

# ILLUMINATING APPARATUS AND METHOD FOR CONTROLLING ENERGY OF A LASER SOURCE

## 5 CROSS REFERENCE TO RELATED APPLICATIONS

The disclosures of US 11/318,127 , filed 22.12.2005, of US 60/731,539, filed 28.10.2005 and of US 60/753,829, filed 23.12.2005 are considered part of and are incorporated by reference in the disclosure of this application

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## BACKGROUND OF THE INVENTION

15 The present invention relates to an illuminating apparatus for illuminating a sample on a work stage with a narrow illuminating line of controlled energy according to the preambles of claims 1 and 18 and a method for controlling energy of a laser source when illuminating a sample on a work stage with a narrow illuminating line according to the preambles of claims 9 and 25.

20 Many technical applications in electronics and display technology require a thin polycrystalline silicon (Si) layer on glass. Such panels are typically used for liquid crystal display (LCD), organic light emitting diode (OLED) and solar cell technology. The standard process to produce such panels is to first deposit amorphous Si layers on glass by chemical vapour deposition (CVD) or sputter processes. Subsequently a polycrystalline  
25 film is formed by laser annealing such as excimer laser crystallization (ELC) or sequential lateral solidification (SLS) techniques. An overview of these different common techniques is given e.g. in US 7,061,959 which is herewith incorporated by reference. B2.

30 A quite novel technique for conversion of amorphous silicon into polycrystalline silicon is the so called thin beam directional x-tallization (TDX) process. This process uses a pulsed narrow narrowly focused laser line with a width (so called short axis) dimension of about 10  $\mu\text{m}$  and a longitudinal (so called long axis) dimension of about 500 mm which is

scanned in the short axis direction in order to melt the thin Si layer having a thickness of 30 to 100 nm.

When applying the ELC, SLS or TDX processes a thin silicon layer on glass is melted by an illumination line being emitted by a high energy excimer laser, preferably a XeCl excimer laser, and being shaped by a beam shaping optics. According to the present application beam shaping optics means a module between the laser and the imaging optics performing at least one of the following functions:

- changing the shape and / or divergence in one or two directions perpendicular to the direction of beam propagation.
- homogenizing the intensity at a field and /or pupil plane in one and /or two directions
- changing the spatial and / or temporal coherence.

After having shaped said beam by means of said beam shaping optics said beam has a rectangular cross section which upon further propagation scales in size in long and/or short axis direction.

Such beam shaping optics may comprise one or more beam expanders for expanding the laser beam in the long axis direction, one or more homogenizers for homogenizing the beam in the long and/or short axis direction and preferably one or more devices for limiting the dimension of the beam in short axis direction. WO 2006/066706 A2 discloses an example for an apparatus for generating a narrow illuminating line being capable for applying the TDX process.

The energy density of the laser line on the silicon layer has to be homogenous in the long axis direction and lie within a certain process window. The theoretical process window is reduced by effects like long axis uniformity fluctuations, beam position and pointing fluctuations, variations of the Si film thickness and/or a variation of the overall energy reaching the panel. The latter is mainly induced by variations of beam parameters of the laser that influence the transmission of the optical system. For these reasons the relevant process parameters have to be measured and stabilized.

Usually, the laser energy is stabilized by a feed back loop that measures the energy close to the exit window of the laser. This is the most frequently used laser energy stabilization

technique since nearly each commercially available laser is equipped with such a feedback loop. A laser annealing system comprising such a laser energy stabilization system works quite well, however, it does not prevent variations of energy density along the laser line on the silicon layer leading to poor crystal quality when using the TDX process.

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US 7,061,959 B2 discloses an energy monitor feedback to the laser in a stabilization metrology module (SMM). The SMM is part of the beam shaping optics as defined above. A drawback of such an arrangement is a non negligible variation of energy density of the laser line on the silicon layer.

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Furthermore, US 7,061,959 B2 discloses an energy monitor feedback at the work stage. Energy monitoring at the work stage itself has the advantage of controlling energy instantaneously at the location where the light is absorbed and the energy from the laser is converted into heat melting the amorphous semiconductor film. Nevertheless, at that location the light energy may only be measured at time periods when no panel is located there. Therefore, the energy monitoring may only be performed by use of a removable service tool for a one-time adjustment purposes or by an energy meter which is arranged between panels when scanning the laser line in operation mode.

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US 5,721,416 A1 discloses the arrangement of a transparent mirror in the beam path between a reducing optics and a final window for branching off a partial beam (a few percent) which then are imaged by a microscope lens on a solid body image converter to monitor the beam profile. The solid body image converter is provided for monitoring purposes, only. A feedback of the monitored signal to the laser is not intended.

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### SUMMARY OF THE INVENTION

Therefore, it is an object of the present invention to provide an illuminating apparatus and a method for controlling energy of a laser source with improved reduction of variations of energy density of the laser line on the sample being illuminated.

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This object may be achieved by an illuminating apparatus for illuminating a sample on a work stage with a narrow illuminating line of controlled energy with the features of the characterizing portions of claims 1 and 18 and a method for controlling energy of a laser source when illuminating a sample on a work stage with a narrow illuminating line with the features of the characterizing portions of claims 9 and 25.

Advantageous variations and embodiments are subject matters of the sub claims.

Since some beam parameters like pointing, divergence, and polarization are changing over time, the transmission through the beam shaping optics is subjected to change. This influences one of the main process parameters, namely the energy density on the panel.

An illuminating apparatus is provided for illuminating a sample on a work stage with a narrow illuminating line of controlled energy, whereby said illuminating line is generated from emitted from a laser said illuminating line has an dimension in a first direction and an dimension in a second direction being perpendicular to said first direction whereby said first direction dimension exceeds said second direction dimension by a multiple. Furthermore said illumination apparatus comprises a beam shaping optical system for shaping said laser beam into a line shape, an energy measuring device for measuring energy of said laser beam and an energy control system for generating a control signal upon said measured laser beam energy and for controlling the energy output of said laser source based on said control signal, whereby said energy measuring device is arranged in said beam path after said beam shaping optical system and before said work stage. Said energy measuring device, in the following for simplicity called process energy monitor (PEM) measures the energy incident on the panel and feeds a signal back to the control loop of the laser.

Said illumination apparatus may not only be limited to laser annealing and/or laser crystallization purposes, such as related to ELC, SLS or TDX processes, but also to any laser light exposures requiring a thin illuminating line having a high aspect ratio of e.g. several hundreds or even thousands.

It has been found that energy measurement relying only on a fraction of the beam at an outer edge may only deliver a useful control signal, if the energy at the outer edge is a good measure of the total beam energy which in general will not be the case. Therefore, according to a preferred embodiment said control signal is generated such that it is  
5 indicative of an averaged beam energy along the dimension of said line shaped beam in said first direction.

It is quite difficult to place an energy meter directly in the beam path of an illuminating apparatus according to the present invention without disturbing beam performance and/or  
10 output energy. One solution may be that said energy measuring device comprises a beam splitter for coupling out a fraction of said line shaped beam and a detector for detecting said fraction.

In general, said detector may be an array of any kind being capable of detecting laser light.  
15 In particular, said detector may be a two dimensional array having sensors in two dimensions or a one dimensional array having light detecting elements only in one direction, i.e. being oriented preferably in long axis direction. In a preferred embodiment according to the present invention said detector comprises a plurality of photodiodes being arranged side by side in said first direction for collecting said fraction. Despite these  
20 photodiodes may be arranged such that a few rows of photodiodes form a two dimensional sensor array the most preferred embodiment consists in a one dimensional array of photodiodes being placed side by side.

In order to reduce the number of photodiodes as far as possible the detector of the  
25 illuminating apparatus according to the invention further comprises a plurality of spherical lenses for focusing said fraction onto said plurality of photodiodes. It may be worth mentioning that also cylindrical lenses or double cylindrical lenses with cylindrical surfaces transversely crossing each other or any other focusing lenses may be used. Nevertheless, for manufacturability reasons spherical lenses will be preferred.

30 In a preferred embodiment said illuminating apparatus according to the invention may further comprise a reducing optics in said beam path after said beam shaping optical system for reducing said line shaped beam in said second direction. Said energy measuring

device may be located in the beam path direction before or after said reducing optics. Alternatively, said energy measuring device may also be located in said reducing optics itself. When said beam is narrowed significantly by said reducing optics the collection (and the subsequent detection) of the most relevant part of the beam may be easier.

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A further preferred embodiment of said illuminating apparatus according to the invention comprises an imaging optics for imaging said line shaped beam onto said sample. Said imaging optics may comprise said reducing optics. Beam imaging may improve illuminating line properties on the sample, namely the panel.

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According to another preferred embodiment said beam shaping optical system comprises a homogenizer for homogenizing said laser beam at least along its dimension in said first direction. Said energy measuring device is thus located in the beam path after said homogenizer. Typical homogenizers for use in said beam shaping optical system are disclosed in US 5,721,416 A1 or WO 2006/066706 A2.

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In another preferred embodiment said beam shaping optical system comprises a field defining optical device for defining the dimension of said laser beam at least in said second direction. US 5,721,416 A1, US 60/731,539, and US 60/753,829 disclose arrangements for defining or limiting the dimension of said laser beam at least in said second direction.

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According to another aspect of the present invention a method is provided for controlling energy of a laser source when illuminating a sample on a work stage with a narrow illuminating line, whereby said illuminating line is generated from a laser beam propagating along a beam path and being emitted from said laser source and having an dimension in a first direction exceeding an dimension in a second direction being perpendicular to said first direction by a multiple, which further comprises the steps of shaping said laser beam into a line shape, measuring the energy of said laser beam in said beam path after said beam shaping optical system and before said work stage, generating a control signal upon said measured laser beam energy, and controlling energy output of said laser source based on said control signal.

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Preferably, said method according to the invention is characterized in that said control signal is indicative of an averaged beam energy along the dimension of said line shaped beam in said first direction. Alternatively relying only on a fraction at an outer edge of the beam is disadvantageous since the energy at the outer edge in general might not reflect the energy of the total beam.

According to a further preferred embodiment the method according to the invention comprises the step of splitting said laser beam in said beam path after said beam shaping optical system and before said work stage and coupling out a fraction and detecting said fraction.

Said method further preferably comprises the step of averaging a beam energy of said fraction along the dimension of said fraction in said first direction. It is not necessary and in some cases hardly possible also to average the beam energy in said second direction. Averaging the beam energy along the dimension in said first direction contains enough information for generating a control signal. The averaging may be done by integrating the beam energy along the long axis direction, only. A weighing of the signal with respect to the length being integrated is not necessary.

A further preferred embodiment of said method is characterized in the step of dividing said fraction into a plurality of sub beams and focusing said plurality of sub beams onto a detector array comprising e.g. a plurality of photodiodes. Alternatively pyroelectric and thermoelectric sensors can be used. This implies a reduction in the number of necessary detector array elements such as photodiodes as well as an efficient way to collect the beam dimension in total. Focusing of a plurality of beams also has the advantage that an adjustment of the detector with respect to the beam to be detected may be realized much easier than without having any focusing means.

According to a further variant said method according to the invention comprises the step of reducing said line shaped beam in said second direction. Said energy may be measured in said beam path direction before, after or during reducing said line shaped beam in said second direction.

Optionally, said method according to the invention may be characterized in further imaging said line shaped beam onto said sample or panel. Imaging the beam has the advantage of being able to alter the illuminating line properties at the intermediate field plane and thus on the sample or panel.

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The method according to the invention may further comprise the step of homogenizing said laser beam at least along its dimension in said first direction. The beam energy may be measured in the beam path after homogenizing said laser beam.

10 According to still another aspect of the invention an illuminating apparatus for illuminating a sample on a work stage is provided with a narrow illuminating line of controlled energy, said illuminating line being generated from a laser beam propagating along a beam path and being emitted from a laser source and having an dimension in a first direction exceeding an dimension in a second direction being perpendicular to said first direction by  
15 a multiple. Said apparatus further comprises a beam shaping optical system for shaping said laser beam into a line shape, an energy measuring device for measuring energy of said laser beam and an energy control system for generating a control signal, which is indicative of an averaged beam energy along the dimension of said line shaped beam in said first direction, of said measured laser beam energy and for controlling energy output  
20 of said laser source as a result of said control signal.

Preferably, as is already mentioned with respect to the first aspect of the invention above, said energy measuring device comprises a beam splitter for coupling out a fraction of said line shaped beam and a detector for detecting said fraction.

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Said detector optionally comprises a plurality of photodiodes being arranged side by side in said first direction for collecting said fraction as is explained above.

Furthermore, for simplicity reasons, said detector may comprise a plurality of spherical  
30 lenses for focusing said fraction onto said plurality of photodiodes.

Said at least two of said photodiodes may be electrically coupled in parallel. Coupling of photodiodes in parallel results in an addition of the photocurrents being generated when

illuminating said photodiodes. A current signal consisting of an addition of photocurrents corresponds to an (not normalized) averaging of beam energy impinging on said photodiodes.

- 5 In general voltage signals are used in order to control laser beam output of the laser. The voltage control signal may be generated by means of measuring the voltage drop along a shunt resistor being electrically coupled in series to (at least one of) said photodiodes.

- 10 In order to keep the loss for measuring the intensity small, one may use reverse biased photodiodes which will also facilitate time resolved detection of the short Excimer laser pulses if desired.

Examples for detection of optical signals are given in Dereniak and Crowe: Optical Radiation Detectors (Wiley) which is herewith incorporated by reference.

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In principle the laser output may be controlled by an electronic feed back loop. The input signal may be generated by several photodiodes. The charge that is generated by the laser pulse in each photo diode may be added electronically. In order to keep dark currents low it is possible that the photo diodes are not biased.

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- According to still another aspect of the invention a method for controlling energy of a laser source when illuminating a sample on a work stage with a narrow illuminating line is provided, whereby said illuminating line being generated from a laser beam propagating along a beam path and being emitted from said laser source and having an dimension in a first direction exceeding an dimension in a second direction being perpendicular to said first direction by a multiple, said method comprises the steps of shaping said laser beam, measuring energy of said shaped laser beam, generating a control signal upon said measured laser beam energy, whereby said control signal is indicative of an averaged beam energy along the dimension of said line shaped beam in said first direction and controls the energy output of said laser source based on said control signal.
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According to a preferred version of this method according to the invention a fraction of said line shaped beam is coupled out and subsequently detected. Further preferably, said

fraction is divided into a plurality of beam lets. Each of said beam lets is afterwards detected separately.

Following the method described in the foregoing paragraphs preferably each of said plurality of beamlets is focused separately for detection.

In a preferred embodiment said method comprises the step of converting detection signals being generated upon detecting each of said beamlets separately into a sum signal. Such a sum signal represents an averaging of said beam being detected. Said sum signal may subsequently be converted into said control signal (for example in the way as described above).

#### BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described hereinafter with reference to the drawings, whereby

Figure 1 shows schematically a TDX apparatus according to the present invention,  
Figure 2 shows schematically a section of said TDX apparatus according to Figure 1,  
Figure 3 shows an energy measuring device incorporated into said TDX apparatus  
according to Figures 1 and 2 according to the invention,  
Figure 4 shows energy fluctuations at a panel/sample when controlling laser output energy with energy monitor being located according to the invention compared to controlling laser output energy with energy meter being located according to prior art.

Figure 1 shows a schematic drawing of an illuminating apparatus, in particular for applying the above mentioned TDX process, according to the present invention. This TDX tool comprises as a light source an excimer laser 10, such as a XeCl- excimer laser emitting a pulsed laser beam 12. Typical pulse widths are 10 - 30 ns at a typical repetition rate of 100 Hz - 10 kHz. The Energy of such a laser pulse is typically in the range of 100 mJ – 1000 mJ.

This laser beam 12 with typical rectangular cross section of 10 x 30 mm is directed along a beam path 13 and converted into a narrow illuminating line 70 via an optical system described in detail in the following. The illuminating line 70 on said sample/panel 66 has an dimension in a long axis direction transverse to the scanning direction of at least 200  
5 mm and an dimension in a short axis direction, i.e. in scan direction, of 3 to 7  $\mu\text{m}$ . This illuminating line 70 with high aspect ratio illuminates a sample such as a panel 66 being positioned on a work stage 68. The work stage 68 is moved with a stage scanning speed of around 10 mm/s resulting in a typical scan increment of e.g. 2  $\mu\text{m}$ /pulse.

10 After having left the laser 10 said light beam 12 is directed to a so called beam delivery unit (BDU) 14. This BDU 14 comprises an entrance window 16, a pulse stretcher 18 for lengthening the pulse width by a factor of 2- / 6. The lengthened laser pulse 12 exits the BDU 14 via an exit window 20.

15 In the following the cross section of said laser beam 12 is converted from a rectangular one into a line shape. For this purpose the laser beam 12 is first directed to a beam preconditioning unit (BPU) 22. The BPU 22 comprises a plurality of optical elements 24. This arrangement of optical elements 24 serves for flattening the intensity profile of said laser beam 12.

20 The beam expanding unit (BEU) 26 being arranged in the beam path 13 after said BPU 22 serves for expanding the laser beam 12 in a lengthwise direction. Hereinafter the lengthwise direction is always indicated with the reference numeral x, the width direction of the laser beam is labelled with the reference numeral y. In the present case the  
25 dimension of the laser beam 12 is carried out by means of four lenses 28 being arranged one after the other on said beam path 13. Instead of the use of such lenses also bent mirrors are known to be capable for use according to the prior art.

For shortening the total dimension of said illuminating apparatus according to the  
30 invention a plurality of plane mirrors may be used. Exemplarily, three mirrors 30, 32, 34 are folding the beam path 13 before said laser beam 12 enters a beam stability metrology unit (BSMU) 36. The beam stability metrology unit 36 comprises an arrangement of optical elements 38 being movable in different directions in order to adjust and/or correct

e.g. the pointing and/or position of the laser beam 12. Respective laser beam monitoring devices (not shown here) are located at the exit of said BSMU 36. Details are e.g. disclosed in US 7,061,959 B2.

5 Following the BSMU 36 in the beam path 13 a homogenizing device 40 for homogenizing said expanded line shaped laser beam 12 is positioned. This homogenizer 40 in the example according to Figure 1 comprises a cylindrical lens array 42 followed by a lens 44, a further cylindrical lens array 46, a rod 48 and a condenser 50. US 5,721,416 A1 or WO 2006/066706 A2 disclose a plurality of different homogenizers being capable of being  
10 inserted in addition or alternatively into the beam path 13 where said homogenizer 40 is located.

Subsequently, the laser beam 12 is directed to folding mirror 52 and in the following to field defining unit (FDU) 54. FDU 54 defines dimension of the laser beam 12 in a field  
15 plane and in particular in the panel plane 66 in short axis direction y. A FDU 54 may comprise an arrangement being described in US 5,721,416 A1 or alternatively one of the arrangements as being disclosed in US 60/731,539 or US 60/753,829.

Since the optical elements following the BDU 14 in the optical beam path 13 until the exit  
20 of the FDU 54 shape the laser beam 12 from a raw laser beam with rectangular cross section into a line beam with a target homogeneous intensity distribution along the long axis direction said respective arrangement of optical elements in the following is called beam shaping unit (BSU). The dashed line identified with the reference numeral 80 in Figure 1 encircles in said afore mentioned optical elements at the BSU.

25 When leaving said BSU 80 the rectangular cross section shaped laser beam 12 is directed to a combined imaging, reducing and folding optics 82 comprising a plurality of plan or cylindrical mirrors 56, 60, 62, respectively. Instead of an arrangement of mirrors 56, 60, 62 also a plurality of cylindrical lenses or a combination of lenses and mirrors may be used.  
30 Typical setups are e.g. disclosed in WO 2006/066706 A2 or in US 5,721,416 A1. The laser beam 12 leaves said imaging, reducing and folding optics 82, which for simplicity reasons in the following is called beam projection unit (BPU) 82, through an exit window 64. The laser beam 12 having an expanded long axis dimension and a reduced short axis dimension

as compared to its dimensions when leaving the BSU 80 is focused as said narrow illuminating line 70 on the panel 66, being e.g. covered with an amorphous silicon layer, on said work stage 68.

5 Summarizing the main features for generating said illuminating line the optical system according to Figure 1, Figure 2 shows the light train as a block diagram. In particular, said laser source and said BSU are drawn as rectangular blocks indicated with the reference numerals 10 and 80, respectively, while said BPU 82 is represented solely by the afore mentioned cylindrical mirror 62. For illustrative purposes the laser beam 12 entering said  
10 BSU 80 is indicated as a single straight line having a point cross section while the laser beam with its cross section further expanding in long axis direction when leaving said BSU 80 is indicated by two diverging lines 12a, 12b and a straight line 70a connecting these lines 12a, 12b, respectively. The illuminating line 70 focused on said panel 66 being positioned on said work stage 68 is indicated by a straight line, said long and short axis  
15 directions are indicated with reference numerals x and y, respectively.

The inventors recognized that since energy density on the panel is the most relevant process parameter, the pulse energy has to be measured close to the panel 66 or at a location with corresponding energy density. This signal has to be fed back to the  
20 stabilization circuit of the laser 10.

The energy density at the panel 66 is mostly given by the laser energy and the optical transmission through the optical system. Changes in system transmission are mostly generated in the beam shaping module 80 when parameters like pointing, beam divergence  
25 or polarization are changing. The influence on system transmission from the projection optics 82 is relatively small. Therefore suitable positions for energy measurements are located along the beam path 13 in the projection module 82 or in the reflected beam from the panel.

30 Therefore, while according to the prior art disclosed in US 7,061,959 B2 an energy meter is located in the beam path 13 between BSMU 94 and homogenizer 40 which is indicated by the optical element 94 in dashed lines in Figure 1, according to the invention an energy meter is located in the beam path 13 between the exit of the BSU 80 and the panel 66.

There are some advantages in positioning the sensor in the projection optics over a direct measurement in the panel level. There is more space available and there is a smaller influence on image quality of the laser line. At some distance from the panel the line has not yet reached its full length and so it is easier to collect the light with a beam splitter.

Thus, in the specific embodiment shown in Figure 1 said energy meter, in the following called process energy monitor (PEM) 58, is located between the mirrors 56 and 60. Said PEM 58 comprises a beam splitter 84, which might be a semitransparent window or a transparent window, and a detector 86 as is shown in Figure 2. The main portion of the line shaped laser beam 12 hitting the front surface of the beam splitter 84 passes the beam splitter 84 and is further imaged and reduced forming the final illuminating line 70 on the panel 66. A fraction 70b of e.g. preferably 0.05 to 0.5 % is reflected on e.g. the rear surface of the beam splitter 84 and directed to the detector 86.

The detector 86 detects said fraction 70b (or at least a part thereof) and converts it into a measured signal 74, e.g. an electrical current or an electrical voltage. The measured signal 74 is fed back via a feed back loop 72 to a control device 76, such as a master controller which generates a control signal 78 for controlling the output energy of said laser beam source 10.

In order to detect a spatially resolved energy density one would need a large two-dimensional sensor. The feedback signal for the laser starts as an analog value that determines the laser energy. To get this signal a numerical (adding up recorded values), electrical (adding currents of photo sensitive elements) or optical integration (adding the light with lens elements) has to be done. For the current problem with a narrow illuminating line the inventors decided to choose a solution using an optical and an electrical averaging method.

Figure 3 shows said energy measuring device 86 being part of said TDX apparatus according to Figures 1 and 2. Approximately 0.2% of the beam energy is coupled out with said aforementioned beam splitter 84 that is realized as a two sided antireflective (AR) coated glass plate. Most of the beam fraction 70b is focused onto four photodiodes 90a,

90b, 90c, 90d by means of four large spherical lenses 88a, 88b, 88c, 88d dividing the fraction 70b into four individual beamlets 92a, 92b, 92c, 92d. The four photodiodes 90a, 90b, 90c, 90d are electrically connected in parallel and in combination electrically connected in series to a shunt resistor  $R_s$ . The electrical circuit comprising said  
5 photodiodes 90a, 90b, 90c, 90d and said shunt resistor  $R_s$  is reverse biased by the reverse bias voltage  $V_0$ .

Upon illuminating the photodiodes 90a, 90b, 90c, 90d photocurrents  $I_{pha}$ ,  $I_{phb}$ ,  $I_{phc}$ ,  $I_{phd}$  are generated. The four individual photocurrents  $I_{pha}$ ,  $I_{phb}$ ,  $I_{phc}$ ,  $I_{phd}$  (which are in general not  
10 identical) are added on said single shared shunt resistor  $R_s$ . The control signal 78 needed for the feed back loop 72 is available at the output of this circuit as an output voltage  $V_{out}$ .

The four photodiodes 90a, 90b, 90c, 90d are electrically connected in parallel. The electrical circuit comprising said photodiodes 90a, 90b, 90c, 90d and an electronic circuit  
15 that adds up the individual charges, analyzes the sum signal and generates an output Voltage  $V_{out}$ . Upon illuminating the photodiodes 90a, 90b, 90c, 90d charges  $Q_{pha}$ ,  $Q_{phb}$ ,  $Q_{phc}$ ,  $Q_{phd}$  are generated. The four individual charges  $Q_{pha}$ ,  $Q_{phb}$ ,  $Q_{phc}$ ,  $Q_{phd}$  (which are in general not identical) are added in said electronic circuit. The control signal 78 needed for the feed back loop 72 is available at the output of this circuit as an output voltage  $V_{out}$ .

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It may be worth mentioning that instead of the above sensing device comprising four photodiodes 90a, 90b, 90c, 90d and an electronic circuit for read out any number of sensor types and their supporting circuitry could be used (photodiode, photomultiplier, pyroelectric, photo resistive, photon drag, etc. may be used.

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When upgrading the TDX apparatus with the PEM device 58 a significant improvement of stability of energy density on the panel 66 and an enlarged process window is observed. Figure 4 shows the normalized line beam energy in the panel plane 66 recorded with an energy meter (such as e.g. disclosed in US 7,061,959 B2). The thin lined curve shows the  
30 fluctuations without PEM 58 but an energy meter 94 being located in the beam path 13 between BSMU 36 and homogenizer 40 that are +/- 3.5%. Using the PEM 58 in the beam path 13 between mirrors 56 and 60 for feedback control of the laser source 10 the

fluctuations (bold curve) were reduced to  $\pm 0.7\%$ . As a result the useful process window could be enlarged by  $5.5\%$ .

## REFERENCE NUMBERS

|    |     |                                      |
|----|-----|--------------------------------------|
|    | 10  | excimer laser                        |
|    | 12  | laser beam                           |
| 5  | 12a | line                                 |
|    | 12b | line                                 |
|    | 13  | beam path                            |
|    | 14  | beam delivery unit (BDU)             |
|    | 16  | entrance window                      |
| 10 | 18  | pulse stretcher                      |
|    | 20  | exit window                          |
|    | 22  | beam preconditioning unit (BPU)      |
|    | 24  | arrangement of optical elements      |
|    | 26  | beam expanding unit (BEU)            |
| 15 | 28  | lens arrangement                     |
|    | 30  | mirror                               |
|    | 32  | mirror                               |
|    | 34  | mirror                               |
|    | 36  | beam stability metrology unit (BSMU) |
| 20 | 38  | arrangement of optical elements      |
|    | 40  | homogenizer                          |
|    | 42  | cylindrical lens array               |
|    | 44  | lens                                 |
|    | 46  | cylindrical lens array               |
| 25 | 48  | rod                                  |
|    | 50  | condenser                            |
|    | 52  | mirror                               |
|    | 54  | field defining unit (FDU)            |
|    | 56  | mirror                               |
| 30 | 58  | process energy monitor (PEM)         |
|    | 60  | mirror                               |
|    | 62  | mirror                               |
|    | 64  | exit window                          |

|    |           |                                                           |
|----|-----------|-----------------------------------------------------------|
|    | 66        | panel                                                     |
|    | 68        | work stage                                                |
|    | 70        | illuminating line                                         |
|    | 70a       | line shaped beam                                          |
| 5  | 70b       | fraction of line shaped beam                              |
|    | 72        | feedback loop                                             |
|    | 74        | measured signal                                           |
|    | 76        | master controller                                         |
|    | 78        | control signal                                            |
| 10 | 80        | illumination system/beam shaping unit (BSU)               |
|    | 82        | imaging optics/reducing optics/beam projection unit (BPU) |
|    | 84        | beam splitter/transparent mirror                          |
|    | 86        | detector                                                  |
|    | 88a       | lens                                                      |
| 15 | 88b       | lens                                                      |
|    | 88c       | lens                                                      |
|    | 88d       | lens                                                      |
|    | 90a       | photodiode                                                |
|    | 90b       | photodiode                                                |
| 20 | 90c       | photodiode                                                |
|    | 90d       | photodiode                                                |
|    | 92a       | focused beam let                                          |
|    | 92b       | focused beam let                                          |
|    | 92c       | focused beam let                                          |
| 25 | 92d       | focused beam let                                          |
|    | 94        | energy meter (prior art)                                  |
|    | x         | first direction                                           |
|    | y         | second direction                                          |
| 30 | $V_0$     | bias voltage                                              |
|    | $V_{out}$ | output voltage                                            |
|    | $R_s$     | shunt resistor                                            |
|    | $I_{pha}$ | photocurrent                                              |

|           |              |
|-----------|--------------|
| $I_{phb}$ | photocurrent |
| $I_{phc}$ | photocurrent |
| $I_{phd}$ | photocurrent |

## CLAIMS

1. Illuminating apparatus for illuminating a sample (66) on a work stage (68) with a sharp illuminating line (70) of controlled energy, said illuminating line (70) being generated  
5 from a laser beam (12) propagating along a beam path (13) and being emitted from a laser source (10) and having a dimension in a first direction (x) exceeding a dimension in a second direction (y) being perpendicular to said first direction (x),  
comprising:  
- a beam shaping optical system (80) for shaping said laser beam (12) into a line shape  
10 (70a),  
- an energy measuring device (58) for measuring energy of said laser beam (12),  
- an energy control system (76) for generating a control signal (78) upon said measured laser beam energy and for controlling energy output of said laser source (10) and /or transmission of one or more components of said beam shaping optical system (80) upon  
15 said control signal (78),  
characterized in that  
- said energy measuring device (58) is arranged in said beam path (13) after said beam shaping optical system (80) and before said work stage (68).
- 20 2. Illuminating apparatus according to claim 1, characterized in that said control signal (78) being indicative of an averaged beam energy along the dimension of said line shaped beam (70a) in said first direction (x).
3. Illuminating apparatus according to one of the preceding claims, characterized in that  
25 said energy measuring device (58) comprises a beam splitter (84) for coupling out a fraction (70b) of said line shaped beam (70a) and a detector (86) for detecting said fraction (70b).
4. Illuminating apparatus according to claim 3, characterized in that said detector (86)  
30 comprises a plurality of photodiodes (90a, 90b, 90c, 90d) being arranged side by side in said first direction (x) for collecting said fraction (70b).

5. Illuminating apparatus according to claim 4, characterized in that said detector (86) further comprises a plurality of lenses (88a, 88b, 88c, 88d) for focusing said fraction (70b) onto said plurality of photodiodes (90a, 90b, 90c, 90d).
- 5 6. Illuminating apparatus according to one of the preceding claims, characterized in that further comprises a reducing optics (82) for reducing said line shaped beam (70a) in said second direction (y).
7. Illuminating apparatus according to one of the preceding claims, characterized in that  
10 further comprises an imaging optics (82) for imaging said line shaped beam (70a) onto said sample (66).
8. Illuminating apparatus according to one of the preceding claims, characterized in that  
15 said beam shaping optical system (80) comprises a homogenizer (40) for homogenizing said laser beam (12) at least along its dimension in said first direction (x).
9. Illuminating apparatus according to one of the preceding claims, characterized in that  
20 said beam shaping optical system (80) comprises a field defining optical device (54) for defining the dimension of said laser beam (12) at least in said second direction (y).
10. Method for controlling energy of a laser source (10) when illuminating a sample (66) on a work stage (68) with a narrow illuminating line (70), whereby said illuminating line (70) being generated from a laser beam (12) propagating along a beam path (13) and being emitted from said laser source (10) and having an dimension in a first direction (x)  
25 exceeding an dimension in a second direction (y) being perpendicular to said first direction by a multiple, comprising the steps of:
- shaping said laser beam into a line shape (70a) with a beam shaping optical system (80),
  - measuring energy of said laser beam (12),
  - generating a control signal (78) upon said measured laser beam energy, and
  - 30 - controlling energy output of said laser source (10) and / or transmission of one or more components of said beam shaping optical system (80) upon said control signal (78),
- characterized in

- measuring said energy of said laser beam (12) in said beam path (13) after said beam shaping and before said work stage (68).

11. Method according to claim 10, characterized in that said control signal (78) being  
5 indicative of an averaged beam energy along the dimension of said line shaped beam (70a) in said first direction (x).

12. Method according to one of the claims 10 or 11, characterized in splitting said laser beam (12) in said beam path (13) after shaping said beam and before said work stage (68)  
10 and out coupling a fraction (70b) by splitting and detecting said fraction (70b).

13. Method according to claim 12, characterized by averaging a beam energy of said fraction (70b) along the dimension of said fraction (70b) in said first direction (x).

14. Method according to claim 13, characterized in dividing said fraction (70b) into a  
15 plurality of sub beams (92a, 92b, 92c, 92d) and focusing said plurality of sub beams (92a, 92b, 92c, 92d) onto a plurality of photodiodes (90a, 90b, 90c, 90d).

15. Method according to one of claims 10 to 14, characterized in further reducing said line  
20 shaped beam (70a) in said second direction (y).

16. Method according to one of claims 10 to 15, characterized in further imaging said line shaped beam (70a) onto said sample (66).

17. Method according to one of claims 10 to 16, characterized in that said beam shaping  
25 comprises homogenizing said laser beam (12) at least along its dimension in said first direction (x).

18. Method according to one of claims 10 to 16, characterized in that said beam shaping  
30 comprises defining the dimension of said laser beam (12) at least in said second direction (y).

19. Illuminating apparatus for illuminating a sample (66) on a work stage (68) with a narrow illuminating line 870) of controlled energy, said illuminating line (70) being generated from a laser beam (12) propagating along a beam path (13) and being emitted from a laser source (10) and having an dimension in a first direction (x) exceeding an  
5 dimension in a second direction (y) being perpendicular to said first direction (x) by a multiple, comprising:  
- a beam shaping optical system (80) for shaping said laser beam (12) into a line shape (70a),  
- an energy measuring device (58) for measuring energy of said laser beam (12),  
10 - an energy control system (76) for generating a control signal (78) upon said measured laser beam energy and for controlling energy output of said laser source (10) upon said control signal (78),  
characterized in that  
- said control signal (78) being indicative of an averaged beam energy along the dimension  
15 of said line shaped beam (70a) in said first direction (x).

20. Illuminating apparatus according to claim 19, characterized in that said energy measuring device (58) comprises a beam splitter (84) for coupling out a fraction (70b) of said line shaped beam (70a) and a detector (86) for detecting said fraction (70b).

20

21. Illuminating apparatus according to claim 20, characterized in that said detector (86) comprising a plurality of photodiodes (90a, 90b, 90c, 90d) being arranged side by side in said first direction (x) for collecting said fraction (70b).

25 22. Illuminating apparatus according to claim 21, characterized in that said detector (86) further comprises a plurality of spherical lenses (88a, 88b, 88c, 88d) for focusing said fraction (70b) onto said plurality of photodiodes (90a, 90b, 90c, 90d).

23. Illuminating apparatus according to claim 22, characterized in that said at least two of  
30 said photodiodes (90a, 90b, 90c, 90d) being electrically coupled in parallel.

24. Illuminating apparatus according to one of claims 22 or 23, characterized in that at least one of said photodiodes (90a, 90b, 90c, 90d) being electrically coupled in series to a shunt resistor ( $R_s$ ).
- 5 25. Illuminating apparatus according to one of claims 22 to 24, characterized in that at least one of said photodiodes (90a, 90b, 90c, 90d) being electrically reverse-biased ( $V_0$ ).
26. Method for controlling energy of a laser source (10) when illuminating a sample (66) on a work stage (68) with a narrow illuminating line (70), whereby said illuminating line  
 10 (70) being generated from a laser beam (12) propagating along a beam path (13) and being emitted from said laser source (10) and having an dimension in a first direction (x) exceeding an dimension in a second direction (y) being perpendicular to said first direction (x) by a multiple, comprising the steps of:
- shaping said laser beam (12) into a line (70a),
  - 15 - measuring energy of said line shaped laser beam (12),
  - generating a control signal (78) upon said measured laser beam energy,
  - controlling energy output of said laser source (10) upon said control signal (78),
- characterized in that
- said control signal (78) being indicative of an averaged beam energy along the dimension  
 20 of said line shaped beam (70a) in said first direction.
27. Method according to claim 26, characterized in coupling out a fraction (70b) of said line shaped beam (70a) and detecting said fraction.
- 25 28. Method according to claim 27, characterized in dividing said fraction (70b) into a plurality of beamlets (92a, 92b, 92c, 92d) and detecting each of said beamlets (92a, 92b, 92c, 92d) separately.
29. Method according to claim 28, characterized in focusing each of said plurality of beam  
 30 lets (92a, 92b, 92c, 92d) separately.

30. Method according to one of claim 28 or 29, characterized in converting detection signals ( $I_{pha}$ ,  $I_{phb}$ ,  $I_{phc}$ ,  $I_{phd}$ ) being generated upon detecting each of said beamlets (92a, 92b, 92c, 92d) separately into a sum signal (74).
- 5 31. Method according to claim 30, characterized in converting said sum signal (74) into said control signal (78,  $V_{out}$ ).