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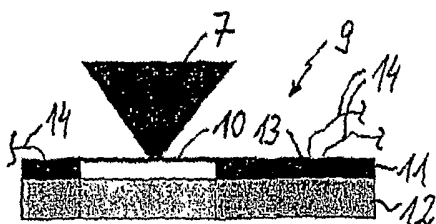
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(54) Title: SPATIALLY RESOLVING RADIATION DETECTOR AND FABRICATING AND OPERATING METHODS



(57) Abstract: Spatially resolving radiation detector and fabricating and operating methods. The invention relates to a spatially resolving radiation detector comprising a radiation-sensitive sensor element, to an aerial image measuring device equipped therewith, to a device for imaging error determination of an optical system comprising such an aerial image measuring device, to a microlithography projection exposure apparatus which is assigned such a device, and also to a fabricating method and an operating method therefor. According to the invention, the sensor element comprises a radiation-sensitive sensor structure element arrangement comprising at least one preferably nanoscale, punctiform or linear

sensor structure element with an irradiation-dependent electrical measurement property, a minimum structure size of the sensor structure element in at least one direction being chosen so as to correspond to a predetermined spatial resolution of the radiation detector. Use e.g. for EUV aerial image measurement technology in microlithography.



WO 2006/089724 A1

Spatially resolving radiation detector and fabricating
and operating methods

[0001] The invention relates to a spatially resolving radiation detector comprising a radiation-sensitive sensor element, to an aerial image measuring device equipped with such a spatially resolving radiation detector for detection of an aerial image, to a device for imaging error determination of an optical system comprising a measurement object structure to be imaged and an aerial image measuring device of this type, to a microlithography projection exposure apparatus, which is assigned such a device for imaging error determination of an optical component of the projection exposure apparatus, to a method for fabricating a self-supporting photodiode strip for the spatially resolving radiation detector, and to a method for operating a device for imaging error determination according to the invention.

[0002] In microlithography for semiconductor wafer patterning, the trend is still toward using ever shorter exposure wavelengths. In the course of this trend, intensive work is currently being done with regard to the use of EUV radiation for wafer structure exposure, that is to say with exposure radiation in the extreme UV range or soft X-ray range. 13.5 nm is an emission wavelength that is predominantly being discussed for this. In order to be able to fully utilize the short exposure wavelengths to obtain structures having comparably small minimum dimensions, the exposure optics should have a correspondingly high resolution. This means that devices for measuring associated optical components with correspondingly high accuracy or spatial resolution should be provided.

[0003] In order to measure optical components in microlithography with regard to image quality, the so-called aerial image measurement technique is often used, as an alternative to a structure-generating meas-

urement technique in which a measurement structure is imaged onto a photoresist layer of a wafer and the photoresist structure thus generated is subsequently measured. The aerial image measurement technique makes use of an aerial image sensor that detects the intensity distribution of an aerial image of a measurement object structure in at least one lateral direction and also in a longitudinal direction in a spatially resolved manner, typically using a precision table ("stage") that can be moved mechanically at least in the longitudinal direction. In principle, imaging techniques and scanning techniques can be differentiated here.

[0004] One imaging technique known for optical systems in the UV and DUV spectral range involves imaging the aerial image with sufficient magnification through a micro-objective onto a sensor surface, such as onto a CCD array that is part of a camera with an image converter. It is not easy to use this technique in the EUV spectral range since suitable diffractive elements for optical imaging are not available in this wavelength range and it is therefore necessary to realize all of the optics, such as the micro-objective, with multilayer mirrors and/or with reflection in glancing light incidence. The quality requirements made of the micro-objective e.g. with regard to wavefront errors are comparable to those of the measured optical system. Owing to the limited maximum reflectance of available multilayer mirrors, the use of a larger number of mirrors results in correspondingly high transmission losses and a reduction of the number of mirrors increases the length of the assembly.

The use of a scintillator as a sensor element that converts the image-generating EUV radiation into visible or ultraviolet light, which can then be imaged by means of a conventional micro-objective, does not constitute a practicable solution since the emission wavelength of the scintillator, owing to the diffraction limitation and the typical high numerical apertures in the region of one, is only approximately twice as high as the minimum structure dimension to be resolved and would therefore – in an

impracticable manner – itself have to lie in the EUV range if structure dimensions in the EUV wavelength range are to be resolved.

[0005] A further known imaging technique circumvents the diffraction limitation of the optical system by using a photocathode layer, in which the aerial image generates a photoelectron image that can be detected in a suitable manner, e.g. by magnifying imaging by means of a photoelectron emission microscope (PEEM) onto a spatially resolving detector, e.g. a scintillator with an associated camera. However, the conversion efficiency of photocathodes is typically only in the region of a few percent, and it is found that, by taking account of the typical secondary electron energy distributions, the quantum efficiency is unsatisfactorily low for EUV applications.

[0006] The published patent application WO 03/058344 A2 describes such aerial image detectors with a photocathode surface. An electron beam scanning of the photoelectron image in the photocathode layer is proposed as an alternative therein. It is proposed as a further alternative to use a conventional photodiode array, such as a CCD array, upstream of which is a diaphragm with a corresponding array of fine openings, the size of which is chosen to be smaller than the size of the individual photodiode elements in order to achieve a desired resolution, opening diameters of between 50 nm and 125 nm being specified by way of example.

[0007] In the case of the scanning measurement techniques, the resolution not only in the longitudinal direction but also in the lateral plane is attributed to a mechanical movement of a precision table. In one known procedure of this type, the precision table is used to guide a mask through the aerial image, the mask exit being compatible with the required resolution. An integral intensity measurement is effected downstream, which can be realized by means of photodiodes in the EUV

range as well. Problems are posed, however, by the provision of masks suitable for the EUV range. This is because said masks have to have, on the one hand, suitably small structural dimensions, e.g. gap widths, and, on the other hand, a thickness that is significantly smaller than the depth of focus.

[0008] The journal article C.H. Fields et al., Initial Experiments on Direct Aerial Image Measurements in the Extreme Ultraviolet, OSA TOPS on Extreme Ultraviolet Lithography, 1996, volume 4, page 124, describes a scanning measurement system in which a periodic measurement structure made of lines and interspaces is imaged onto a slit sensor which comprises one or a plurality of narrow slits and a sensor surface element arranged behind the latter and is arranged on a moveable precision table, by means of which it is guided across the aerial image in scanning fashion.

[0009] The technical problem on which the invention is based is to provide a spatially resolving radiation detector which can be realized with relatively low outlay and enables a high-resolution radiation detection even in the EUV range. A further object of the invention is to provide an aerial image measuring device that can be used to detect aerial images with high spatial resolution, in particular including those which are generated by imaging EUV radiation. A further object of the invention is to provide a device for high-resolution imaging error determination of an optical system using an aerial image measuring device with a spatially resolving radiation detector. The invention furthermore aims to provide a microlithography projection exposure apparatus which is assigned such a device for imaging error determination. Further objects of the invention are to provide a method for producing a self-supporting photodiode strip for a spatially resolving radiation detector and a method for operating a device for imaging error determination that is equipped with a spatially resolving radiation detector.

[0010] The invention solves this problem by providing a spatially resolving radiation detector having the features of Claim 1, an aerial image measuring device having the features of Claim 11, a device for imaging error determination having the features of Claim 12, a microlithography projection exposure apparatus having the features of Claim 13, a fabricating method having the features of Claim 15, and an operating method having the features of Claim 16 or 17. Advantageous developments of the invention are specified in the subclaims.

[0011] According to the invention, the sensor element of the spatially resolving radiation detector comprises a radiation-sensitive sensor structure element arrangement comprising at least one punctiform or linear sensor structure element, a minimum structure size of the sensor structure element in at least one direction being chosen so as to correspond to a predetermined, desired spatial resolution of the radiation detector. This is understood in the present case to mean that the minimum structure size of the sensor structure element is coordinated with a required spatial resolution of the radiation detector. In one advantageous embodiment of the invention, the minimum structure size is at most approximately equal in magnitude to the required spatial resolution, but in other applications it may also be greater than this, e.g. greater by up to approximately a factor of two. The term "punctiform or linear" in the present case means an areal extent of the sensor structure element which is of the order of magnitude of the minimum structure size in all or in one direction of extent. The sensor structure element has one or more electrical properties that change in an irradiation-dependent manner, so that the irradiance acting locally on the sensor structure element can be detected by means of a measurement of the corresponding electrical measurement quantities, e.g. by means of a resistance or conductivity measurement.

[0012] It is found that such radiation-sensitive sensor structure elements can also be realized for the spatially resolving detection of EUV radiation with comparatively low outlay for production and operation. Thus, the minimum structure size for the radiation-sensitive sensor structure element or sensor structure elements, in one development of the invention, is less than approximately 100 nm and for corresponding applications also less than approximately 20 nm, whereby a spatial resolution of the radiation detector that is suitable for the EUV range can be achieved. In other words, it is thereby possible to realize a nanoscale radiation detector in which the extent of the detection-active, radiation-sensitive sensor structure element or sensor structure elements in at least one direction is limited to at most a few tens of nanometers.

[0013] In one development of the invention, the sensor structure element arrangement has at least two crossing linear elements which, in the crossover region, hold a punctiform sensor structure element, e.g. a radiation-sensitive nanopellet.

[0014] In a refinement of the invention, the sensor structure element arrangement comprises a resistance measuring strip or a nanofiber or nanotube element as linear sensor structure element. The resistance measuring strip has an irradiation-dependent-variable electrical resistance and thus permits a detection of the irradiation intensity by way of its measured electrical resistance. Nanofiber and nanotube elements are known per se. The linear sensor structure element used may also be a photodiode strip having a stacked layer construction with a pn junction in the stack direction, in the present case the term pn junction being meant, for the sake of simplicity, such that it also encompasses "pin" junctions, that is to say those with an intrinsically conducting semiconductor layer, or generally layer junctions which are suitable for charge separation by means of the photoelectric effect. By way of example, layer sequences made of two or more semiconductor layer films,

metal/oxide/semiconductor or generally metal/insulator/semiconductor layer sequences or metal/semiconductor layer sequences are suitable for this.

[0015] In one development of the invention, the respective sensor structure element is arranged in a self-supporting manner or on a transmissive carrier. This avoids disturbing influences from the surroundings of the sensor structure element in that the radiation can pass through largely unimpeded there.

[0016] In one development of the invention, the sensor element can be positioned on a sensor element carrier which can be moved in scanning fashion. It is thus possible to provide a spatially resolving radiation detector whose sensor element is guided in scanning fashion e.g. across an aerial image to be detected.

[0017] In another refinement of the invention, the sensor structure element arrangement comprises a plurality of punctiform or linear photocathode sensor structure elements made of electrically insulating material on a carrier made of electrically non-insulating, e.g. semiconducting material, and also a scanning electron microscope scanning unit for scanning the photocathode sensor structure elements. This makes it possible to realize a spatially resolving radiation detector in which the sensor element can be positioned for example in the plane of an aerial image and the corresponding photoelectron image formed by the photocathode sensor structure elements can be scanned by the scanning electron microscope scanning unit.

[0018] An aerial image measuring device according to the invention has a spatially resolving radiation detector according to the invention for detection of an aerial image. A device for imaging error determination of an optical system according to the invention comprises a measurement ob-

ject structure to be imaged, and an aerial image measuring device according to the invention for detection of the aerial image generated by the optical system through imaging of the measurement object structure. A microlithography projection exposure apparatus according to the invention is assigned a device - according to the invention - for imaging error determination of an optical component of the projection exposure apparatus. The projection exposure apparatus may, in particular, be one of the stepper or scanner type for semiconductor wafer patterning.

[0019] The method according to the invention for fabricating a self-supporting photodiode strip for a spatially resolving radiation detector according to the invention can be carried out with relatively low outlay and is suitable in particular also for providing a photodiode strip having a minimum structure dimensioning suitable for EUV radiation detection applications.

[0020] A method according to the invention for operating a device for imaging error determination of an optical system using an aerial image measuring device according to the invention, equipped with a spatially resolving radiation detector according to the invention, comprises, inter alia, guiding the sensor element arrangement in scanning fashion by means of a correspondingly moveable sensor element carrier across the aerial image of a measurement object structure positioned on the object side, said aerial image being generated by the optical system.

[0021] A further operating method according to the invention for a device for imaging error determination of an optical system comprising an aerial image measuring device according to the invention, equipped with a spatially resolving radiation detector according to the invention, comprises positioning a sensor element with a sensor structure element arrangement comprising a plurality of photocathode sensor structure elements on a carrier on an image side of the optical system such that the

photocathode structure elements are situated on the incident-radiation-remote side of their carrier, and guiding a scanning electron microscope scanning unit in scanning fashion across the photocathode structure elements in order to obtain an electron microscope image which corresponds to the aerial image of the measurement object structure generated by the optical system and can be evaluated in a suitable manner.

[0022] Advantageous embodiments of the invention are illustrated in the drawings and are described below. In the drawings:

- Figure 1 shows a schematic illustration of a microlithography projection exposure apparatus with an assigned device for imaging error determination of a projection objective thereof with an aerial image measuring device,
- Figure 2 shows a schematic side view of a part of the system of Figure 1,
- Figure 3 shows a schematic sectional view of a spatially resolving radiation detector with a linear sensor structure element in the form of a resistance measuring strip,
- Figure 4 shows a plan view of the spatially resolving radiation detector of Figure 3,
- Figure 5 shows a partially sectional perspective view of a spatially resolving radiation detector with a punctiform sensor structure element,
- Figure 6 shows a plan view of the radiation detector of Figure 5,

Figure 7 shows a plan view of a substrate with two layer construction regions lying next to one another for realizing a respective radiation detector element in the manner of Figures 3 and 4 in different fabricating stages,

Figure 8 shows a sectional view of a completed resistance measuring strip from Figure 7,

Figures 9 to 12 show plan views of a sensor element with a photodiode strip in different production stages,

Figure 13 shows a sectional view of the layer construction of the completed photodiode strip of Figures 9 to 12, and

Figure 14 shows a schematic side view of a spatially resolving radiation detector with photocathode sensor structure elements and an associated scanning electron microscope scanning unit.

[0023] Figure 1 schematically illustrates in block diagram form a projection exposure apparatus for EUV microlithography and a device for imaging error determination assigned thereto. The microlithography projection exposure apparatus has a conventional construction, only the components of interest in the present case being reproduced in representative fashion in Figure 1, to be precise an illumination system 1 for generating EUV exposure radiation e.g. having a wavelength of 13.5 nm and a high-resolution projection objective 2 for imaging mask structures that can be positioned in an object plane 3 e.g. by means of a customary reticle stage. During normal exposure operation (not shown here), the projection objective 2 images the mask structure introduced on the object side onto a wafer or onto a photoresist layer applied thereto on the image side, for which purpose the wafer is positioned as usual e.g. by

means of a wafer stage in an image plane 4 of the projection objective 2. The projection exposure apparatus may be of any of the conventional types, in particular of the scanner or stepper type. The invention also encompasses in the same way microlithography projection exposure apparatuses which operate with exposure radiation having other wavelengths, in particular in the EUV range, but also in all other wavelength ranges that are conventionally used for this purpose.

[0024] Figure 1 shows the projection exposure apparatus in a measurement operating mode, in which the assigned device for imaging error determination is coupled and activated in order to measure the projection objective 2 with regard to imaging errors. This device is based on an aerial image measurement technique and comprises for this purpose a measurement mask 5 to be positioned on the object side, that is to say in the beam path upstream of the projection objective 2, and an aerial image measuring device 6 to be positioned on the image side, that is to say in the beam path downstream of the projection objective 2.

[0025] Figure 2 illustrates the aerial image measurement technique in a schematic side view. The measurement mask 5 carries a measurement object structure 5a to be imaged, which is preferably positioned in the object plane 3 of the projection objective 2, e.g. by positioning the measurement mask 5 on the reticle stage. The measurement object structure 5a is illuminated by measurement radiation 7 and imaged by the projection objective 2, so that an aerial image arises in the image plane 4 thereof, said aerial image being detected and evaluated by the aerial image measuring device 6. For this purpose, the aerial image measuring device has a construction that is known per se, and therefore not shown in any greater detail here, with a spatially resolving radiation detector, of which a moveable precision table 6a and a sensor element 6b fitted thereon are reproduced in representation fashion in Figure 2. The precision table 6a may be e.g. a customary wafer stage or a stage

which is provided for measurement operation instead of the wafer stage. In the example shown, the precision table 6a is moveable both in the longitudinal direction (z direction), that is to say parallel to the optical axis 8 of the optical system examined, here of the projection objective 2 or the entire microlithography projection exposure apparatus, and in the lateral plane perpendicular thereto (xy plane). In this way, the spatially resolving sensor element 6b can be displaced as required along the focal direction and be guided laterally across the aerial image.

[0026] The invention characteristically comprises specific realizations for the sensor element 6b, which are explained in more detail below with reference to Figures 3 to 14. What is common to the corresponding spatially resolving radiation detectors is that they comprise a sensor element comprising a radiation-sensitive sensor structure element arrangement having at least one punctiform or linear sensor structure element with an irradiation-dependent electrical measurement property, a minimum structure size of the sensor structure element in at least one direction being chosen so as to correspond to a predetermined spatial resolution of the radiation detector.

[0027] In the exemplary case mentioned concerning the use of an EUV exposure radiation having a wavelength of e.g. 13.5 nm, the ability to obtain minimum structure sizes of structures exposed on a wafer of the same order of magnitude is sought, that is to say in the range of approximately 10 nm to approximately 30 nm. The resolution of the projection objective 2 is to be chosen accordingly, which in turn leads to a required, predetermined spatial resolution of the radiation detector of the same order of magnitude, that is to say e.g. between approximately 10 nm and approximately 30 nm, preferably significantly less than 18 nm. This specifically means, in the case of using the spatially resolving radiation detector in the EUV wavelength range, that the respective

sensor structure element is of nanoscale design, that is to say its extent in at least one direction is at most a few 10 nm.

[0028] Any measurement object structure known per se from conventional aerial image measuring systems can be used for the measurement object structure 5a, which therefore does not need more detailed explanation here. The measurement radiation 7 may be, in particular, the same radiation – supplied by the illumination system 1 – as is supplied by said illumination system during normal exposure operation. Depending on the measurement technique used, various types of measurement object structures and, if appropriate, further measuring components are customary and can be used in the present case, including various known interferometric measuring techniques. It should be mentioned here that, depending on the requirement, the device for imaging error determination may already be integrated into the projection exposure apparatus or, as an alternative to this, the optical component to be measured, here the projection objective 2, may be brought into an associated measurement set-up. The evaluation of the aerial image by the aerial image measuring device 6 may be utilized, for example by means of a control loop, for performing suitable settings on the illumination system 1 and/or on the projection objective 2, e.g. by means of customary lens manipulators present there.

[0029] Figures 3 and 4 show, as a first realization variant, a sensor element 9 whose sensor structure element arrangement comprises a self-supporting radiation-sensitive resistance nanofilament 10, that is to say comprises a narrow, nanoscale strip made of a preferably homogeneous, semiconducting or insulating material whose electrical resistance changes depending on the irradiance. The nanofilament 10 is supported on both sides by an insulation layer structure 11, e.g. made of SiO₂, which is situated on a substrate 12, e.g. an Si wafer. Alongside the nanofilament 10, an associated signal amplifier 13 is integrated on the sub-

strate 12, and connecting wires 14 lead to a customary drive and evaluation unit (not shown).

The amplifier 13 may be, in particular, a preamplifier for signal conditioning which is positioned in direct proximity to the actively sensing element 10 together with the latter on a detector chip. By moving the sensor element 9 laterally in a direction nonparallel, e.g. perpendicular, to the longitudinal extent of the nanofilament 10, it is possible to guide the nanofilament 10 across the entire extent of an aerial image to be detected. Changes that occur in the illuminance in the aerial image in this case are detected by means of corresponding changes in the resistance of the nanofilament 10, so that the entire aerial image can be detected with nanoscale spatial resolution and imaging errors of the projection objective 2 which generates the aerial image can be determined with a correspondingly high resolution in this way.

[0030] Figures 5 and 6 illustrate a realization variant for a sensor element 15 comprising an individual punctiform sensor structure element 16, which, in the example shown for high-resolution sensing of EUV radiation 7, is correspondingly a nanoscale-punctiform sensor structure element, that is to say that the extent of the radiation-sensitive region of the sensor structure element 16 is limited in all directions in nanoscale fashion to at most approximately ten or a few tens of nanometers. This punctiform sensor structure element 16 is therefore also referred to as a nanopellet hereinafter.

[0031] As can be seen from Figures 5 and 6, the radiation-sensitive nanopellet 16 is held so as to be clamped in a self-supporting manner between two nanofilaments 17a, 17b which run perpendicular to one another essentially parallel to the lateral xy plane of the sensor element 15. The nanofilaments 17a, 17b are supported on both sides by an insulation structure 18, e.g. made of SiO_2 , on a substrate 19, e.g. an Si wafer.

A respective connection end of each nanofilament 17a, 17b is connected via contact wires 20 to a signal amplifier 21 arranged on the substrate 19, connecting wires 22 leading from said signal amplifier and likewise from the respective other connection end of the nanofilaments 17a, 17b. Consequently, in this example the nanofilaments 17a, 17b function as holding and connecting elements for the nanopellet 16. The positioning of the nanopellet 16 in the crossover region of the nanofilaments 17a, 17b may be effected for example with the aid of an atomic force microscope (AFM).

[0032] During operation, the sensor element 15 and thus the radiation-sensitive nanopellet 16 is guided in two-dimensionally scanning fashion across the entire region of the aerial image to be detected, and a displacement in the longitudinal z direction may additionally be effected as also in all other cases and as is customary. Changes in the local irradiance in the aerial image are manifested in corresponding changes in the resistance of the nanopellet 16, which, for their part, can be detected by means of the nanofilaments 17a, 17b and the electrical connections thereof.

[0033] Figures 7 and 8 illustrate a production process in parallel for a plurality of sensor elements in the manner of Figure 4 on a common substrate 23, such as a customary SOI (silicon-on-insulator) wafer. For this purpose, firstly an electrically insulating layer structure 24, e.g. made of an oxide material, is formed on the substrate 23 and a membrane structure 25 made of the nanofilament material, e.g. made of Si, is formed thereon. A membrane window 26 is introduced into the substrate 23 by means of rear-side etching. The left-hand part of Figure 7 shows a detector element 27 in this production stage. Afterward, the membrane layer 25 is patterned laterally to form a membrane filament 28, which then functions as a resistance nanofilament, e.g. by means of conventional electron beam lithography and etching processes or alternatively

by nanopatterning using a focused ion beam. The processing precision can be verified as required e.g. by means of a scanning electron microscope. By way of example, a conventional dual beam machine is suitable for the processing. A part of the membrane layer 26 that remains on both sides of the membrane filament 28 serves for making contact with subsequently fitted contact wires 29. A sensor element 30 completed in this way is illustrated in plan view in the right-hand part of Figure 7 and in cross section in Figure 8.

[0034] During operation of a radiation detector comprising a sensor element in the manner of Figure 4 or 5 and 6 or 7 and 8, a suitable bias voltage is applied to the nanofilament 10, 28 or the nanopellet 16 in order to build up an electric extraction field for transporting photoelectrons generated during irradiation. By means of a conductivity measurement, it is then possible to determine the effective irradiance, e.g. when scanning an EUV aerial image. The length of the irradiation-sensitive semiconducting region of the nanofilament 10 or 28 is expediently chosen to be approximately equal to the lateral extent of the illuminated region to be scanned in this direction. It is thus possible to minimize signal losses through recombination.

[0035] Figures 9 to 13 illustrate a method for producing a sensor element in which the sensor structure element arrangement comprises a self-supporting photodiode strip, that is to say a linear photodiode. For this purpose, firstly as in the example of Figures 7 and 8, a self-supporting semiconducting membrane 31, e.g. made of Si, is formed with interposition of an insulation layer 32, e.g. made of an oxide material, on a substrate 33, e.g. an SOI wafer, as illustrated in Figure 9. The membrane 32 is subsequently covered by an oxide layer 34 with the exception of an exposed contact region 31a, see Figure 10. Next, a metal layer 35 is applied to the oxide layer 34, as illustrated in Figure 11. A narrow, e.g. nanoscale strip 36 is subsequently generated by corre-

sponding patterning of the layer construction up to the rear-side membrane window 37 e.g. by means of a focused, rapid ion beam.

[0036] Figure 13 shows a cross section through the layer construction of the narrow sensor strip 36 above the membrane window 37. As can be seen from this, the sensor strip 36 comprises in each case in patterned form the metal layer 35, the oxide layer 34 and the underlying semiconductor membrane layer 31 above the insulation layer 32. In this way, in the longitudinal z direction, a pn junction is formed by the metal/oxide/semiconductor layer construction, which generates an electric field for charge separation, that is to say that the narrow sensor strip 36 constitutes an e.g. nanoscale, linear photodiode with a PIN junction. The detector element with the self-supporting linear photodiode strip 36 is completed by fitting the associated connecting links 38, as illustrated in Figure 12. As an alternative, the charge-scattering pn junction may be realized by a different layer sequence known per se for this purpose, e.g. generally a metal/insulator/semiconductor layer sequence, two differently doped semiconductor layers, a metal/semiconductor junction, or as a pin junction having an intrinsic semiconductor layer.

[0037] Apart from the realizations described above in conjunction with Figures 3 to 13, further realizations according to the invention of spatially resolving radiation detectors of the scanning type can be realized which comprise one or a plurality of punctiform or linear sensor structure elements as actively sensing components. This encompasses in particular radiation detectors in which the sensor structure element arrangement comprises a nanofiber in the form of a carbon nanotube as linear sensor structure element, which can be mounted in a self-supporting manner or be arranged on a carrier. Such nanotubes are known per se, so that reference may be made to the literature in this regard, and are used in scanning tunneling microscopes, for example.

[0038] Further embodiments comprise, as linear sensor structure element, a photodiode strip in the manner of the example of Figures 9 to 13, but wherein the photodiode strip is arranged on a carrier. The carrier for the nanotube or the photodiode strip is in each case chosen such that it does not cause any disturbances, in particular any charging-dictated electric interference fields, for the sensor structure element during measurement operation. By way of example, the carrier may be chosen to be transmissive for the examined radiation, or it may be composed of a material having good electrical conductivity, e.g. a metallic material, in which case it is then isolated from the sensor structure element by means of a suitable electrical insulation layer.

[0039] An estimation shows that it is possible, using a spatially resolving radiation detector according to the invention of the scanning type in the manner of Figures 3 to 13, to scan with the required nanoscale resolution EUV aerial images such as are generated during the high-precision measurement of optical components of microlithography projection exposure apparatuses operating in EUV. Thus, an irradiance of an exposure apparatus in the manner of Figure 1 in the image plane 4 of approximately 10 mW/cm^2 and a linear nanoscale sensor structure element having a width of approximately 10 nm, a thickness of approximately 10 nm and a length of the irradiated surface of approximately $2 \text{ }\mu\text{m}$ and also an absorption length for the EUV radiation of approximately 15 nm shall be assumed by way of example for an irradiation with continuous light. This then results in a photon flux converted into photoelectrons of approximately $6.5 \times 10^4/\text{s}$, whereby a maximum signal/noise ratio of approximately 255 is achieved for a measurement integration time of one second. Each photon generates on average approximately 20 photoelectrons, which results in a photocurrent intensity of approximately 200 fA, which can be measured e.g. using an electrometer amplifier.

[0040] In the case of irradiation with pulsed light with a repetition rate of the pulsed radiation source of approximately 1000 Hz, approximately 90 photons are detected for an individual pulse and converted into photoelectrons with a conversion efficiency of approximately 20. If the charge pulses are stored on an on-chip capacitor having a capacitance of approximately 1 pF, which corresponds to a junction capacitance of a diode having an areal extent of $200\text{ }\mu\text{m} \times 200\text{ }\mu\text{m}$, this produces a voltage rise across said capacitance of approximately 0.2 mV per pulse. In the case of pulsed radiation sources, in order to eliminate electronic noise, the measurement integration time can be synchronized with the radiation source, so that in this case, too, it is possible to optimize the signal/noise ratio apart from the shot noise of the photons.

[0041] Further possible realizations of spatially resolving radiation detectors according to the invention comprise a sensor structure element arrangement comprising one or a plurality of punctiform or linear, preferably nanoscale, sensor structure elements in which nonlinear amplification effects or quantum effects occur as a result of irradiation, it being possible to detect the radiation intensity by measuring said effects. By way of example, EUV radiation can be absorbed in a correspondingly designed, nanoscale, punctiform or linear sensor structure element having a thickness of approximately 10 nm and an absorption length of approximately 15 nm, each photon giving rise on average to 18.6 photoelectrons. If the charge carrier lifetime is comparable to the pulse duration of e.g. approximately 10 ns or longer, an average photoelectron density of approximately one photoelectron per 10^4 atoms is established in the absorbent sensor structure element, a typical atomic density in the solid e.g. of aluminum being assumed. This corresponds to a sphere having a radius of approximately 13.5 atomic radii. This ratio means a massive intervention in the band structure of the material, so that quantum effects occur which can be utilized for signal amplification given a suitable construction of the absorbent sensor structure element.

[0042] For imaging error determination of the projection objective 2 of Figure 1 or generally of any other optical system using a measurement object structure to be imaged and an aerial image measuring device comprising a spatially resolving radiation detector of the scanning type according to the invention, the following procedure may then be adopted. Firstly, the measurement object structure to be imaged is positioned on an object side of the optical system to be measured and the spatially resolving radiation detector or the sensor element thereof is positioned on a sensor element carrier that can be moved in scanning fashion, such as a moveable precision table corresponding to Figure 2, on an image side of the optical system. This is followed by activating the optical system for imaging the measurement object structure, and the detector or the sensor element thereof comprising the punctiform or linear sensor structure element or sensor structure elements is guided in scanning fashion across the aerial image of the measurement object structure that is generated by the optical system. The measurement signals obtained by the detector are then evaluated in a conventional manner to determine one or a plurality of imaging errors of the optical system.

[0043] It goes without saying that, in further advantageous embodiments of the invention, the sensor structure element arrangement of the radiation detector may also comprise a plurality of sensor structure elements which are arranged for example in a one-dimensional row or in a two-dimensional array. In this case, a sensor structure element arrangement may also contain a mixture of one or a plurality of punctiform and one or a plurality of linear sensor structure elements.

[0044] Figure 14 schematically illustrates a further type of a spatially resolving radiation detector 40 according to the invention. This radiation detector 40 has a photocathode structure 41 on a self-supporting mem-

brane 42, which is supported on both sides by a carrier layer structure 43, e.g. made of Si. In this case, the photocathode structure 41 is situated on the light-remote rear side of the membrane 42, that is to say the membrane side remote from the incident radiation 7 to be detected. In the case of EUV radiation 7, the photocathode structure is correspondingly patterned in nanoscale fashion. The membrane 42 is composed e.g. of a material that is semitransparent to EUV, such as Si, having a thickness of e.g. approximately 200 nm. For the EUV wavelength at 13.5 nm, such an Si membrane has a transmission of more than 70%. The photocathode structure 41 is composed of an electrically insulating material, e.g. made of SiO_2 , Si_3N_4 , Ti_3N_4 etc., which is able to absorb EUV radiation and convert it into photoelectrons. The photocathode structure 41 preferably comprises individual insulating islands having a lateral extent of only a few nanometers as punctiform sensor structure elements which are arranged regularly in a two-dimensional array. The photocathode islands 41 may be applied to the membrane 42 such that they have already been patterned by means of a technology known per se, or, as an alternative, firstly a photocathode layer is applied and is subsequently patterned e.g. by means of electron beam lithography.

[0045] A local pn junction forms in each case between the nanoscale photocathode islands 41 and the carrier membrane 42. With this type of detector, the photocathode structure 41 is scanned by a scanning electron microscope unit 44 from the light-remote side by means of an electron beam 45 being guided over the photocathode structure 41 by a scanning method. The photocathode islands 41 are charged electrostatically under the influence of the electron beam 45. In the event of irradiation e.g. with the EUV radiation 7, charge carrier pairs are generated in the photocathode islands 41 and discharge the local capacitances or charges. The accompanying change in the electrostatic potential of the respective photocathode island, which functions as a sensor pixel in this case, directly affects the kinetic energy of the secondary electrons

and is manifested in the recorded electron microscope image as potential contrast which can be evaluated.

[0046] It goes without saying that the scanning electron microscope unit 44 indicated only schematically in Figure 14 is of a customary construction which is suitable for this and need not be discussed in any greater detail here. Consequently, while electrostatic charges on insulating samples constitute rather a disturbing phenomenon in normal scanning electron microscopy, this effect is exploited in the present case for high-resolution, two-dimensional EUV aerial image detection or for other spatially resolving detection of EUV radiation or other radiation. The patterning of the photocathode 41 coordinated with the required resolution, preferably in the form of a nanopatterning, prevents the charges from flowing apart, as may occur in the case of an unpatterned photocathode layer.

[0047] An estimation shows that a sufficient image intensity for an aerial image measurement in typical microlithography projection exposure apparatuses e.g. of the scanner or stepper type can be achieved with such a radiation detector in accordance with Figure 14. By way of example, a photocathode island or nanocell as image pixel having a lateral extent of approximately $15\text{ nm} \times 15\text{ nm}$ and a thickness of approximately 10 nm shall be assumed for this purpose. Given an EUV absorption length of approximately 15 nm , on average 0.07 photon is absorbed per pixel and laser pulse. In order to obtain a signal/noise ratio of approximately 30, about 1200 pulses are necessary, that is to say that the exposure time is somewhat more than one second. In order to take account of possible high losses from scattering processes, a photon-photoelectron conversion efficiency of only about one is assumed. During an exposure, approximately 900 photoelectrons are then accumulated on a pixel. Given a typical junction capacitance of 20 nF/cm^2 , the capacitance of a pixel is $4.5 \times 10^{-20}\text{ F}$. This produces a change in the potential of the pixel of more

than 3000 V during the exposure. Such a change in potential leads to a distinct potential contrast in the energy distribution of the secondary electrons during scanning with the scanning electron microscope.

[0048] For imaging error determination or aerial image detection e.g. in a system in the manner of Figure 1 with the radiation detector of Figure 14, firstly the measurement object structure to be imaged is positioned on the object side and the detector or the sensor element thereof with the photocathode structure 41 is positioned in or near the image plane. This is followed by activating the scanning electron microscope scanning unit 44 and the optical system to be measured for imaging the measurement object structure. The scanning electron microscope scanning unit 44 guides the electron beam 45 in scanning fashion across the photocathode structure 41. The electron microscope image that arises is then evaluated in a suitable manner.

[0049] It goes without saying that spatially resolving radiation detectors according to the invention are suitable not only for aerial image detection for the purpose of imaging error measurement of optical components of microlithography projection exposure apparatuses of all types, but furthermore also for detection of aerial images of any other applications of aerial image measurement technology and generally for any applications which require a spatially resolved detection of the illuminance of a radiation. The invention is suitable in particular for detecting radiation of any EUV wavelengths and thus for corresponding EUV applications, but is not restricted thereto. Thus, by way of example, radiation in the rest of the UV range can also be detected in spatially resolved fashion by radiation detectors according to the invention, for which purpose the dimensioning of the punctiform or linear sensor structure element or sensor structure elements is to be modified in a suitable manner.

Claims

1. Spatially resolving radiation detector comprising a radiation-sensitive sensor element, characterized in that the sensor element comprises a radiation-sensitive sensor structure element arrangement comprising at least one punctiform or linear sensor structure element (10) with an irradiation-dependent electrical measurement property, a minimum structure size of the sensor structure element in at least one direction being chosen so as to correspond to a predetermined spatial resolution of the radiation detector.
2. Spatially resolving radiation detector according to Claim 1, wherein the minimum structure size of the at least one sensor structure element is chosen to be at most approximately equal in magnitude to the predetermined spatial resolution.
3. Spatially resolving radiation detector according to Claim 2, wherein the predetermined spatial resolution lies in the EUV wavelength range and/or the minimum structure size of the at least one sensor structure element is chosen to be less than approximately 100 nm, in particular less than approximately 20 nm.
4. Spatially resolving radiation detector according to any of Claims 1 to 3, wherein the sensor element arrangement comprises a punctiform sensor structure element (16) which is held by two linear strips (17a, 17b) in a crossover region thereof.
5. Spatially resolving radiation detector according to any of Claims 1 to 4, wherein the sensor element arrangement comprises a punctiform or linear element with irradiation-dependent-variable electri-

cal resistance or a nanofiber or nanotube element as sensor structure element.

6. Spatially resolving radiation detector according to any of Claims 1 to 5, wherein the sensor element arrangement comprises a photodiode strip (36) as linear sensor structure element, said photodiode strip having a stacked layer construction with a pn junction in the stack direction.
7. Spatially resolving radiation detector according to Claim 6, wherein the stacked layer construction comprises a semiconductor/semiconductor layer sequence or a metal/insulator/semiconductor layer sequence, in particular a metal/oxide/semiconductor layer sequence, or a metal/semiconductor layer sequence.
8. Spatially resolving radiation detector according to any of Claims 1 to 7, wherein the sensor structure element arrangement comprises one or a plurality of linear sensor structure elements which are arranged in a self-supporting manner or on a transmissive carrier.
9. Spatially resolving radiation detector according to any of Claims 1 to 8, wherein a sensor element carrier (6a) is provided which can be moved in scanning fashion and on which the sensor structure element arrangement can be positioned.
10. Spatially resolving radiation detector according to any of Claims 1 to 9, wherein
 - the sensor structure element arrangement comprises a plurality of punctiform or linear photocathode sensor structure elements (41) made of electrically insulating material on a carrier made of electrically semiconducting material, and

- a scanning electron microscope scanning unit (44) is provided for scanning the photocathode sensor structure elements.
11. Aerial image measuring device comprising a spatially resolving radiation detector according to any of Claims 1 to 10 for detection of an aerial image.
 12. Device for imaging error determination of an optical system, comprising
 - a measurement object structure (5a) to be imaged, and
 - an aerial image measuring device according to Claim 11 for detection of the aerial image generated by the optical system through imaging of the measurement object structure.
 13. Microlithography projection exposure apparatus, which is assigned a device according to Claim 12 for imaging error determination of an optical component of the same.
 14. Microlithography projection exposure apparatus according to Claim 13, wherein it is one of the stepper or scanner type for semiconductor wafer patterning.
 15. Method for fabricating a self-supporting photodiode strip (36) for a spatially resolving radiation detector according to Claim 6 or 7, comprising the following steps:
 - providing a substrate (32, 33) with a self-supporting membrane (31) made of electrically semiconducting material,
 - forming an insulation layer (34) made of electrically insulating material on the membrane whilst exposing a contact-making region (31a) of the membrane,
 - forming an electrically conductive layer (35) on the insulation layer, and

- patterning the layer construction comprising membrane, insulation layer and electrically conductive layer to generate the self-supporting photodiode strip with a corresponding layer construction.
16. Method for operating a device for imaging error determination of an optical system according to Claim 12 comprising an aerial image measuring device according to Claim 11, equipped with a spatially resolving radiation detector according to Claim 9, comprising the following steps:
- positioning the measurement object structure (5a) to be imaged on an object side (3) of the optical system (2),
 - positioning the sensor element on a sensor element carrier (6a) that can be moved in scanning fashion on an image side (4) of the optical system,
 - activating the optical system for imaging the measurement object structure,
 - guiding the sensor structure element arrangement in scanning fashion across the aerial image of the measurement object structure that is generated by the optical system, and
 - evaluating the measurement signals obtained by the sensor structure element arrangement to determine one or a plurality of imaging errors of the optical system.
17. Method for operating a device for imaging error determination of an optical system according to Claim 12 comprising an aerial image measuring device according to Claim 11, equipped with a spatially resolving radiation detector according to Claim 10, comprising the following steps:
- positioning the measurement object structure (5a) to be imaged on an object side (3) of the optical system (2),

- positioning the sensor element (41) on an image side (4) of the optical system such that the photocathode sensor structure elements (41) are situated on the incident-radiation-remote side of their carrier (42),
- activating the scanning electron microscope scanning unit (44) and guiding the electron beam (45) in scanning fashion across the photocathode structure elements and activating the optical system for imaging the measurement object structure, and
- evaluating the electron microscope image obtained to determine one or a plurality of imaging errors of the optical system.

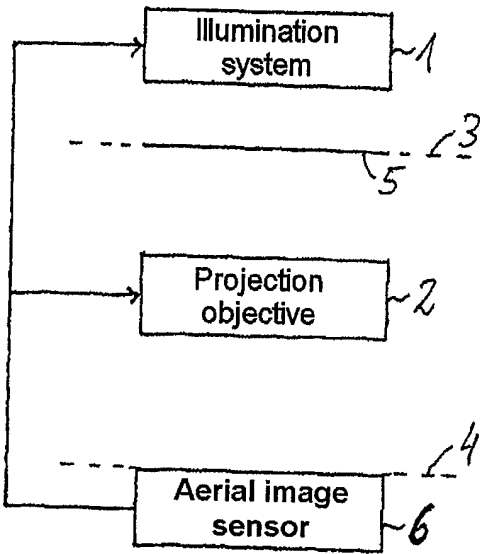


Fig. 1

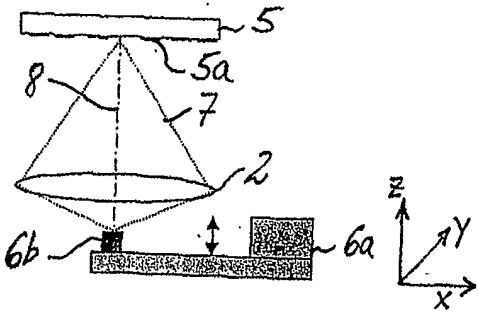


Fig. 2

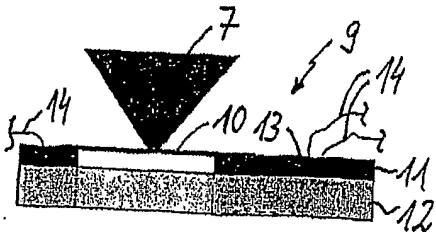
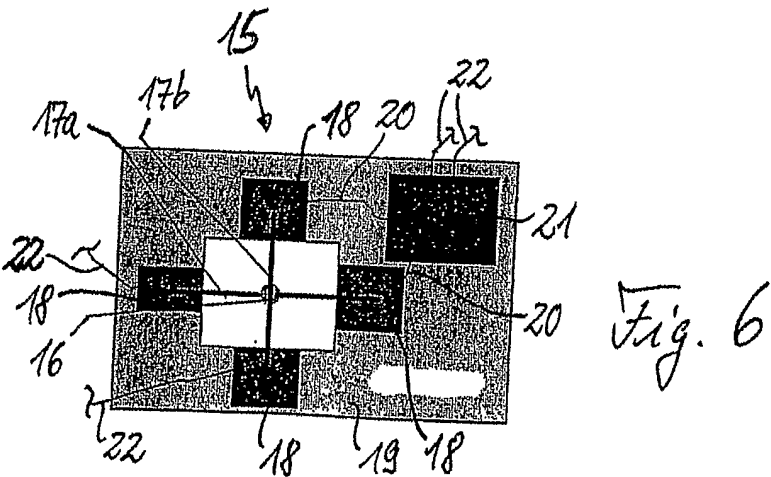
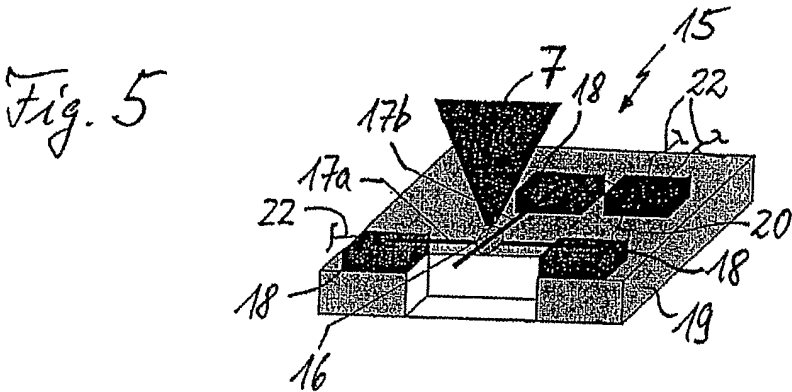
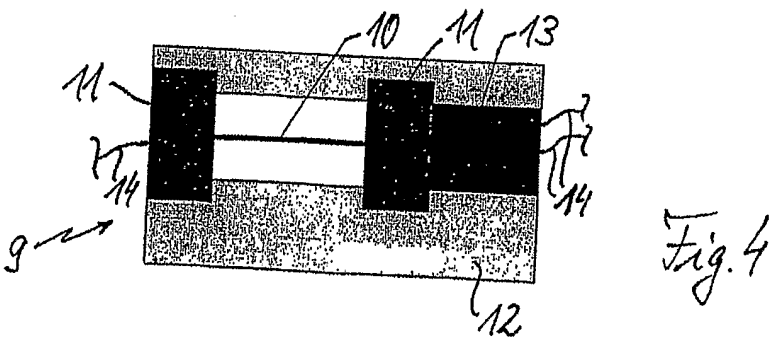
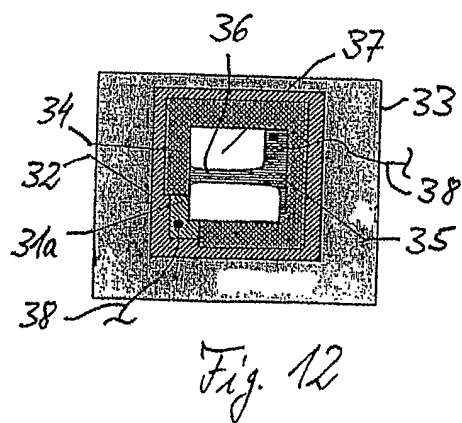
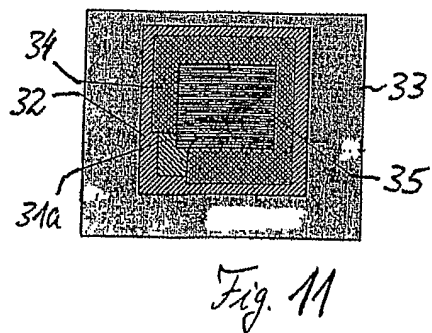
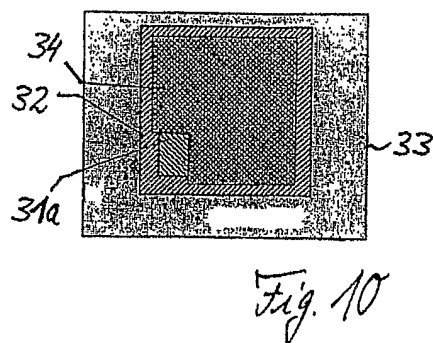
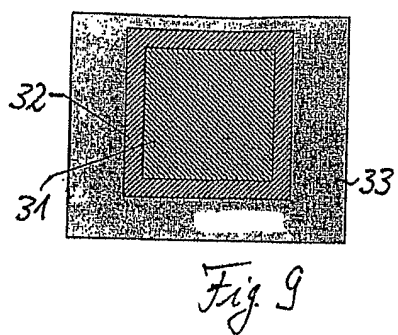
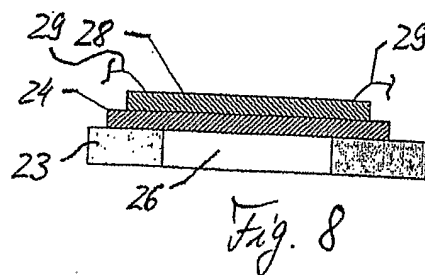
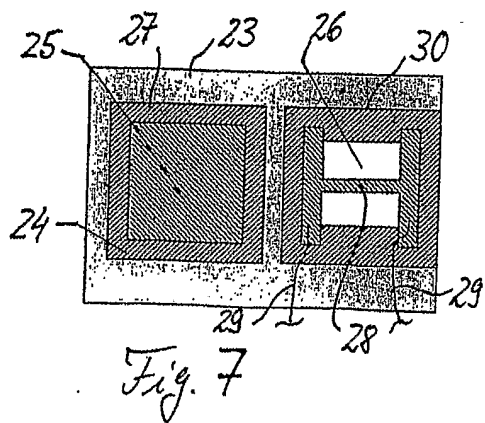
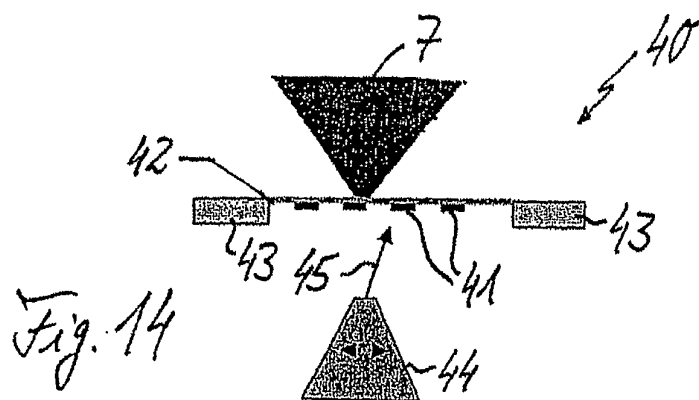
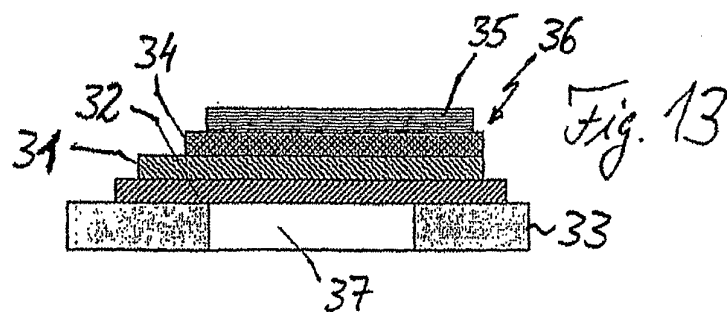


Fig. 3







INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2006/001589

A. CLASSIFICATION OF SUBJECT MATTER
 INV. G03F7/20 H01L31/08

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)

H01L G03F B82B G01T

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2005/008787 A (JAPAN SCIENCE AND TECHNOLOGY AGENCY; NATIONAL INSTITUTE OF ADVANCED IN) 27 January 2005 (2005-01-27) abstract; figures 2,3 -----	1-9, 11-14,16
X	FIELDS C H ET AL: 1996, OSA TRENDS IN OPTICS AND PHOTONICS. VOL.4 EXTREME ULTRAVIOLET LITHOGRAPHY. FROM THE OPTICAL MEETING OPT. SOC. AMERICA WASHINGTON, DC, USA, PAGE(S) 124 - 127 , XP009065101 ISBN: 1-55752-435-1 cited in the application the whole document -----	1-3,6-9, 11-14,16
X	US 6 130 431 A (BERGER ET AL) 10 October 2000 (2000-10-10) the whole document ----- -/--	1-3,6-9, 11-14,16

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

☒ See patent family annex.

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* & * document member of the same patent family

Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

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PCT/EP2006/001589

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 5 365 092 A (JANESICK ET AL) 15 November 1994 (1994-11-15) columns 10-12; figure 2 -----	1-4,9, 11-14,16

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Information on patent family members

International application No

PCT/EP2006/001589

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