a stainless steel mirror or UV pri or any other suitable reflector, situated at any suitable angle (e.g., 45 degrees to chan the direction of the light beam by 90 degrees). Using a stainless steel mirror reduces complications that might result from possible metal deposition on the prism surfaces light beam can be directed toward vapor flux 200. As shown in Fig. 8, conduit 64 re the amount of deposition on reflector 66 from vapor flux 200.

When the light beam is directed at vapor flux 200, vapor flux information car monitored as described above, for example, based on atomic absorption. An apertur slit 68 can be used to control the amount of metal flux 200 sampled. This is in the ca where the absorption is too high that the AA signal is not sensitive enough to the cha in the metal flux. A mechanical shutter can be included to eliminate the necessity of white light path even in the case that the system does not have a plate in the chamber be used as a shutter. After passing through vapor flux 200, the light beam can be transmitted back outside inner chamber wall 72 through an additional length of cond including any suitable reflectors to direct the light beam outside the inner chamber.

With shuttering capability, both I_{in} and I_{out} can be obtained with a single dete in some embodiments. As mentioned above, the HCL has a background besides the emission line. Referring to Fig. 9, light transmitted through optical fiber 74 can be collimated by passing it through collimating lens 76. The collimated light beam can be passed through a UV bandpass filter 78 and to detector 80, which can include a si photodiode, which can be positioned outside the deposition chamber.

In one embodiment, a procedure for metal flux measurement includes the following steps:

1. Set HCL optical attenuator to zero transmission. Read the background sig I_{back}. I_{back} is from stray light and the dark current of the detector.
2. With shutter on (no metal flux), adjust the fiber optic attenuator so that th silicon photodiode output is within the linear range of the detector. The si $I_{shut} = I_{in} + I_{back}$.
3. Open the shutter (metal flux on). The signal is $I_{open} = I_{out} + I_{back}$.

From Beer's law:

$$N = \alpha \ln [(I_{shut} - I_{back}) / (I_{open} - I_{back})].$$

The value for α can be measured by directly measuring the thickness of the deposited film. Referring to Fig. 10, the photodiode output waveform is shown. Du production, the moving plate can act as a shutter. As shown in Fig. 10, the photodio output waveform can be idealistic square wave function in case of shuttered flux. In some embodiments, the waveform can have a sloped signal, as shown in FIG. 11. Tl signal can have any slope that can result from the flux, including in the case of a shu flux.

In the case when the metal flux cannot be shuttered, the light intensity monitc photodiode and the "white" LED can be included to calibrate out any change in the transmission in the AA optical path e.g. due to metal deposition on the optical eleme The light intensity monitoring photodiode can be called PD2. The AA signal photod can be called PD1. The calibration can be made between PD1 and PD2 for both the sensing light and the white LED, assuming that the background signals from the two are always subtracted already.

In certain circumstances, procedure for calibration can be:

1. Metal source off
2. Turn on HCL until stable
3. With white LED off or LED fiber attenuator set to zero output, set the HC light level to a convenient value for measurement using the HCL fiber attenuator
4. Read PD1 and PD2 outputs
5. Initial calibration factor k_{HCLi} = PD1 output/PD2 output
6. Take out the UV bandpass filters for the photodiode detectors
7. With HCL fiber attenuator set to zero output, set the LED light level to a convenient value for measurement using the LED fiber attenuator
8. Read PD1 And PD2 outputs
9. Initial calibration factor k_{LEDi} = PD1 output/PD2 output

In other circumstances, during metal flux measurement, the HCL can be kept to maintain its stability. Therefore, PD1 can always have an output I_{AA} as the AA si However, the transmission of the optics may change due to metal deposition on the c elements. A correction measurement can be made. For this measurement, the white whose light is not attenuated to any significant extent by the metal flux can be used. procedure to make transmission correction can be:

1. Block off the HCL light
2. Take out the UV bandpass filters
3. LED on
4. Take reading:
    a. PD1 : I_{LED1}

b. PD2: I_{LED2}

5. Take the ratio $k_{LED} = I_{LED1}/I_{LED2}$
6. Transmission correction factor $\beta = k_{LEDi}/k_{LED}$
7. The transmission correction factor has to be applied to the AA signal.
8. Turn off LED
9. Unblock HCL
10. Replace UV bandpass filters
11. Take reading:
    a. PD1 : I_{AA}
    b. PD2: I_{HCL}

$I_{out} = I_{AA}$

$I_{in} = I_{HCL}*k_{HCLi}/\beta$.

Therefore

$$N = \alpha \ln (I_{in}/I_{out})$$

$$= \alpha \ln (I_{HCL}*k_{HCLi}/\beta I_{AA})$$

$$= \alpha \ln [(\text{PD2 signal}/\text{PD1 signal})*(k_{HCLi}/\beta)]$$

Here α has the same value as the α for the shuttered case.

A number of embodiments of the invention have been described. Neverthele will be understood that various modifications may be made without departing from t spirit and scope of the invention. It should also be understood that the appended dra are not necessarily to scale, presenting a somewhat simplified representation of varic preferred features illustrative of the basic principles of the invention.

WHAT IS CLAIMED IS:

1. A method of measuring position-sensitive vapor flux density comprising:
directing a measuring light beam through a vapor flux of deposition to a pixe
array sensor, wherein the measuring light beam includes a wavelength capabl
being absorbed by the vapor flux of deposition;
measuring attenuation of the measuring light beam by the pixel array sensor;
calculating the absorption from the attenuation of the measuring light beam.

2. The method of claim 1, further comprising calculating a vapor flux densit
correlating the absorption to a vapor flux density.

3. The method of claim 2, wherein the method further comprises:
splitting the measuring light beam, wherein the split portions of the measurin
light beam are directed through the vapor flux at different positions and detec
by different segments of the pixel array sensor respectively; and
correlating the absorption to vapor flux density at different positions to obtai
position-sensitive vapor flux density.

4. The method of claim 2, wherein the method further comprises:
generating a calibration light beam, wherein the calibration light beam is spli
directed along the same measuring channel and through the vapor flux, and it
attenuation is detected by the same pixel array sensor;
splitting the calibration light and the measuring light by a pixel array sensor i
comprising a top slit and bottom slit, wherein one of the slits can be used for
calibration light, the other one of the slits can be used for the measuring light
shuttering the calibration light beam during measurement; and
reading the pixel array sensor, subtracting a contribution from undesired opti
coating via the calibration light beam in the measuring channel, and correlati
absorption to vapor flux density after calibration.

5. The method of claim 4, wherein the calibration light beam is white light.

6. The method of claim 4, wherein the calibration light beam is generated by monochromatic light source, wherein the calibration light can only be absorbed by o coating, not the vapor flux.

7. The method of claim 1, wherein the pixel array sensor comprises a charge coupled device detector.

8. The method of claim 1, wherein the pixel array sensor comprises a complementary metal-oxide-semiconductor detector.

9. The method of claim 1, wherein the pixel array sensor comprises a charge coupled device detector having a wavelength measurement range of about 200 to abo 500 nm.

10. The method of claim 1, wherein the pixel array sensor comprises a complementary metal-oxide-semiconductor detector having a wavelength measurem range of about 200 to about 500 nm.

11. The method of claim 1, wherein the pixel array sensor comprises a charg coupled device detector having a wavelength measurement range of about 100 to abo 2000 nm.

12. The method of claim 1, wherein the pixel array sensor comprises a complementary metal-oxide-semiconductor detector having a wavelength measurem range of about 100 to about 2000 nm.

13. The method of claim 2, wherein the method further comprises:

directing a reference light beam to a second sensor without passing through t vapor flux, wherein the reference light beam and the measuring light beam ar generated by the same light source;

measuring attenuation of the reference light beam by the second sensor; and

calculating vapor flux density by comparing the attenuation of the measuring beam and the attenuation of the reference light beam to eliminate the effect o fluctuation of the light source.

14. The method of claim 13, wherein the measuring light beam and the refer light beam are generated by a light source comprising a hollow cathode lamp.

15. The method of claim 13, wherein the measuring light beam and the refer light beam are generated by a light source comprising a monochromatic light source.

16. A method measuring a vapor flux density in an in-line deposition process comprising:

directing a measuring light beam along a measuring channel through a vapor of deposition to a pixel array sensor, wherein the measuring light beam inclu wavelength capable of being absorbed by the vapor flux of deposition and th measuring channel is under a plurality of separate rollers and a plurality of separate substrates;

directing a reference light beam to a second sensor without passing through t vapor flux;

using the gap between the rollers to pass flux to the measuring channel;

measuring attenuation of the measuring light beam by the pixel array sensor;

measuring attenuation of the reference light beam by the second sensor;

using the moving substrates and rollers as the flux and radiation shields for t pixel array sensor and second sensor; and

calculating vapor flux density by comparing the attenuation of the measuring beam and the attenuation of the reference light beam to eliminate the effect o fluctuation of the light source, calculating the absorption from the attenuatior correlating the absorption to vapor flux density.

17. The method of claim 16, wherein the method further comprises:

splitting the measuring light beam, wherein the split portions of the measurin light beam are directed through the vapor flux at different positions and detec by different segments of the pixel array sensor respectively; and

correlating the absorption to vapor flux density at different positions to obtai position-sensitive vapor flux density.

18. The method of claim 16, wherein the method further comprises:
generating a calibration light beam, wherein the calibration light beam is spli directed along the same measuring channel and through the vapor flux, and it attenuation is detected by the same pixel array sensor;
splitting the calibration light and the measuring light by a pixel array sensor i comprising a top slit and bottom slit, wherein one of the slits can be used for calibration light, the other one of the slits can be used for the measuring light
using the moving substrates to shutter the flux on and off;
using the shutter-off position to calibrate the measurement; and
reading the pixel array sensor, subtracting a contribution from optical coating the calibration light beam in the measuring channel, and correlating absorptic vapor flux density after calibration.

19. The method of claim 16, wherein the method further comprises:
positioning an additional flux and radiation shield to protect the pixel array s and second sensor, wherein the shield comprises a window transparent in the measuring wavelength range in the measuring channel; and
opening an aperture on the additional flux and radiation shield to allow the v flux to pass the measuring channel, wherein the dimension of the aperture is significantly bigger than the measuring light beam diameter.

20. The method of claim 16, wherein the measuring light beam and the refer light beam are generated by a light source comprising a hollow cathode lamp.

21. The method of claim 16, wherein the measuring light beam and the refer light beam are generated by a monochromatic light source.

22. The method of claim 18, wherein the calibration light beam is generated light source comprising a monochromatic light source.

23. A method of manufacturing an in-situ flux monitor system for in-line deposition process with plurality of separate rollers and plurality of moving substrate comprising:

generating a measuring light beam including a wavelength that can be absorb by a vapor flux of deposition along a measuring channel under plurality of separate rollers and plurality of moving substrates;

creating a reference signal by splitting a portion of the measuring light beam, wherein the reference light beam portion of the light beam is directed along a reference channel without passing through the vapor flux;

passing flux through the gap between the rollers to the measuring channel;

measuring the attenuation of the measuring light beam by a first sensor;

measuring the attenuation of the reference light beam by a second sensor; an

calculating vapor flux density by comparing the attenuation of the measuring beam and the attenuation of the reference light beam to eliminate the effect o fluctuation of the light source, calculating the absorption from the attenuatior correlating the absorption to vapor flux density.

24. The method of claim 23, wherein the method further comprises:

generating a calibration light beam, wherein the calibration light beam is dire along the same measuring channel and through the vapor flux, and its attenua is detected by the same first sensor;

splitting the calibration light and the measuring light by a first sensor mask comprising a top slit and bottom slit, wherein one of the slits can be used for calibration light, the other one of the slits can be used for the measuring light using the moving substrates to shutter the flux on and off;

using the shutter-off position to calibrate the measurement; and

reading the first sensor, subtracting the contribution from optical coating via calibration light beam in the measuring channel, and correlating absorption tc vapor flux density from calibration.

25. The method of claim 23, wherein the method further comprises:
positioning an additional flux and radiation shield to protect the first sensor a second sensor, wherein the shield comprises a window transparent in the measuring wavelength range in the measuring channel;
opening an aperture on the additional flux and radiation shield to allow the va flux to pass the measuring channel, wherein the dimension of the aperture is significantly bigger than the measuring light beam diameter.

26. The method of claim 23, wherein the method further comprises:
using the signal change caused by the moving substrates to count the number substrates, check distances between the substrates, and compute the moving s of substrates, wherein the moving substrates shutter the flux on and off and th spacing between the moving substrates determines the length of signal chang cycle.

27. An in-situ flux monitor system for in-line deposition process with pluralit separate rollers and plurality of moving substrates comprising:
a first light source to generate a measuring light beam including a wavelengt can be absorbed by a vapor flux of deposition along a measuring channel;
an optic device to create a reference signal by splitting a portion of the measu light beam, wherein the portion of the light beam, the reference light beam, is directed along a reference channel without passing through the vapor flux;
a plurality of optic fibers to direct the measuring channel under a plurality of separate rollers and plurality of moving substrates, wherein the flux pass thro the gap between the rollers to the measuring channel;
a mounting backbone, wherein the entire system is mounted on the backbone the backbone is made from material with a very small coefficient of thermal expansion to minimize the possible misalignment due to thermal expansion;
a first sensor to measure the attenuation of the measuring light beam;
a second sensor to measure the attenuation of the reference light beam; and
a measurement module to calculate vapor flux density by comparing the attenuation of the measuring light beam and the attenuation of the reference l beam to eliminate the effect of fluctuation of the light source, calculating the

absorption from the attenuation, and correlating the absorption to vapor flux density.

28. The system of claim 27, wherein the system further comprises:
a second light source to generate a calibration light beam, wherein the calibra light beam is directed along the same measuring channel and through the vap flux, and its attenuation is detected by the same first sensor;
a first sensor mask comprising a top slit and bottom slit to split the calibratio light and the measuring light, wherein one of the slits can be used for the calibration light, the other one of the slits can be used for the measuring light
a configuration to use the moving substrates to shutter the flux on and off, wh the shutter-off position is used to calibrate the measurement; and
a calibration module to read the first sensor, subtract the contribution from op coating via the calibration light beam in the measuring channel, and correlate absorption to vapor flux density from calibration.

29. The system of claim 28, wherein the configuration further comprises:
an additional flux and radiation shield to protect the first sensor and second sensor, wherein the shield comprises a window transparent in the measuring wavelength range in the measuring channel;
an aperture on the additional flux and radiation shield to allow the vapor flux pass the measuring channel, wherein the dimension of the aperture is signific bigger than the measuring light beam diameter.

30. The system of claim 27, wherein the first light source comprises a hollov cathode lamp.

31. The system of claim 27, wherein the first light source comprises a monochromatic light source.

32. The system of claim 27, wherein the mounting backbone comprises cera

33. The system of claim 27, wherein the mounting backbone comprises grap

34. The system of claim 28, wherein the second light source comprises a monochromatic light source.

35. The system of claim 27, wherein the measurement module further uses tl signal change caused by the moving substrates to count the number of substrates, che distances between the substrates, and compute the moving speed of substrates, where the moving substrates shutter the flux on and off and the spacing between the movin substrates determines the length of signal change cycle.

36. The system of claim 27, wherein the optic fiber comprises sapphire.

37. The system of claim 27, wherein the optic fiber comprises quartz.

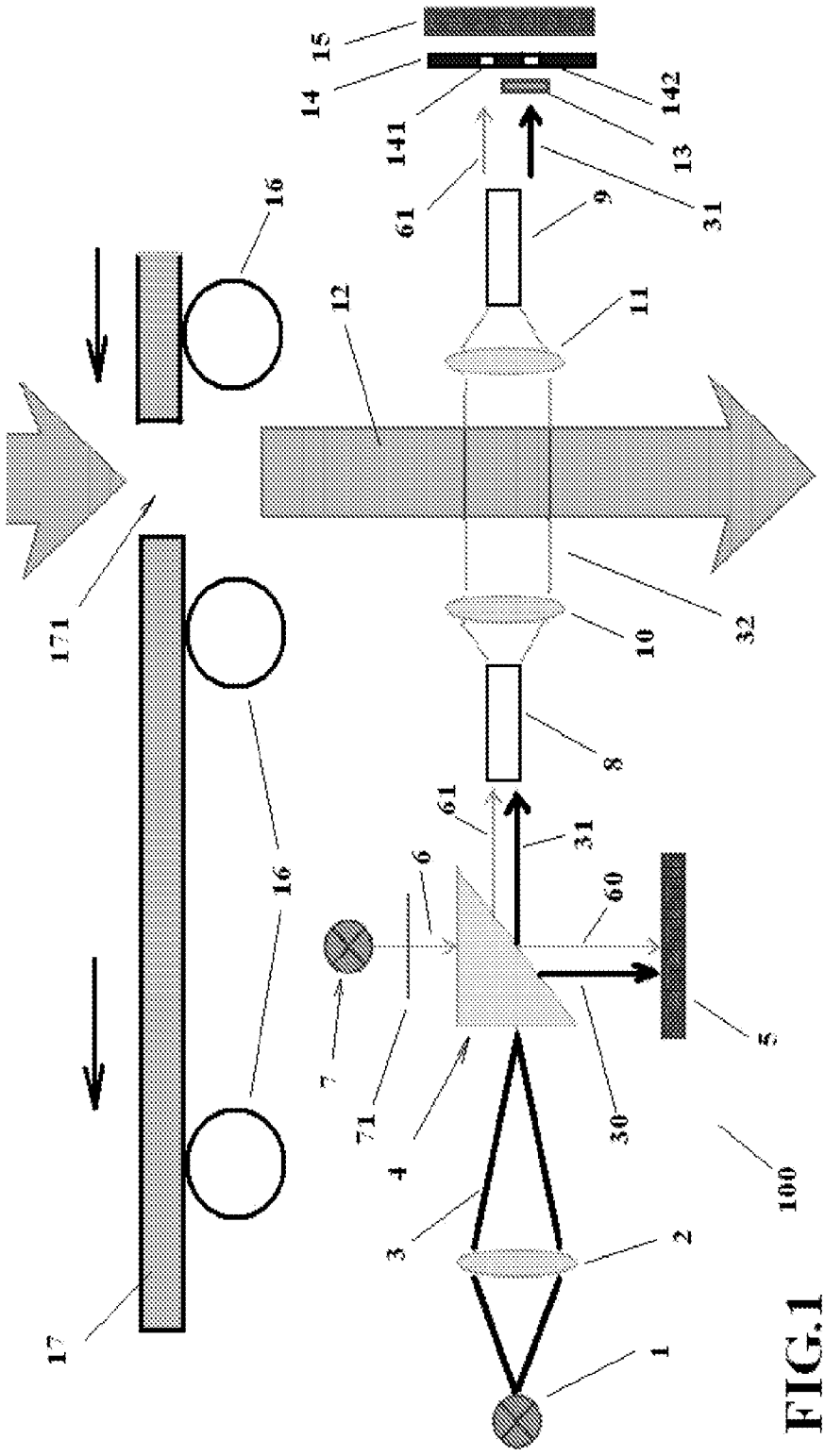

15
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17
1

FIG.1

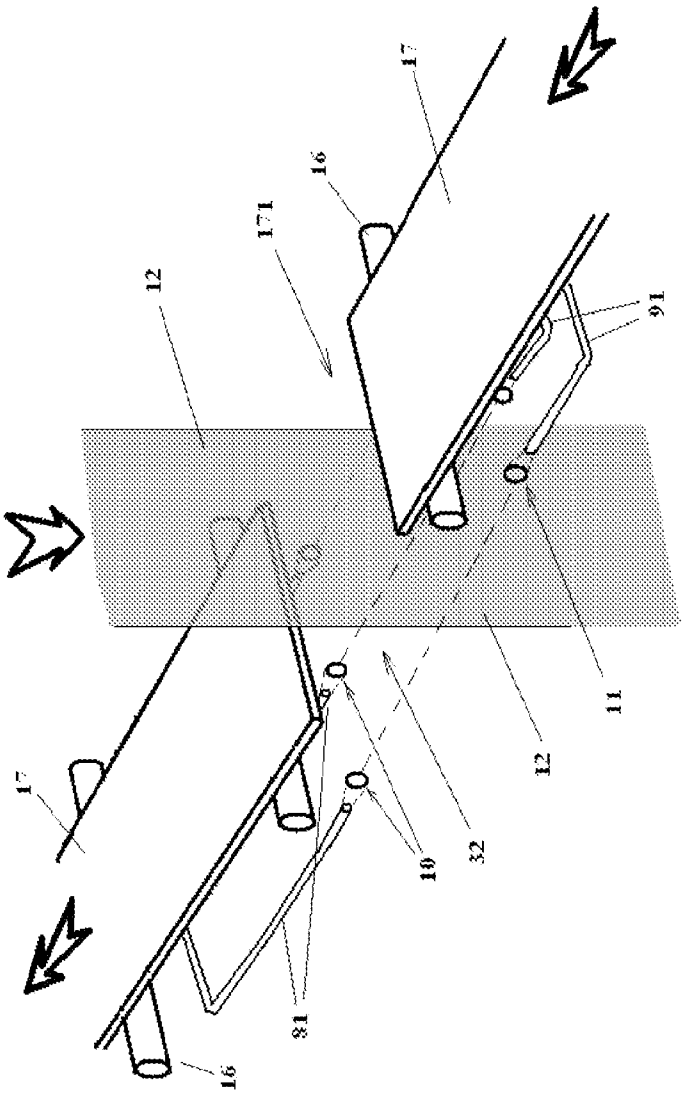


FIG.2

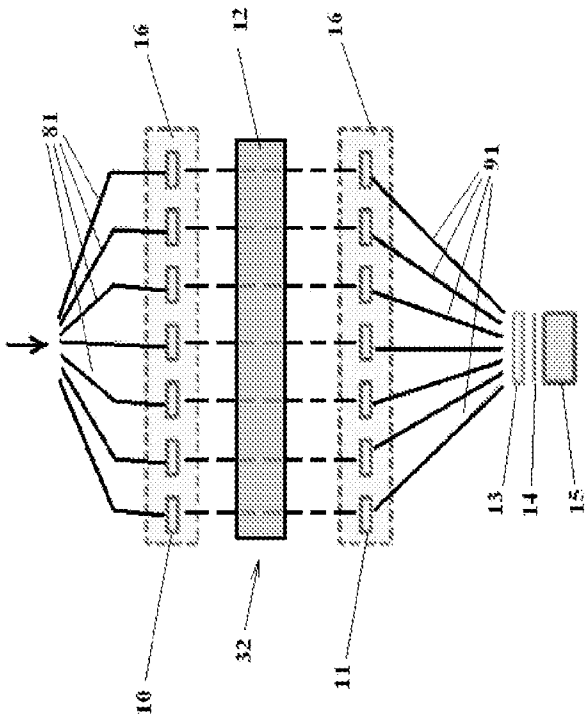


FIG.3

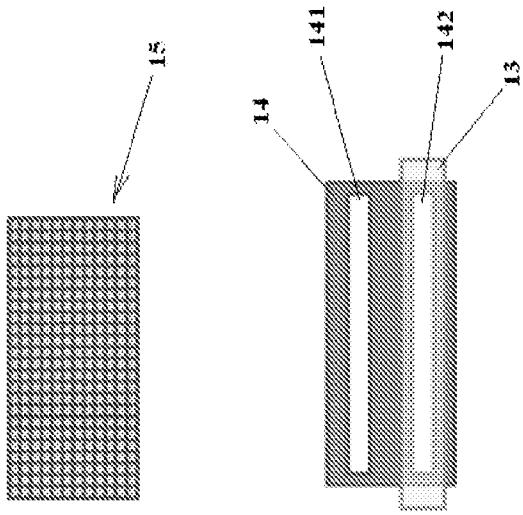


FIG.4

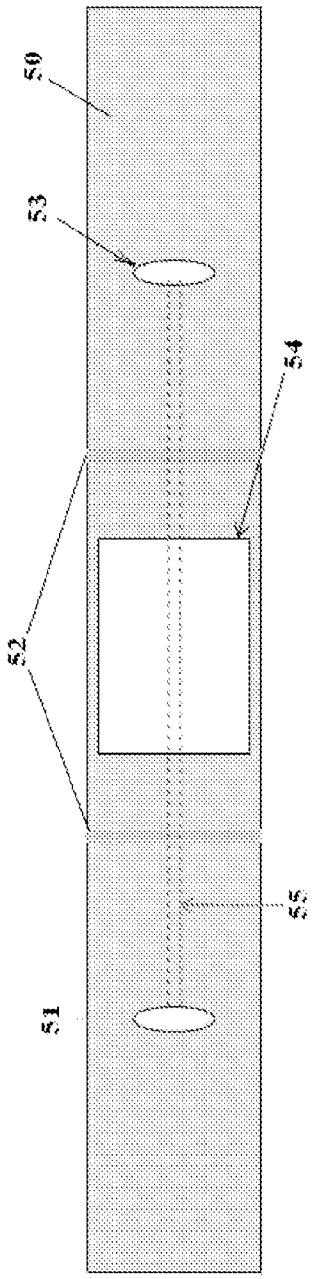


FIG.5

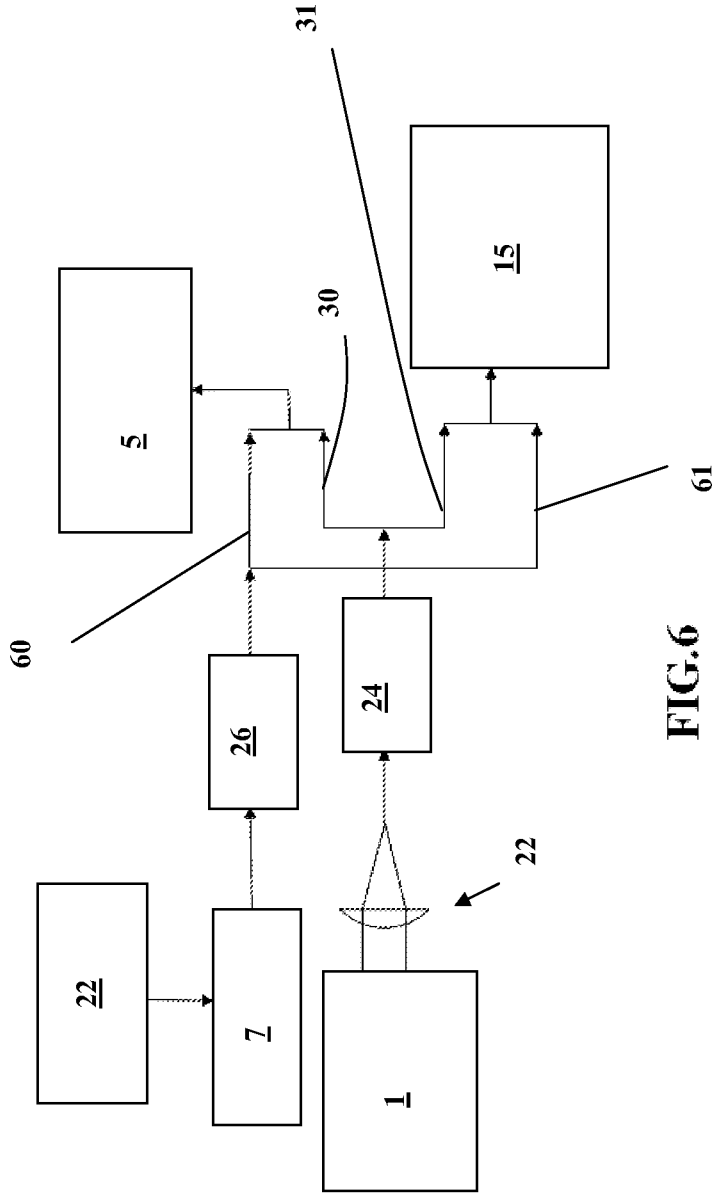


FIG.6

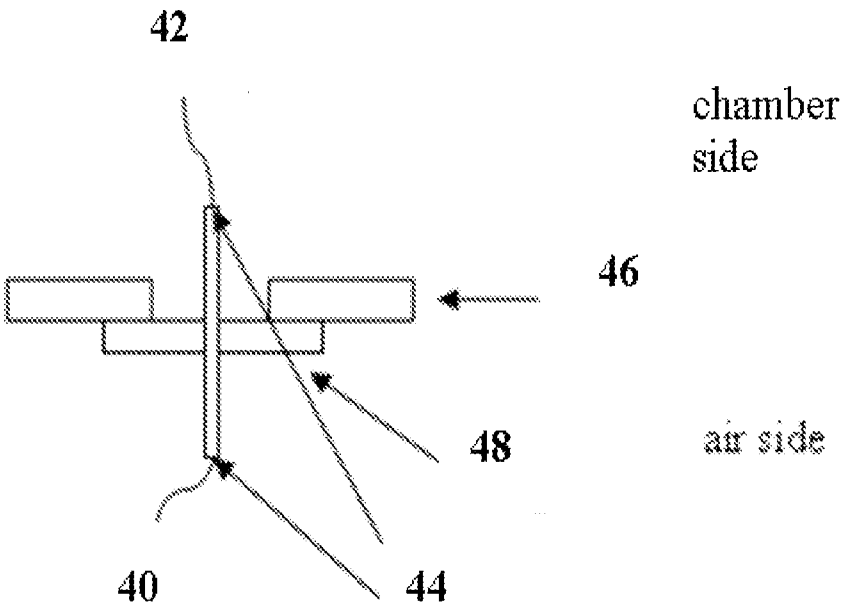


FIG.7

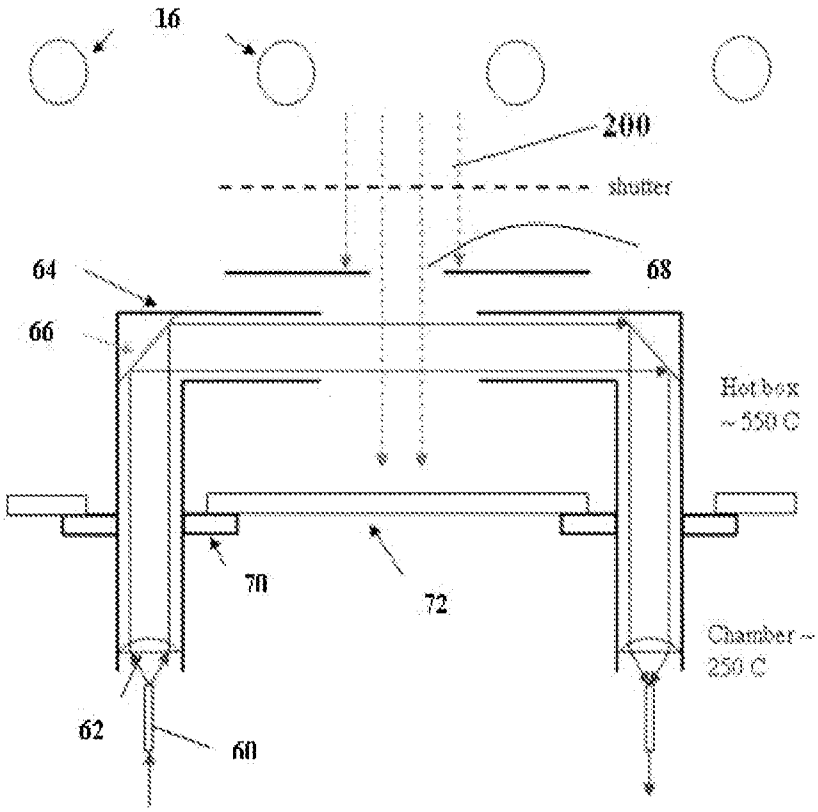


FIG.8

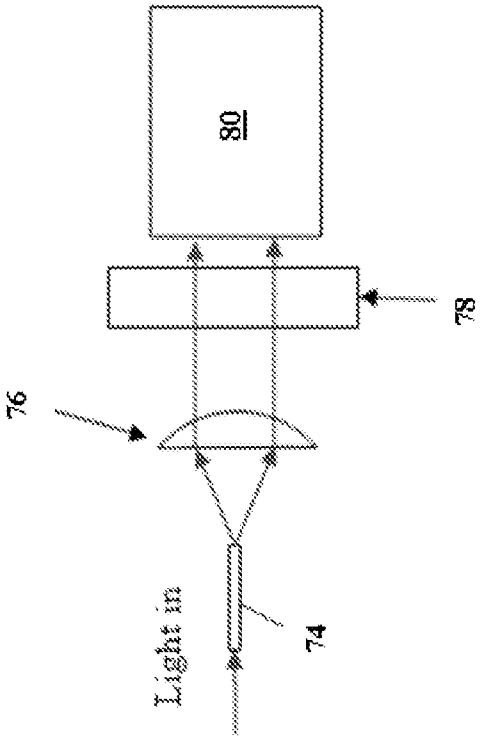


FIG. 9

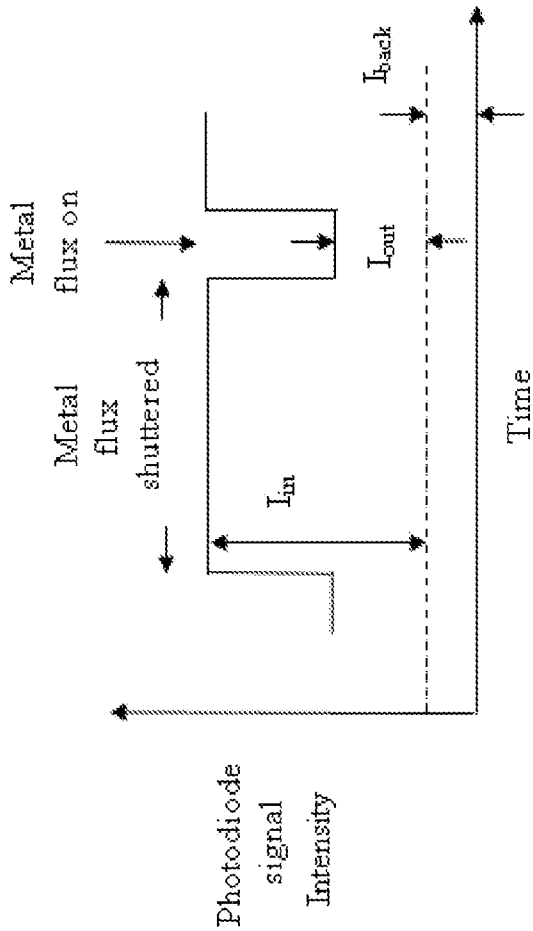

Metal
flux on
Metal
flux
shuttered
I_{back}
I_{out}
I_{in}
Time
Photodiode
signal
Intensity

FIG.10

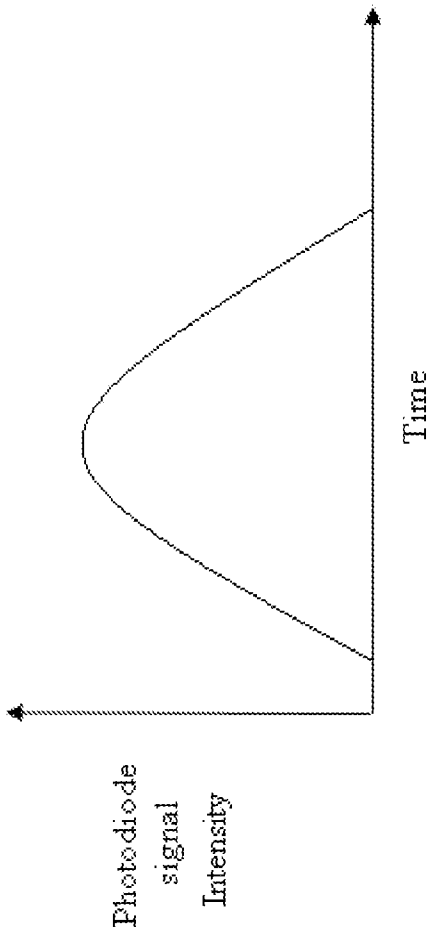


FIG.11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 10/62482

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G01J 3/28 (2011.01)
USPC - 356/326 ; 216/60
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)
IPC (8) - G01J 3/28 (2011.01)
USPC - 356/326; 216/60

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 356/326; 216/60 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PUBWEST (PGPB,USPT,USOC,EPAB,JPAB) Terms - beam light wavelength position speed rollers sensor CCD detector laser under below between through flux monitor vapor conveyor in-line shadow shutter shield attenuate reference deposit deposition substrate
Google - flux vapor deposition substrate light-beam rollers in-line conveyor CCD; flux monitor vap

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6,038,017 B1 (PINSUKANJANA, ET AL.) 14 March 2000 (14.03.2000), col 2, ln 63 to col 3, ln 4; col 5, ln 21-27; col 6, ln 66 to col 7, ln 5; col 6, ln 66 to col 7, ln 5; col 11, ln 35-47; col 13, ln 54-60	1-15
Y	US 6,391,647 B1 (SPERLING, ET AL.) 21 May 2002 (21.05.2002), col 5, ln 53 to col 6, ln 5	1-15
A	US 2009/0095616 A1 (LU) 16 April 2009 (16.04.2009), entire document	1-37
A	US 6,891,612 B1 (KOIKE, ET AL.) 10 May 2005 (10.05.2005), entire document	1-37
A	US 2006/0208191 A1 (KESSLER, ET AL.) 21 September 2006 (21.09.2006), entire document	1-37
A	US 6,075,588 A (PINSUKANJANA, ET AL.) 13 June 2000 (12.06.2000), entire document	1-37
A	US 6,040,914 A (BORTZ, ET AL.) 21 March 2000 (21.03.2000), entire document	1-37
A	US 6,038,017 A (PINSUKANJANA, ET AL.) 14 March 2000 (14.03.2000), entire document	1-37
A	US 5,598,260 A (BREWER, ET AL.) 28 January 1997 (28.01.1997), entire document	1-37
A	US 4,377,238 A (WILKS, ET AL.) 22 March 1983 (22.03.1983), entire document	1-37

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 February 2011 (23.02.2011)	08 MAR 2011
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)