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(54) METHOD OF FORMING A PATTERN OF SUB-MICRON BROAD FEATURES

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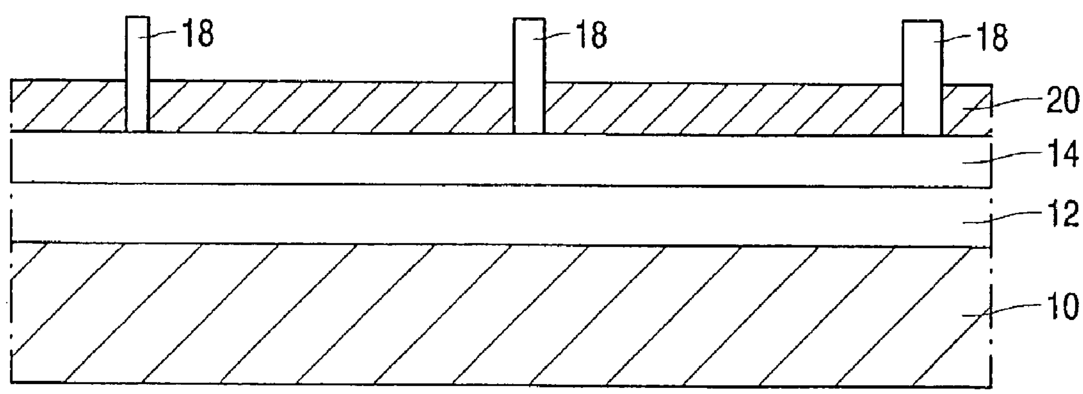
(57) ABSTRACT

A pattern of very fine features (18) can be produced by illuminating an inorganic negative tone resist layer (16), provided on an electroplating base layer (14), by a beam (EB), which is able to cure the resist to a cured pattern according to the pattern to be formed, removing the non-illuminated portions of the resist layer and electroplating a layer (20) between the cured portions (18) of the resist layer.



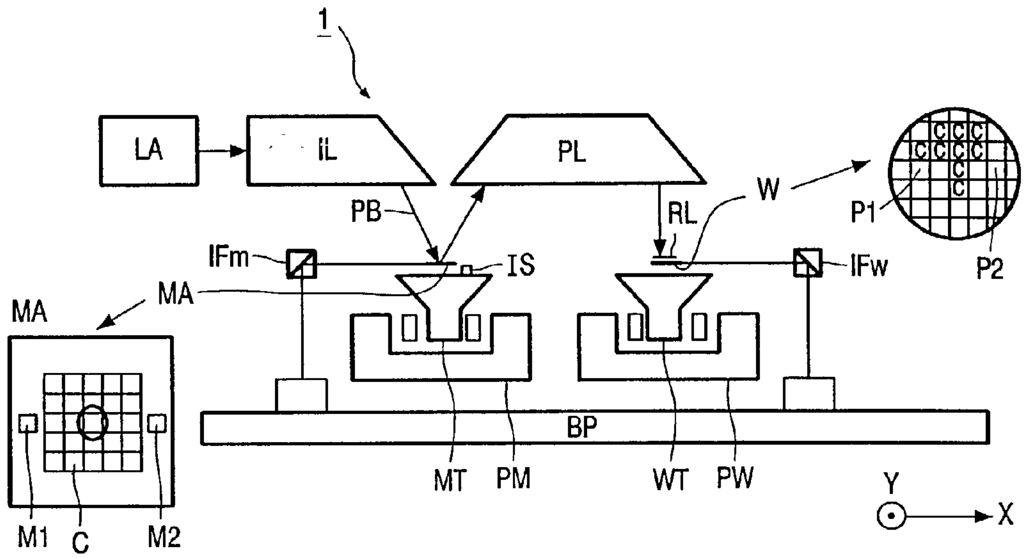

1
LA
IL
PL
PB
RL
W
P1
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FIG. 1

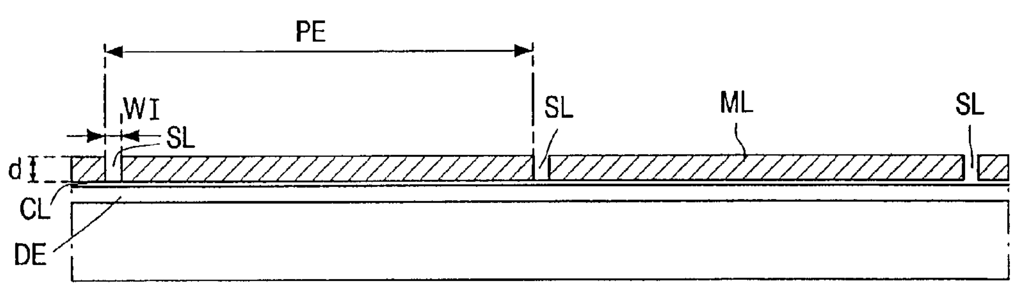
PE
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FIG. 2

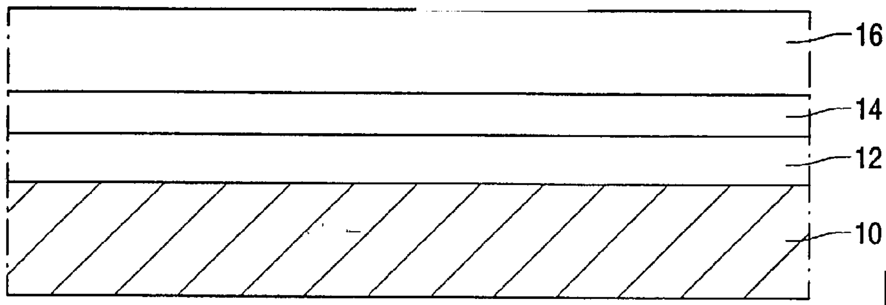

FIG. 3A

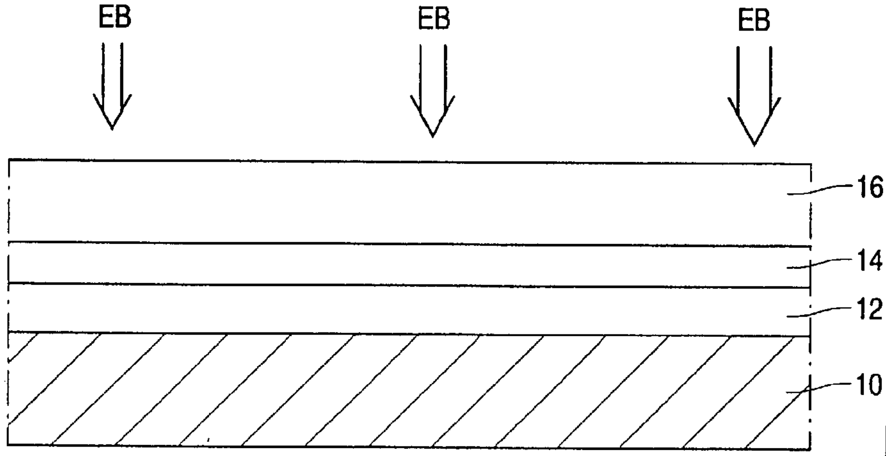

FIG. 3B

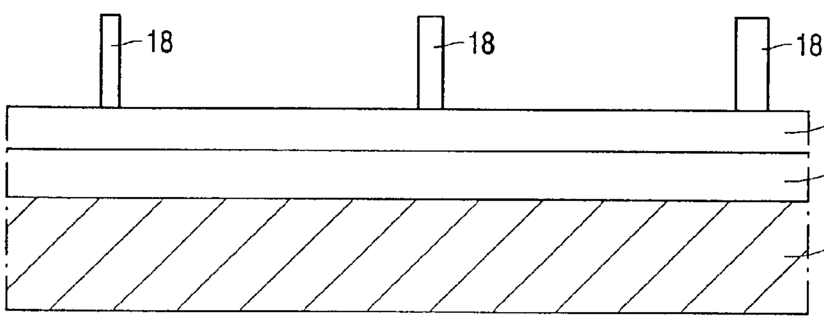

FIG. 3C

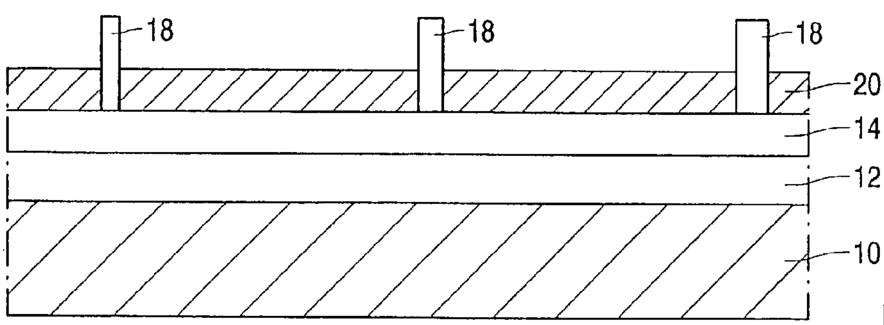

FIG. 3D

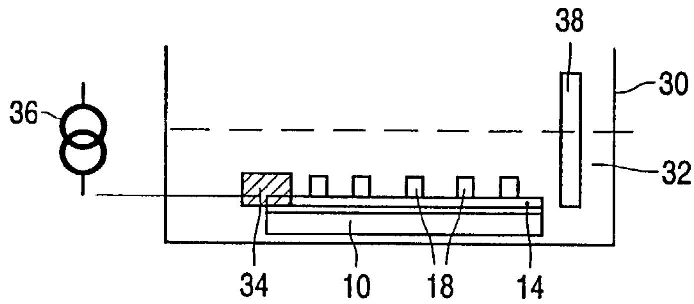

FIG. 4

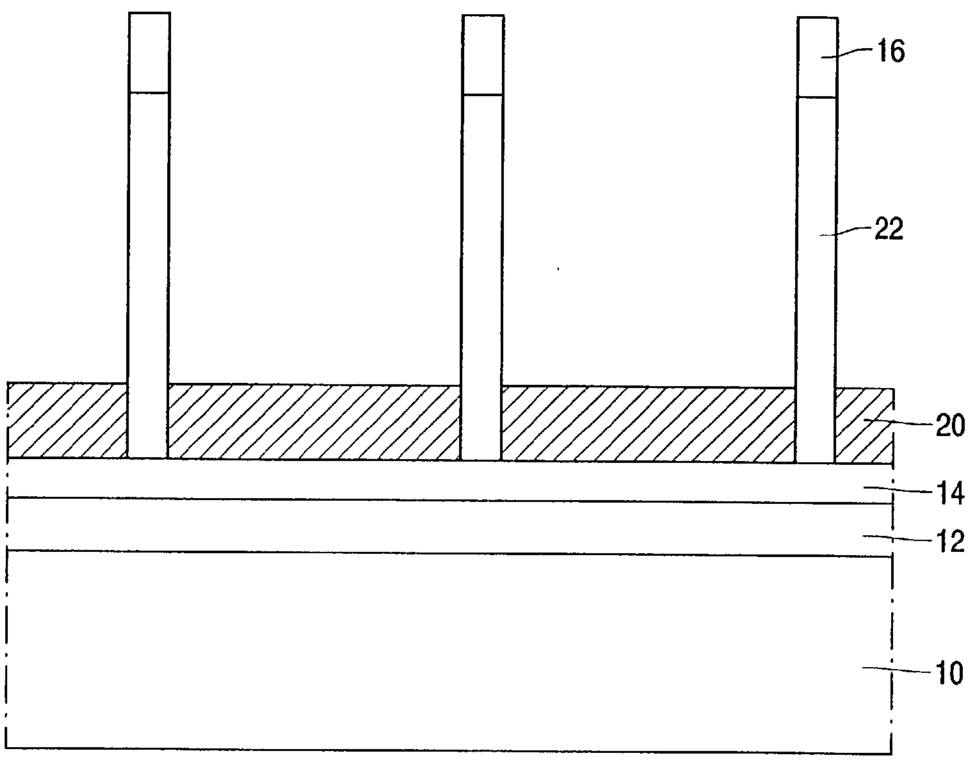

FIG. 7

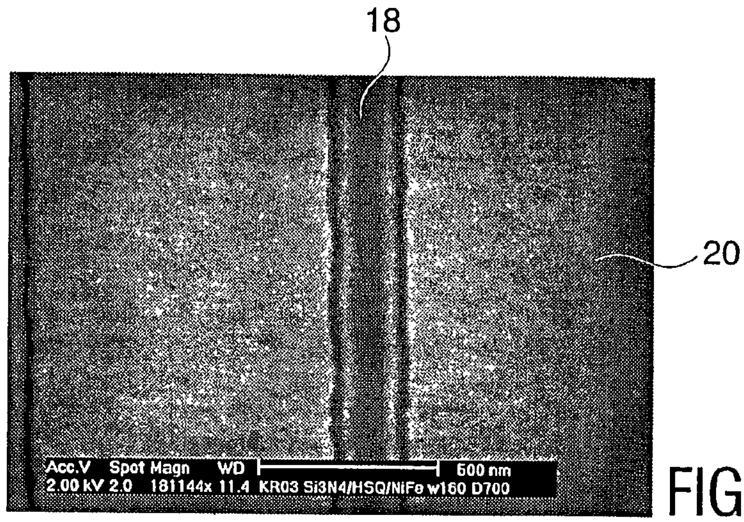

FIG.5a

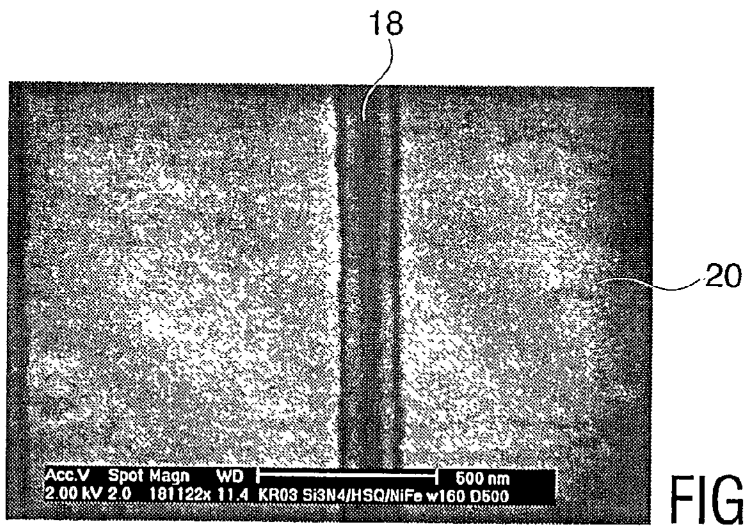

FIG.5b

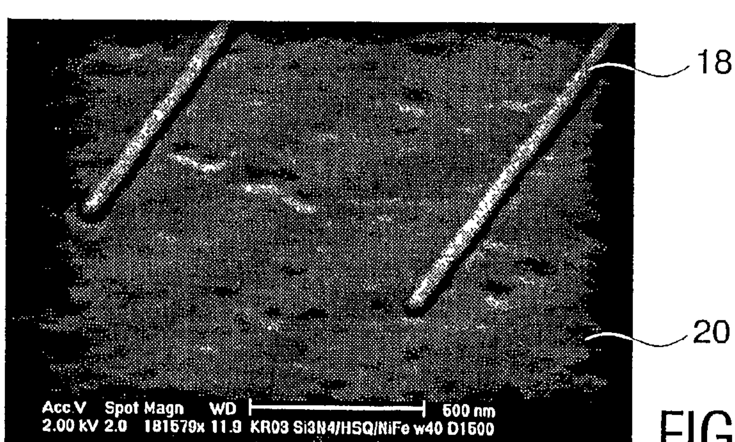

FIG.6

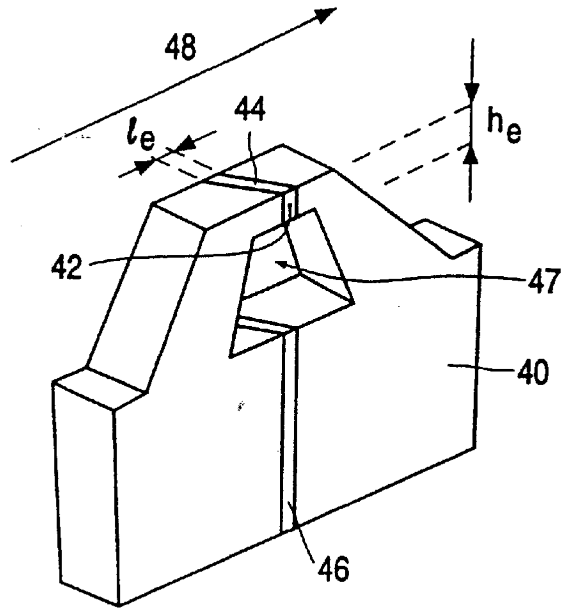

FIG. 8

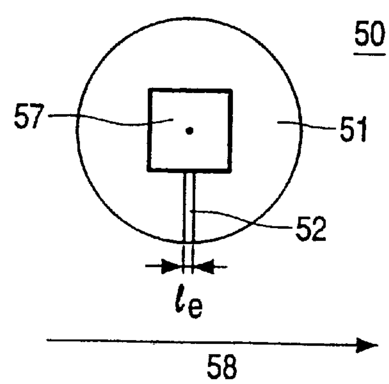

FIG. 9

METHOD OF FORMING A PATTERN OF SUB-MICRON BROAD FEATURES

[0001] The invention relates to a method of forming a pattern of sub-micron broad features in a metal layer, which method includes the steps of:

[0002] forming a resist layer, comprising a negative tone resist material, on a substrate;

[0003] illuminating selected portions of the resist layer by a beam, which is able to cure the resist to a cured pattern according to the pattern to be formed, and

[0004] removing non-illuminated portions of the resist layer.

[0005] The invention also relates to a pattern of features manufactured by means of this method.

[0006] The pattern of features may be a grating structure, for example an optical grating for use in an optical apparatus, or may form part of an image sensor, which is used in a lithographic projection apparatus. Such an apparatus is an essential tool in the manufacture of integrated circuits (ICs) by means of masking, material removing and implantation techniques. The projection apparatus is used to successively image different mask patterns at the same area of a semiconductor substrate, each mask pattern at a different level of the substrate. This apparatus includes, in this order, an illumination unit for supplying a projection beam, a mask holder for accommodating a mask, a substrate holder for accommodating a substrate and a projection system arranged between the mask holder and the substrate holder. The mask is provided with a mask pattern corresponding to the pattern of device features that is to be formed in that substrate level that is to be configured by the specific mask. The projection system images the mask pattern into a resist layer coated on the substrate. This projection system may be a system of lenses or a system of mirrors or a combination of such systems. To control the performance of the projection system and possibly of the illumination unit, the projection apparatus comprises an image sensor. Such an image sensor is a device composed of a radiation-sensitive element, for example an array of photo diodes or a charge-coupled device (CCD), and a light-shielding element comprising an array of radiation transmission areas arranged in front of the radiation-sensitive element. The image sensor may be arranged in or on the substrate holder. For measuring the performance of the projection system, a mask provided with a test pattern, for example a grating pattern, is positioned in the mask holder and illuminated by the projection beam. The test pattern is imaged, by means of the projection system, on the image sensor. The lightshielding element has a pattern of transmission areas corresponding to the test pattern. The output signals of the image sensor are supplied to an electronic processing circuit in which these signals are compared with standard signals corresponding to the test pattern itself.

[0007] The size of the device features that can be imaged by the lithographic apparatus in the resist layer depends on he resolving power, or resolution, of the projection system of this apparatus. This resolution is proportional to λ/ NA, wherein λ is the wavelength of the projection beam used in the apparatus and NA is the numerical aperture of the projection system. To produce devices, such as ICs, with a higher density, and hence higher operating speeds, smaller device features have to be imaged so that a projection system with a higher resolution should be used. To control a lithographic projection apparatus with such a high-resolution projection system, an image sensor with an increased resolving power should be used. This means that the width of the transparent openings in the radiation shield, for example the width of the transparent strips of a grating, should be considerably decreased.

[0008] Current lithographic projection apparatus employ ultraviolet (UV) radiation having a wavelength of 365 nm, generated by mercury lamps, or deep UV (DUV) radiation having a wavelength of 248 nm, 193 nm or 157 nm and generated by exciter lasersnm In principle, a feature width as small as 100 mn can be imaged. with an apparatus operating with a radiation of 157 nm. For future lithographic projection apparatus, which should image device features having a width smaller than 100 nm, it has been proposed to use extreme UV (EUV) radiation, also called soft-X ray radiation, which has a considerably smaller wavelength. EUV radiation is understood to mean radiation with a wavelength from a few to some tens ofNMs and preferably of the order of 13 nm. For an EUV image sensor, the grating strips should be further decreased. A typical EUV image sensor grating has strips in the form of grooves or ridges with a width of 50-150 nm and a pitch, or grating period, of 2000 nm, which strips are processed in a 50-100 nm thick metallic layer, for example a nickel (In) or silver (Erg) layer. Such a layer is commonly deposited by means of chemical vacuum deposition (CVD) on any type of non-conductive substrate.

[0009] The most obvious technique to produce such a grating with small grooves, or spaces in the metal layer, seems to be reactive ion etching. However, for groove widths of 50-150 nm, this etching technique does not provide the required quality in most transition or alloy layers, because etching products are non-volatile. The term transition refers to the fact that the grooves formed in these layers do not show vertical walls between their bottom surface and the upper surface of the layer, but a smooth transition between these surfaces. Also the so-called “lift-off” method is not suitable. This method may be used to produce a single isolated groove having a small width, but when producing a series of such grooves, like those of a grating, the grooves grow towards each other, which results in a bad wall definition of the grooves. The lift-off method is used to perform, when transferring the resist pattern to the metal pattern, a contrast reversal, i.e. ridges in the resist become slits in the metal. Grooves having widths of the order of 50 nm can only be obtained in a reproducible manner by writing corresponding strips in a negative tone resist by means of an electron beam. A negative tone resist is understood to mean a resist of which the illuminated portions remain after development of the resist. The grating pattern formed in the resist layer is the negative of the required grating pattern.

[0010] It is an object of the present invention to provide a method which is very suitable for producing a pattern of very small features, like a grating with very small grating grooves, which method does not use a lift-off step and thus does not suffer from the disadvantages inherent in such a step. The method is characterized in that the resist material is an inorganic material and in that the additional steps of:

[0011] forming an electroplating base layer on the substrate before applying the resist layer, and

[0012] electroplating a layer between the cured portions of the resist layer are carried out.

[0013] The grating structure is now formed by depositing the supporting material between the grating strips and outside the area of these strips, instead of transferring the resist structure to the supporting material by means of etching techniques.

[0014] The method is preferably further characterized in that a siloxane is used as a resist material.

[0015] Most preferably, the method is further characterized in that hydrogen silsesquioxane (HSQ) is used as a resist material.

[0016] As described in the paper: "HSQ/ Novolak bilayer resist for high aspect ratio nanoscale e-beam lithography " presented on Proc. 44th International Conference on Electron-, Ion- and Photon-Beam Technology and Nanofabrication (EIPBN2000), Palm Springs Calif. 2000 and published in Journal of Vacuum Science and Technology B 18,6 (2000), 3419, hydrogen silsesquioxane (HSQ) is sensitive to electrons and can be used as a negative tone resist for a fine pattern writing electron beam. When manufacturing a grating structure for EUV radiation, HSQ provides the great advantage of being transparent to EUV radiation after it has been cross-linked by the electron beam.

[0017] Other siloxane materials can also be used as negative tone resist materials for the envisaged purpose.

[0018] If the absorption of a HSQ material is large and the penetration depth for the writing beam small so that a thin layer of HSQ would have to be used, the method is preferably further characterized in that a double layer comprising a hydrogen silsesquioxane top layer and a novolak bottom layer is used as a resist layer.

[0019] Then a pattern of features having a larger depth can be produced.

[0020] According to a further aspect of the invention, the method is characterized in that a layer of one of the materials: silver, nickel and permalloy is electroplated between the illuminated portions of the resist layer.

[0021] These materials show the advantages of having a low transmission for radiation, especially EUV radiation.

[0022] According to a still further aspect of the invention, the method is characterized in that a layer of one of the materials: silver, gold, aluminum, copper and molybdenum is used as an electroplating base layer.

[0023] Because of their low electrical resistance, silver, gold, aluminum and copper are excellent materials for an electroplating base and allow several materials, having a higher resistance, to be electroplated In addition to a low resistance, molybdenum has the additional advantage of being transparent to EUV radiation.

[0024] To prevent that plating material from being deposited on the substrate surface remote from the resist carrying-surface during the electroplating process, the method is further characterized by the intermediate step of covering the substrate surface, which is to be provided with the pattern of features, with an insulating layer before the electroplating base layer is applied.

[0025] As an alternative, instead of the resist-carrying surface, said remote surface can be covered with an insulating layer.

[0026] As both a HSQ layer and a molybdenum layer are sufficiently transparent to EUV radiation, a formed pattern structure comprising the illuminated portions of the HSQ layer may be used as a pattern of features for use in an EUV projection apparatus. If the pattern of features is to be used with radiation other than EUV radiation, other combinations of resist and electroplating base materials have to be chosen. The presence of HSQ, or another resist material, in the openings of the metal layer prevents contaminants from being deposited in the openings, which is an important advantage in a production environment for ICs or other devices. Another important advantage of HSQ is that a pattern of features formed of this material will not be ablated by EUV radiation, i.e. soft X-ray radiation, during its use in an apparatus employing such a radiation.

[0027] The pattern of features produced by means of the present method may also be used outside the field of lithography and for radiation other than EUV radiation. For such applications of the pattern of features, the method may be characterized by the additional step of removing the illuminated portions of the resist layer after finishing the electroplating process.

[0028] The features of the structure thus obtained consist of fully transparent openings in the electroplated, non-transparent, metal layer.

[0029] The invention also relates to a pattern of features manufactured by means of the method as described above. This pattern is characterized in that the features have a submicron width and are arranged at mutual distances which are substantially larger than the feature widths.

[0030] The pattern of features may be implemented in several applications. In a first application the pattern of features forms a mask pattern of a lithographic mask, wherein the pattern of features constitute mask features which are transparent to lithographic projection radiation, and the pattern areas between the features constitute mask areas which are nontransparent to lithographic projection radiation.

[0031] This kind of mask pattern is especially suitable for an EUV mask, but may also be used in a mask for a lithographic projection apparatus which employs a different, short wavelength, radiation.

[0032] In a second application, the pattern of features forms a grating structure, wherein the pattern of features constitute transparent grating strips and the pattern areas between the features constitute non-transparent intermediate strips.

[0033] This kind of grating structure is especially suitable for use in an EUV mask, or different wavelength, lithographic projection apparatus, for example as an alignment mark or in an image sensor for such an apparatus. The grating structure may also be used outside the field of lithography; in general, in all applications wherein gratings with small grating strips are required.

[0034] In a third application, a feature in the form of a slit in a magnetizable layer forms a magnetic gap in a thin-film magnetic recording head.

[0035] These and other aspects of the invention are apparent from and will be elucidated by way of non-limitative example, with reference to the embodiments described hereinafter.

[0036] In the drawings:

[0037] **FIG. 1** schematically shows an embodiment of a lithographic projection apparatus, which comprises elements wherein the invention may be implemented;

[0038] **FIG. 2** shows a part of an embodiment of an EUV image sensor;

[0039] **FIGS. 3***a*-**3***d* show the successive steps of the method;

[0040] **FIGS. 4 and 5** show SEM photographs of a 160 nm wide ridge produced by the method using different electron beam doses;

[0041] **FIG. 6** shows a SEM photograph of a 40 nm wide ridge produced by the method;

[0042] **FIG. 7** shows a pattern of ridges comprising a HSQ/novolak double resist layer;

[0043] **FIG. 8** shows a known thin-film magnetic head, and

[0044] **FIG. 9** shows such a head produced by the method of the invention.

[0045] The main modules of the lithographic projection apparatus schematically depicted in **FIG. 1** are:

[0046] an illumination system LA/ IL for supplying a projection beam PB of EUV radiation;

[0047] a mask table MT comprising, as is known in the art, a mask holder (not shown) for holding a mask MA;

[0048] a substrate table WT comprising, as is known in the art, a substrate holder (not shown) for holding a substrate W, e.g. a resist coated silicon wafer, and

[0049] a projection system PL for imaging an illuminated portion of the mask MA on a target portion, i.e. an IC area, or die, C

[0050] The projection system in an EUV projection apparatus is a system of reflective elements.

[0051] The apparatus is also provided with a number of measuring systems, one of which is an alignment measuring device for determining mutual alignment, in an XY-plane of the mask MA and the substrate W. Another measuring system is an interferometer system IFw for measuring the X and Y-position and orientation of the substrate holder, and thus of the substrate. Still another measuring system is a focus-error detection system for determining a deviation between the focus, or image, field of the projection system PL and the surface of the resist layer on the substrate W. These measuring systems form part of servosystems, which comprise electronic signal processing and control circuits, by means of which the position and orientation of the substrate and the focus can be corrected with reference to the signals supplied by the measuring systems. In **FIG. 1**, PW represents the actuator, or positioning, means for the substrate table WT.

[0052] The mask MA for use with the lithographic projection apparatus shown in **FIG. 1** is a reflective mask. The apparatus may be a stepping apparatus or a step-and-scanning apparatus, which are both known in the art. In addition to a substrate a step-and-scanning apparatus comprises, positioning means PW and a substrate interferometer system IFw, also a mask positioning means PM and a mask interferometer system IFm.

[0053] The exposure, or projection, beam PB supplied by the illumination system LA/IL is a beam of EUV radiation with a wavelength, for example, of the order of 13 nm. With such a beam, very small device, or IC, features, of the order of 100 nm or smaller can be imaged in the resist layer. The illumination system supplying such a beam may comprise a plasma source LA, which may be a discharge plasma source or a laser-produced plasma source, which are both known in the art.

[0054] The illumination system comprises various optical components to capture and guide source radiation and to shape this radiation to a suitable projection beam PB, which illuminates the mask pattern. The beam PB reflected by the mask passes through the projection system PL, which focuses this beam in the resist layer on top of the substrate to form an image of the mask pattern at the position of a selected target, or IC area of the substrate.

[0055] As shown in the left section of **FIG. 1**, the mask MA comprises, for example two, mask alignment marks **M1**, **M2** outside the area of the mask pattern C. Preferably, these alignment marks are constituted by diffraction gratings. These marks are preferably twodimensional, i.e. they include grating strips extending in the X and Y-direction in **FIG. 1**. Substrate W comprises at least two wafer alignment marks, two of which, **P1** and **P2** are shown in the right-hand section of **FIG. 1** The marks **PI** and **P2** are positioned outside the area of the substrate where images of the mask pattern have to be formed. The mask and substrate alignment marks are used to detect the degree of alignment of the substrate and the mask during an alignment step, which precedes the step of exposure of the substrate with the mask pattern. This detection can be performed by imaging, by means of a dedicated alignment beam, a mask alignment mark and a substrate wafer alignment mark onto each other, or by imaging a mask alignment mark and a substrate alignment mark onto a reference mark. The grating alignment marks for use in an EUV projection apparatus should have grating strips with a very small width. Such fine mask alignment marks are difficult to produce with conventional techniques.

[0056] For monitoring the imaging performance of the projection apparatus and for calibrating its measuring systems, the apparatus comprises an image sensor, schematically represented by component IS in **FIG. 1**. This image sensor may be integrated in the substrate table WT. An early embodiment of an image sensor is described in U.S. Pat. No. 4,540,277. This image sensor, which is used for determining magnification of the projection system and/or for calibration of the alignment system, comprises a glass plate coated with a chromium layer. In this layer, light-transmitting zones having a width of 1.5 μm are etched, which zones correspond to apertures in the mask. The mask is projected on the chromium layer and the mutual alignment of the apertures and the corresponding openings are determined by measuring the amount of light passing through the openings by means of photodiodes arranged behind the openings.

[0057] As EUV radiation is absorbed by glass, such an image sensor cannot be used in an EUV lithographic apparatus. For such an apparatus, the light-transmitting zones of the image sensor should be openings to its radiation-sensitive elements. Moreover, these openings should be much smaller than the light-transmitting zones in the image sensor of U.S. Pat. No. 4,540,277. The structure of openings for an EUV image sensor is typically a grating structure with grating slits.

[0058] **FIG. 2** shows a cross-section of a small part (only two grating periods PE are shown) of an embodiment of such a grating pattern. The grating slits SL have a right-angled cross-section. The slits have a width WI of 50-150 nm and a depth d of 50-100 nm. The grating period, or pitch, PE is of the order of 2000 nm. These grooves are processed in a metal layer (ML), for example nickel (Ni) or silver (Ag). The slit layer may be deposited on an opto-electronic device OED, which comprises an EUV radiation-sensitive detector DE, which converts the incident radiation into an electric signal. The grating may be a onedimensional or a two-dimensional grating, i.e. the grating slits extend in one direction or in two, for example mutually perpendicular, directions. These kinds of grating are used to measure in one direction or in two directions, respectively. The electronic circuitry for processing the detector signals may be integrated in the opto-electronic device OED. Between the grating and the OED, a radiation-converting layer CL may be interposed, which converts the EUV radiation into a radiation for which the detector, for example a photodiode, shows a better sensitivity.

[0059] According to the invention, a grating pattern like that shown in Fig.**2** and having the required quality can be obtained in a relatively simple manner by performing the processing steps illustrated in **FIGS. 3***a*-**3***d*. As shown in **Fig.3***a*, a substrate **10**, for example a silicon substrate, or an OED (not shown) is coated with a layer **14** of a conductive material, preferably molybdenum. This layer is deposited by means of a sputter process. The layer **14** is covered with a layer **16** of hydrogen silsesquioxane, which is a negative tone resist sensitive to electron beam (E-beam) radiation, for charged-particles radiation in general and also for electromagnetic radiation with a wavelength smaller than 1576 nm. When necessary, the resist may be submitted to a soft bake, for example heated to 120-150° for 2 minutes, which does not change the essential characteristics of the resist. Next, as is shown in **FIG. 3***b* by the arrows EB, the resist layer **16** is illuminated by an electron beam at those positions where transparent strips are to be formed. A "writing " E-beam performs this illumination, i.e. the E-beam is positioned at a point where a grating strip has to start or to end and is scanned over a length corresponding to the length of the strip to be formed. Instead of an E-beam writing apparatus, an E-beam projection apparatus can be used. Then the resist layer is illuminated by a broad beam via a mask which contains a mask pattern corresponding to the pattern of features to be formed. The electrons entering the HSQ layer cause a cross-linking of the HSQ material. As a subsequent step, the HSQ resist layer is developed and nonilluminated resist is removed. The illuminated HSQ material, at the positions of the strips, remains and this material forms a pattern of ridges **18** as shown in **FIG. 3***c*. Then a nontransparent layer **20** of plating material such as metal is deposited by means of electroplating between these ridges and outside the area of the ridges, as shown in **FIG. 3***d*. An advantage of the method is that no plating material is deposited on top of the ridges.

[0060] The layer **20** may be a silver or nickel layer. If the pattern of features is for use in an EUV apparatus, this layer preferably comprises the alloy $Ni_{0.78}Fe_{0.22}$, known as Permalloy. The attenuation length of this material for EUV radiation is 15 nm, which means that after this beam has passed a 15 nm thick permalloy layer, its intensity is reduced to 1/e (or 37%) of the original intensity. For example, 100 nm thick molybdenum transmits 0,8% of EUV radiation incident on it, so that such a layer is a non-transparent layer for EUV radiation. The cross-linked HSQ material of the ridges **18**, which behaves like SiO_2, has an attenuation length of 98 nm and molybdenum has an attenuation length of 162, nm so that these materials are to a high degree transparent to EUV radiation, provided that their thickness is not too large.

[0061] The pattern of ridges **18** obtained by the method of the invention illustrated in **FIGS. 3***a*-**3***d* thus forms a pattern of transparent slits in a non-transparent surface area. The advantage of this method is that the ridges **18** and the molybdenum layer **14** do not need to be removed to obtain a grating pattern which shows sufficient contrast, i.e. a pattern having strips the transparency of which differs sufficiently from that of their environment for EUV radiation.

[0062] Such a grating pattern may be deposited on a detector or an opto-electronic device to obtain an EUV image sensor. If the sensitive layer of the detector is buried under an additional layer, such layers should be removed beforehand so that the detector is freed. For this application and for a grating structure in general, the structure of ridges is periodic, which means that the distance between all ridges is the same. The width WI of the ridges, and thus of the grating slits, is determined by the width of the electron beam EB and the dose of the beam, which is expressed in $\mu C/cm^2$ wherein C stands for the unity of charge: Coulomb. For patterns other than a grating pattern, for example a mask pattern, the dose and width of the electron beam can be varied to obtain a pattern having slits of different width, as is shown in **FIGS. 3***c* and **3***d* by the ridges **18***a*, **18***b* and **18***c*.

[0063] The method may also be performed with a resist material, an electroplating base material and a plating material, which are different from the materials mentioned above. The choice of the materials is determined by the envisaged application of the pattern of features and in particular by the wavelength of the radiation used in such an application. The plating material should be non-transparent to the radiation and both the resist material and the electroplating base material should be transparent in case the resist ridges remain present in the end product.

[0064] Instead of a one-dimensional pattern, a two-dimensional pattern can also be produced. In the latter case, the electron beam has to scan the HSQ layer in two, for example perpendicular, directions at those positions of the HSQ layer where transparent areas are to be formed.

[0065] **FIG. 4** shows the principle of the electroplating process. The substrate with the layer **14** and the pattern of ridges **18** is brought into a holder **30** filled with an electrolyte **32**, which comprises the metal that is to be deposited on the plating base layer **14** and between the ridges. The layer **14** is electrically connected, for example by means of copper terminal block or clip **34**, to the first pole of a current source **36**. The holder comprises an electrode **38**, which is connected to the second pole of the current source. When the source is switched on, electrons are injected in the base layer **14** so that this layer becomes negatively electrically charged. This layer begins to attract the metal ions from the electrolyte **32**. At the surface of layer **14**, the ions are de-charged and the neutral metal atoms precipitate on the surface to form a metal layer **20** on the surface of the layer **14**.

[**0066**] In order to obtain a stable metal layer of constant thickness, it is necessary that the electrical resistance of the plating base layer is smaller than that of material to be deposited. If this is not the case, the metal ions will be first deposited on the clip **34** and then on the already formed portion of metal layer, instead of on the entire surface of the base layer **14**. An unstable metal layer of varying thickness will then be formed. In general, materials having a low electrical resistance, i.e. a high conductivity such as silver (Ag), aluminum (Al), gold (Au) and copper (Cu) are suitable materials for the plating base layer **14**. These materials allow plating of a large number of metals having a lower conductivity. If a pattern of slits or openings, which are transparent to EUV radiation is to be produced, a layer of molybdenum should be used as a plating base layer As this material has a relatively high resistance of 5.20 $\mu\Omega$.cm, the choice of materials which can be plated is limited. However, an alloy of nickel (Ni) having a higher resistance of 6.84 $\mu\Omega$.cm, such as $Ni_{0.78}Fe_{0.22}$ (permalloy) is a very suitable material for this purpose.

[**0067**] To prevent metal from being deposited on the lower surface of the substrate, this surface could be coated with an isolating layer. For the same purpose, an isolating layer **12**, shown in the **FIG. 3**, is preferably applied to the upper surface of the substrate. The layer **12** may be a silicon dioxide (SiO_2) layer. When the pattern on structure forms part of an EUV image sensor, the isolating layer is preferably a silicon nitride (Si_3N_4) layer. With such a layer, a good adhesion of the plating base layer can be obtained and oxidation can be prevented. The Si_3N_4 layer may form the top layer of the detector of the EUV image sensor.

[**0068**] In an embodiment of the method, a molybdenum layer with a thickness of 50 nm is used as a plating base layer and the deposited $Ni_{0.78}Fe_{0.22}$ layer **20** has a thickness of 100 nm. Ridges having a width in the 100 nm range and in the sub-100 nm range down to 50 nm or even less have been produced. The height of the produced ridges may vary in a range of several tens to several hundreds of nm.

[**0069**] By way of example, **FIG. 5*a*** shows a SEM (scanning electron microscope) photograph of a central portion of an HSQ ridge protruding from a $Ni_{0.78}Fe_{0.22}$ layer produced with an electron beam dose of 700 μC/cm^2. **FIG. 5*b*** shows the central portion of such a ridge produced with a dose of 500 μC/cm^2. The design width of the ridge is 160 nm and the measured width is about 160 nm. These Figures demonstrate the influence of the electron beam dose on the width of the produced ridge. **FIG. 6** shows a SEM photograph, in perspective view, of two HSQ ridges protruding from a $Ni_{0.78}Fe_{0.22}$ layer produced with an electron beam dose of 1500 μC/cm^2. The design width of the ridges is 40 nm and the measured width is 50 mn.

[**0070**] The height of the HSQ ridges that can be produced is limited by the electron forward scattering in HSQ, thus by the penetration depth of electrons in this material. If ridges with a height of more than 100 nm are required, a double layer resist comprising a negative tone resist HSQ upper coat and a hard-baked novolak resist as a lower coat can be used as resist layer, instead of a single HSQ resist layer **16**. FIG .7 shows a small part of an embodiment of a pattern of ridges obtained by using such a double layer. These ridges **18** are composed of a part **18*a*** of novolak and a top part **18*b*** of cross-linked HSQ. The thickness of the top part may be of the order of 100 nm and that of the lower part from 100 nm up to, for example, 600 nm. For details about the HSQ/novolak double layer and its use in E-beam lithography, reference is made to the above-mentioned paper: "Hydrogen silses quioxane/novolak bilayer resist for high aspect ratio nanoscale e-beam lithography". The thickness of the ridges is determined by the required contrast in the pattern of features, e.g. the grating, to be produced.

[**0071**] The method may also be used to produce a fine grating pattern wherein the width of the transparent slits is of the order of the width of the non-transparent areas between these slits. For example, such a grating may have a duty cycle of 0.5, which means that the width of the transparent slits is equal to that of the non-transparent slits. Such a grating may be an optical grating, i.e. a grating for visible and ultraviolet light. To obtain such a grating, the ridges of HSQ of **FIG. 3*d*** are removed so that only the metal layer **20** provided with slits remains. For a transmission layer, the substrate onto which the grating is formed should be transparent. For obtaining a reflective grating, the substrate should be reflective.

[**0072**] An optical grating produced by the method of the invention may be used in any optical apparatus where such a fine grating is needed, for example for diffraction of a radiation beam, for beam splitting, for colour separation of a white beam, etc. Such a grating may also be used as an alignment mark in a lithographic projection apparatus, for example an EUV projection apparatus such as the mask alignment mark **M1** or **M2** in **FIG. 1**. As the transparent slits which can be produced by the present method may be very small, a very accurate alignment of the mask alignment mark, and thus of the mask with respect to a reference mark becomes possible.

[**0073**] The method can also be used to produce a pattern of fine features, other than a grating, for use in an imaging system such as an optical imaging system, an EUV imaging system and even an X-ray imaging system. The pattern is, for example, an array of annular transparent strips, or slits, having a varying width, which strips together form a Fresnel lens.

[**0074**] The method can be further used for the production of lithographic masks, for example, EUV masks. The method can be applied for producing features of the mask pattern itself, for example an IC pattern and/or for producing so-called assisting features, for example scattering bars, which compensate for proximity effects occurring when imaging fine mask patterns. Currently, an electron beam writing apparatus is already used for producing transparent masks for EUV and EUV lithography and reflective masks for EUV lithography. The use of a HSQ resist and electroplating allows production of a pattern of features, which have well-defined perpendicular walls, also in materials hitherto known as transition materials. Such a pattern cannot be obtained with ion etching or lift-off techniques. Because the features are in the form of ridges, they cannot fill with dust. In case the ridges are HSQ ridges, they cannot be ablated by EUV radiation.

[**0075**] In general, the method can be used for accurately producing sub-micron, and especially sub-100 nm wide slits, or transparent strips in a metallic layer. Such a layer can be applied not only in lithographic apparatus or, more generally, in optical apparatus, but also in devices for other arts of techniques. An example of such a device is a thin-film magnetic recording head. **FIG. 9** is a top view of an embodiment of such a magnetic head. For reasons of comparison, a known thin-film magnetic head is shown in **FIG. 8**. The known head comprises a yoke **40** of magnetically permeable, or magnetizable, material, which yoke is provided with a gap **42** filled with a non-magnetizable material **44**. The gap has a length le and a height he. A coil is wrapped around the yoke, of which coil only one winding **46** is shown. The arrow **48** indicates the direction along which the optical head and a track of the magnetic record carrier (not shown) move relative to each other, in order to scan the record carrier. This record carrier is read out by detecting the variations in the magnetization of the head induced by the magnetic domains on the carrier.

[**0076**] In the magnetic head of **FIG. 9**, the gap is replaced by a ridge **52** of resist material such as HSQ, which ridge is embedded in a layer of magnetically permeable material **51**. Arrow **58** indicates the track scanning direction. This head is produced by forming a ridge of resist, preferably HSQ, on an electroplating base layer in the way as described above and by electroplating the surroundings of the ridge, with the exception of **57** which is reserved for the coil windings, with a layer **51** of a magnetizable material. The thickness of this layer may be equal to the ridge, which may be of the order of 5 μm. The ridge may have a width of, for example 100-200 nm.

1. A method of forming a pattern of sub-micron broad features in a metal layer, which method includes the steps of:

forming a resist layer, comprising a negative tone resist material, on a substrate;

illuminating selected portions of the resist layer by a beam, which is able to cure the resist to a cured pattern according to the pattern to be formed, and

removing non-illuminated portions of the resist layer, which method is characterized in that the resist material is an inorganic material and in that the additional steps of:

forming an electroplating base layer on the substrate before applying the resist layer, and

electroplating a layer between the cured portions of the resist layer are carried out.

2. A method as claimed in claim 1, characterized in that siloxane material is used as a resist material.

3. A method as claimed in claim 2, characterized in that hydrogen silsesquioxane (HSQ) is used as a resist material.

4. A method as claimed in claim 1, **2**, or **3**, characterized in that a double layer comprising a hydrogen silsesquioxane top layer and a novolak bottom layer is used as a resist layer.

5. A method as claimed in claim 1, **2**, **3** or **4**, characterized in that a layer of one of the materials: silver, nickel and permalloy is electroplated between the illuminated portions of the resist layer.

6. A method as claimed in claim 1, **2**, **3**, **4** or **5**, characterized in that a layer of one of the materials: silver, gold, copper, aluminum and molybdenum is used as an electroplating base layer.

7. A method as claimed in any one of the preceding claims, characterized by the intermediate step of covering the substrate surface, which is to be provided with the pattern of features, with an insulating layer before the electroplating base layer is applied.

8. A method as claimed in any one of the preceding claims, characterized by the additional step of removing the illuminated portions of the resist layer after finishing the electroplating process.

9. A pattern of features manufactured by means of the method of any one of claims 1 to 8, characterized in that the features have a sub-micron width and are arranged at mutual distances which are substantially larger than the feature widths.

10. A pattern of features manufactured by means of the method of any one of claims 1 to 8, forming a lithographic mask, wherein the pattern features constitute mask features which are transparent to lithographic projection radiation and the pattern areas between the features constitute mask areas which are non-transparent to lithographic projection radiation.

11. A pattern of features manufactured by means of the method of any one of claims 1 to 8, forming a grating structure, wherein the pattern features constitute transparent grating strips and the pattern areas between the features constitute non-transparent intermediate strips.

12. A pattern of features manufactured by means of the method of any one of claims 1 to 8, forming a structure of at least one magnetic gap in a thin-film magnetic recording head.

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