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(54) Title: MIRROR FOR THE EUV WAVELENGTH RANGE, METHOD FOR PRODUCING SUCH A MIRROR, PROJECTION LENS FOR MICROLITHOGRAPHY COMPRISING SUCH A MIRROR, AND PROJECTION EXPOSURE APPARATUS FOR MICROLITHOGRAPHY COMPRISING SUCH A PROJECTION LENS

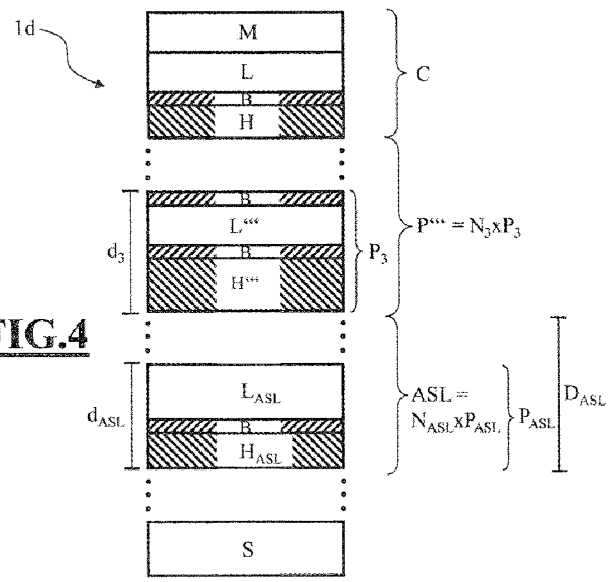

FIG.4

(57) Abstract: The invention relates to a mirror (1a; 1b; 1c; 1d) for the EUV wavelength range having a reflectivity of greater than 40% for at least one angle of incidence of between 0° and 25°, comprising a substrate (S) and a layer arrangement, wherein the layer arrangement comprises at least one layer subsystem (ASL) consisting of a periodic sequence of at least two periods (PASL) of individual layers (LASL, B, HASL) composed of different materials, and wherein the layer subsystem (ASL) has an oxygen doping of between 10 ppb and 0.1 %, in particular between 50 ppb and 50 ppm. Furthermore, the invention relates to a method for coating a mirror (1a; 1b; 1c: 1d) for the EUV wavelength range, wherein an oxygen partial pressure of greater than 10^{-9} mbar, in particular of greater than 10^{-7} mbar, is present during the coating of the layer subsystem (ASL) with oxygen doping. Furthermore, the invention relates to a projection lens for micro lithography comprising such a mirror, and to a projection exposure apparatus comprising such a projection lens.

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Description

Mirror for the EUV wavelength range, method for producing such a mirror, projection lens for microlithography comprising such a mirror, and projection exposure apparatus for microlithography comprising such a projection lens

The invention relates to a mirror for the EUV wavelength range and to a method for producing such a mirror. Furthermore, the invention relates to a projection lens for microlithography comprising such a mirror. Moreover, the invention relates to projection exposure apparatus for microlithography comprising such a projection lens.

Projection exposure apparatuses for microlithography for the EUV wavelength range have to rely on the assumption that the mirrors used for the exposure or imaging of a mask into an image plane have a high reflectivity since, firstly, the product of the reflectivity values of the individual mirrors determines the total transmission of the projection exposure apparatus and since, secondly, the light power of EUV light sources is limited. In this case, the EUV wavelength range is understood to be the wavelength range of light having wavelengths of between 5 nm and 20 nm.

Mirrors for the EUV wavelength range around 13 nm having high reflectivity values are known from DE 101 55 711 A1, for example. The mirrors described therein consist of a layer arrangement which is applied on a substrate and which has a sequence of individual layers, wherein the layer arrangement comprises a plurality of layer subsystems each having a periodic sequence of at least two individual layers of different materials that form a period, wherein the number of periods and the thickness of the periods of the individual subsystems decrease from the substrate toward the surface. Such mirrors have a reflectivity of greater than 30% in the case of an angle of incidence interval of between 0° and 20°.

In this case, the angle of incidence is defined as the angle between the direction of incidence of a light ray and the normal to the surface of the mirror at the point where the light ray impinges on the mirror. In this case, the angle of incidence interval results from the angle interval between the largest and the smallest angle of incidence respectively considered for a mirror.

What is disadvantageous about the abovementioned layers, however, is that their reflectivity in the angle of incidence interval specified is not constant, but rather varies. A variation of the reflectivity of a mirror over the angles of incidence is disadvantageous, however, for the use of such a mirror at locations with high angles of incidence and with high angle of incidence changes in a projection lens for microlithography since such a variation leads for example to an excessively large variation of the pupil apodization of such a projection lens. In this case, the pupil apodization is a measure of the intensity fluctuation over the exit pupil of a projection lens.

Furthermore, what is disadvantageous about the abovementioned layers is that they have a high compressive stress and, on account of this compressive stress, warp the mirror substrate in an impermissible manner, such that the mirror substrate after coating does not follow the desired surface form with a deviation of a maximum of 0.1 nm rms figure.

Therefore, so-called buffer layers or anti-stress layers (ASL) are usually used between substrate and reflective coating, which compensate for the compressive stress of the reflective coating by means of their tensile stress. These layers, particularly in the case of an ASL system composed of molybdenum (Mo) and silicon (Si), are generally very rough since the tensile stresses required necessitate a high Mo proportion and thus thick molybdenum layers within a layer pair of the ASL system. Thick molybdenum layers are increasingly rough on account of the incipient crystal growth of molybdenum.

Rough layers in the HSFR spatial frequency range of a mirror for the EUV wavelength range lead to stray light losses and thus to a loss of total transmission in a projection exposure apparatus, see U. Dinger et al. “Mirror substrates for EUV-lithography: progress in metrology and optical fabrication technology” in Proc. SPIE vol. 4146, 2000, in particular for the definition of the surface roughness in the HSFR range with spatial wavelengths of the roughness of 10 nm to 1 μm and in the MSFR range with spatial wavelengths of the roughness of 1 μm to 1 mm.

Furthermore, what is disadvantageous about an ASL system having a high Mo proportion is that it has a large total thickness of the ASL system of far more than 200 nm, see US 7 203 275 B2. The larger the total thickness of a layer system, the greater the deviation of the layer system from the desired lateral course of the layer system along the surface of the mirror. However, the exact adaptation of the course along the mirror by means of a thickness factor is important for providing a mirror for high angles of incidence and high angle of incidence changes, as will be explained in greater detail in the introductory part below and in the discussion of figures 9 to 16.

Therefore, it is an object of the invention to provide a mirror for the EUV wavelength range which makes possible both a small surface deformation and accurate compliance with the thickness factor along the mirror surface.

This object is achieved according to the invention by means of a mirror for the EUV wavelength range having a reflectivity of greater than 40% for at least one angle of incidence of between 0° and 25°, comprising a substrate and a layer arrangement, wherein the layer arrangement comprises at least one layer subsystem consisting of a periodic sequence of at least two periods of individual layers composed of different materials, and wherein the layer subsystem has an oxygen doping of between 10 ppb and 0.1%, in particular between 50 ppb and 50 ppm.

The inventors have recognized that the tensile stress of a layer subsystem for stress compensation (ASL system) known per se can be increased by adding oxygen during the coating of the layer subsystem. On account of the oxygen doping achieved here of between 10 ppb and 0.1%, in particular between 50 ppb and 50 ppm, the tensile stress present in such a layer subsystem can be virtually doubled. This makes it possible to reduce the total thickness of the known layer subsystems that is necessary for stress compensation. Alternatively or additionally, it is possible to limit the necessary number of periods of the layer subsystem. Consequently, it is possible to provide a mirror according to the invention which, firstly, on account of the stress compensation, has no surface form deviation and, secondly, on account of the limited total thickness of the layer subsystem with oxygen doping, can be controlled more easily with regard to the lateral course of the thickness factor. Furthermore, the reduction of the total thickness leads to a reduction of the costs and the production time, and also to an increase in the process stability during the production of such mirrors.

In one embodiment, the layer arrangement comprises at least one additional layer subsystem which consists of a periodic sequence of at least two periods of individual layers, wherein the periods comprise two individual layers composed of different materials for a high refractive index layer and a low refractive index layer. This at least one additional layer subsystem ensures the high reflectivity of the mirror for the EUV wavelength range.

In this case, the layer subsystems of the layer arrangement of the mirror according to the invention succeed one another directly and are not separated by a further layer system. Furthermore, in the context of the present invention, a layer subsystem is distinguished from an adjacent layer subsystem, even given otherwise identical division of the periods between high and low refractive index layers, if a deviation by more than 0.1 nm is present as deviation in the thickness of the periods of the adjacent layer subsystems since, starting from a difference of 0.1 nm, it is possible to assume a different optical effect of the layer subsystems with otherwise identical division of the periods between high and low refractive index layers.

The terms high refractive index and low refractive index are in this case, in the EUV wavelength range, relative terms with regard to the respective partner layer in a period of a layer subsystem. In the EUV wavelength range, layer subsystems generally function only if a layer that acts with optically high refractive index is combined with an optically lower refractive index layer relative thereto as main constituent of a period of the layer subsystem.

In another embodiment, the layer subsystem having oxygen doping has a total thickness of less than 200 nm. This fosters compliance with the thickness factor along the mirror surface.

In a further embodiment, the layer subsystem having oxygen doping has a stress which, depending on the molybdenum proportion, lies above a linear stress characteristic curve resulting from the corner point of -300 MPa given a molybdenum proportion of 0.3 and a gradient of 80 MPa per increase of 0.1 in the molybdenum proportion. Such layer subsystems having oxygen doping have more tensile stress than comparable layer subsystems without such a doping and are therefore better suited to the stress compensation of other layer subsystems. In the context of this application, the stress of a layer subsystem is always understood as a normalized stress that is normalized to 1 nm period thickness of the associated period.

In one embodiment, the total layer stress of the layer arrangement is less than 100 MPa, in particular less than 50 MPa, particularly preferably less than 20 MPa. Such a total layer stress makes it possible for the surface form of the mirror after coating has taken place to deviate from the surface form of the substrate prior to coating by less than 0.1 nm rms figure.

In another embodiment, the tensile stress of the further layer subsystem having oxygen doping is more than +240 MPa, in particular more than +400 MPa, particularly preferably more than +600 MPa. Such a high tensile stress is expedient if compensating for the compressive stress of so-called narrowband coatings is involved. These are coatings which have high reflectivity values for the EUV wavelength range for angles of incidence of between 0° and approximately 10° and which are generally constructed from so-called "monostacks", i.e. a single layer subsystem for ensuring the high reflectivity. Said monostacks generally consist of many periods of layers having a molybdenum proportion of less than 0.4 and therefore have high compressive stresses.

In a further embodiment, the number of periods of the layer subsystem having oxygen doping is 50 or less. As a result, it is additionally possible to increase the process stability during the coating of mirrors for the EUV wavelength range by means of a reduced number of layers.

In one embodiment, layer subsystem having oxygen doping has a thickness of the periods of 5 nm or less, in particular of 3.5 nm or less. Such thin periods, even in the case of a high proportion of molybdenum, lead to thin molybdenum layers and therefore prevent the crystal growth in this layers. This makes it possible to produce layer subsystems having oxygen doping which have a low surface roughness and thus avoid stray light losses.

In another embodiment, the individual layers of the layer subsystem having oxygen doping consist of materials which are selected or made up as a compound from the group of materials: molybdenum, silicon, B_4C, C, Si nitride, Si carbide, Si boride, Mo nitride, Mo carbide, Mo boride, Ru nitride, Ru carbide and Ru boride. The stress of such layer subsystems can be set in a targeted manner by means of a deliberate selection of the stated materials for the layers of the periods of the layer subsystem having oxygen doping.

In a further embodiment, the reflectivity of a mirror according to the invention given normal incidence is more than 60% and the number of periods of the layer subsystem having oxygen doping is more than 20, in particular more than 25. In the case of a mirror for perpendicular light incidence, i.e. an angle of incidence of 0°, that is expedient for the tensile stresses which are necessary for the stress compensation of the high compressive forces of such mirrors, generally embodied as a monostack, to be distributed among many periods of the layer subsystem having oxygen doping, since otherwise very thick molybdenum layers are required, which lead to stray light losses on account of increased surface roughness.

In one embodiment, the average reflectivity given an angle of incidence interval of 4.8° or greater and given a maximum angle of incidence of 27.2° is more than 39.2%, wherein the number of periods of the further layer subsystem having oxygen doping is more than 15, in particular more than 20. Since broadband coatings, which are coatings having a reflectivity that is as uniform as possible over a relatively large angle of incidence interval even for high angles of incidence, generally warp a mirror to a lesser extent than narrowband coatings, it is expedient to limit the number of periods of the layer subsystem having oxygen doping in the case of these coatings. As a result, it is possible to further increase the process stability for the coating of such broadband mirrors.

In another embodiment of a mirror according to the invention, the two individual layers of the at least one additional layer subsystem that form a period consist either of the materials molybdenum (Mo) and silicon (Si) or of the materials ruthenium (Ru) and silicon (Si). It is thereby possible to achieve particularly high reflectivity values and at the same time to realize production engineering advantages since only two different materials are used for producing the layer subsystems of the layer arrangement of the mirror.

In this case, in a further embodiment, said individual layers are separated by at least one barrier layer, wherein the barrier layer consists of a material which is selected or made up as a compound from the group of materials: B_4C, C, Si nitride, Si carbide, Si boride, Mo nitride, Mo carbide, Mo boride, Ru nitride, Ru carbide and Ru boride. Such a barrier layer suppresses the interdiffusion between the two individual layers of a period, thereby increasing the optical contrast in the transition of the two individual layers. With the use of the materials molybdenum and silicon for the two individual layers of a period, one barrier layer above the Si layer, as viewed from the substrate, suffices in order to provide for a sufficient contrast. The second barrier layer above the Mo layer can be dispensed with in this case. In this respect, at least one barrier layer for separating the two individual layers of a period should be provided, wherein the at least one barrier layer may perfectly well be constructed from various ones of the above-indicated materials or the compounds thereof and may in this case also exhibit a layered construction of different materials or compounds.

Barrier layers which comprise the material B_4C and have a thickness of between 0.35 nm and 0.8 nm, preferably between 0.4 nm and 0.6 nm, lead in practice to high reflectivity values of the layer arrangement. Particularly in the case of layer subsystems composed of ruthenium and silicon, barrier layers composed of B_4C exhibit a maximum of reflectivity in the case of values of between 0.4 nm and 0.6 nm for the thickness of the barrier layer.

In a further embodiment, a mirror according to the invention comprises a covering layer system comprising at least one layer composed of a chemically inert material, which terminates the layer arrangement of the mirror toward the vacuum. The mirror is thereby protected against ambient influences.

In one embodiment, the layer subsystem having oxygen doping is arranged between the substrate and the at least one additional layer subsystem. By means of a corresponding design of the at least one layer subsystem, it is thereby possible to ensure that the layer subsystem having oxygen doping contributes only to the stress compensation and not to the reflectivity of the mirror.

In another embodiment, the surface roughness of the layer terminating the layer arrangement is less than 0.2 nm rms HSFR, in particular less than 0.1 nm rms HSFR. It is thereby possible to avoid stray light losses.

In a further embodiment, a mirror for the EUV wavelength range comprises a substrate and a layer arrangement, wherein the layer arrangement comprises a plurality of layer subsystems. In this case, in order to achieve a high and uniform reflectivity across a large angle of incidence interval, the number of periods for the layer subsystem that is most distant from the substrate must be greater than that for the layer subsystem that is second most distant from the substrate. Furthermore, in order to achieve a high and uniform reflectivity across a large angle of incidence interval, as an alternative or in addition to the measure mentioned above, the first high refractive index layer of the layer subsystem that is most distant from the substrate should directly succeed the last high refractive index layer of the layer subsystem that is second most distant from the substrate.

In one embodiment, the layer subsystems are in this case all constructed from the same materials for the high and low refractive index layers since this simplifies the production of mirrors.

A mirror for the EUV wavelength range in which the number of periods of the layer subsystem that is most distant from the substrate corresponds to a value of between 9 and 16, and a mirror for the EUV wavelength range in which the number of periods of the layer subsystem that is second most distant from the substrate corresponds to a value of between 2 and 12, leads to a limitation of the layers required in total for the mirror and thus to a reduction of the complexity and the risk during the production of the mirror.

In a further embodiment, the layer arrangement of a mirror according to the invention comprises at least three layer subsystems, wherein the number of periods of the layer subsystem that is situated closest to the substrate is greater than for the layer subsystem that is most distant from the substrate and/or is greater than for the layer subsystem that is second most distant from the substrate.

It is possible to achieve particularly high reflectivity values for a layer arrangement in the case of a small number of layer subsystems if the period for the layer subsystem that is most distant from the substrate has a thickness of the high refractive index layer which amounts to more than 120% of the thickness, in particular more than double the thickness, of the high refractive index layer of the period for the layer subsystem that is second most distant from the substrate.

It is likewise possible to achieve particularly high reflectivity values for a layer arrangement in the case of a small number of layer subsystems in a further embodiment if the period for the layer subsystem that is most distant from the substrate has a thickness of the low refractive index layer which is less than 80%, in particular less than two thirds of the thickness of the low refractive index layer of the period for the layer subsystem that is second most distant from the substrate.

In a further embodiment, a mirror for the EUV wavelength range has, for the layer subsystem that is second most distant from the substrate, a thickness of the low refractive index layer of the period which is greater than 4 nm, in particular greater than 5 nm. As a result of this it is possible that the layer design can be adapted not only with regard to the reflectivity per se, but also with regard to the reflectivity of s-polarized light with respect to the reflectivity of p-polarized light over the angle of incidence interval striven for. Primarily for layer arrangements which consist of only two layer subsystems, the possibility is thus afforded of performing a polarization adaptation despite limited degrees of freedom as a result of the limited number of layer subsystems.

In another embodiment, a mirror for the EUV wavelength range has a thickness of the periods for the layer subsystem that is most distant from the substrate of between 7.2 nm and 7.7 nm. It is thereby possible to realize particularly high uniform reflectivity values for large angle of incidence intervals.

In another embodiment, the mirror according to the invention has a thickness factor of the layer arrangement along the mirror surface having values of between 0.9 and 1.05, in particular having values of between 0.933 and 1.018. It is thereby possible for different locations of the mirror surface to be adapted in a more targeted fashion to different angles of incidence that occur there.

In this case, the thickness factor is the factor with which all the thicknesses of the layers of a given layer design, in multiplied fashion, are realized at a location on the substrate. A thickness factor of 1 thus corresponds to the nominal layer design.

The thickness factor as a further degree of freedom makes it possible for different locations of the mirror to be adapted in a more targeted fashion to different angle of incidence intervals that occur there, without the layer design of the mirror per se having to be changed, with the result that the mirror ultimately yields, for higher angle of incidence intervals across different locations on the mirror, higher reflectivity values than are permitted by the associated layer design per se given a fixed thickness factor of 1. By adapting the thickness factor, it is thus also possible, over and above ensuring high angles of incidence, to achieve a further reduction of the variation of the reflectivity of the mirror according to the invention over the angles of incidence.

In a further embodiment, the thickness factor of the layer arrangement at locations of the mirror surface correlates with the maximum angle of incidence that occurs there, since, for a higher maximum angle of incidence, a higher thickness factor is useful for the adaptation.

Furthermore, the object of the present invention is achieved by means of a method for coating a mirror according to the invention for the EUV wavelength range, wherein an oxygen partial pressure of greater than 1E-9 mbar, in particular of greater than 1E-7 mbar, is present for coating the layer subsystem with oxygen doping.
The tensile stress of the layer subsystem is increased by such an addition of oxygen, as has been recognized by the inventors.

In one embodiment, the coating of the further layer subsystem with oxygen doping is performed by magnetron sputtering at a working gas pressure of at least 1E-4 mbar. On account of the high repetition accuracy of this process at higher rates compared with other methods such as e.g. ion beam sputtering or pulsed laser deposition, magnetron sputtering is suitable in particular for the industrial production of EUV layers.

Furthermore, the object of the invention is achieved by means of a projection lens comprising at least one mirror according to the invention.

Moreover, the object of the invention is achieved by means of a projection exposure apparatus according to the invention for microlithography comprising such a projection lens.

Further features and advantages of the invention will become apparent from the following description of exemplary embodiments of the invention with reference to the figures, which show details essential to the invention, and from the claims. The individual features can be realized in each case individually by themselves or as a plurality in any desired combination in a variant of the invention.

Exemplary embodiments of the invention are explained in greater detail below with reference to the figures, in which:

figure 1 shows a schematic illustration of a first mirror according to the invention;

figure 2 shows a schematic illustration of a second mirror according to the invention;

figure 3 shows a schematic illustration of a third mirror according to the invention;

figure 4 shows a schematic illustration of a mirror according to the invention with an explicit schematic illustration of a further layer subsystem (ASL) having oxygen doping;

figure 5 shows a schematic illustration of a projection lens according to the invention for a projection exposure apparatus for microlithography;

figure 6 shows a schematic illustration of the image field of the projection lens;

figure 7 shows an exemplary illustration of the maximum angles of incidence and the interval lengths of the angle of incidence intervals against the distance of the locations of a mirror according to the invention with respect to the optical axis within a projection lens;

figure 8 shows a schematic illustration of the optically used region on the substrate of a mirror according to the invention;

figure 9 shows a schematic illustration of some reflectivity values against the angles of incidence of the first mirror according to the invention from figure 1;

figure 10 shows a schematic illustration of further reflectivity values against the angles of incidence of the first mirror according to the invention from figure 1;

figure 11 shows a schematic illustration of some reflectivity values against the angles of incidence of the second mirror according to the invention from figure 2;

figure 12 shows a schematic illustration of further reflectivity values against the angles of incidence of the second mirror according to the invention from figure 2;

figure 13 shows a schematic illustration of some reflectivity values against the angles of incidence of the third mirror according to the invention from figure 3;

figure 14 shows a schematic illustration of further reflectivity values against the angles of incidence of the third mirror according to the invention from figure 3;

figure 15 shows a schematic illustration of some reflectivity values against the angles of incidence of a fourth mirror according to the invention; and

figure 16 shows a schematic illustration of further reflectivity values against the angles of incidence of the fourth mirror according to the invention.

A respective mirror 1a, 1b, 1c and 1d according to the invention is described below with reference to figures 1, 2, 3 and 4, the corresponding features of the mirrors having the same reference signs in the figures. Furthermore, the corresponding features or properties of these mirrors according to the invention are explained in summary for figures 1 to 4 below following the description concerning figure 4.

Figure 1 shows a schematic illustration of a mirror 1a according to the invention for the EUV wavelength range comprising a substrate S and a layer arrangement. In this case, the layer arrangement comprises a plurality of layer subsystems P', P'' and P''' each consisting of a periodic sequence of at least two periods P_1, P_2 and P_3 of individual layers, wherein the periods P_1, P_2 and P_3 comprise two individual layers composed of different materials for a high refractive index layer H', H'' and H''' and a low refractive index layer L', L'' and L''' and have within each layer subsystem P', P'' and P''' a constant thickness d_1, d_2 and d_3 that deviates from a thickness of the periods of an adjacent layer subsystem. In this case, the layer subsystem P''' that is most distant from the substrate has a number N_3 of periods P_3 that is greater than the number N_2 of periods P_2 for the layer subsystem P'' that is second most distant from the substrate. In addition, the layer subsystem P'' that is second most distant from the substrate has a sequence of the periods P_2 such that the first high refractive index layer H''' of the layer subsystem P''' that is most distant from the substrate directly succeeds the last high refractive index layer H'' of the layer subsystem P'' that is second most distant from the substrate.

Consequently, in figure 1, the order of the high H'' and low refractive index L'' layers within the periods P_2 in the layer subsystem P'' that is second most distant from the substrate is reversed relative to the order of the high H', H''' and low refractive index L', L'' layers within the other periods P_1, P_3 of the other layer subsystems P', P''', such that the first low refractive index layer L'' of the layer subsystem P'' that is second most distant from the substrate also optically actively succeeds the last low refractive index layer L' of the layer subsystem P' that is situated closest to the substrate. Therefore, the layer subsystem P'' that is second most distant from the substrate in figure 1 also differs in the order of the layers from all the other layer subsystems in figures 2 to 4 that are described below.

Figure 2 shows a schematic illustration of a mirror 1b according to the invention for the EUV wavelength range comprising a substrate S and a layer arrangement. In this case, the layer arrangement comprises a plurality of layer subsystems P', P'' and P''' each consisting of a periodic sequence of at least two periods P_1, P_2 and P_3 of individual layers, wherein the periods P_1, P_2 and P_3 comprise two individual layers composed of different materials for a high refractive index layer H', H'' and H''' and a low refractive index layer L', L'' and L''' and have within each layer subsystem P', P'' and P''' a constant thickness d_1, d_2 and d_3 that deviates from a thickness of the periods of an adjacent layer subsystem. In this case, the layer subsystem P''' that is most distant from the substrate has a number N_3 of periods P_3 that is greater than the number N_2 of periods P_2 for the layer subsystem P'' that is second most distant from the substrate. In this case, unlike in the case of the exemplary embodiment concerning figure 1, the layer subsystem P'' that is second most distant from the substrate has a sequence of the periods P_2 which corresponds to the sequence of the periods P_1 and P_3 of the other layer subsystems P' and P''', such that the first high refractive index layer H''' of the layer subsystem P''' that is most distant from the substrate optically actively succeeds the last low refractive index layer L'' of the layer subsystem P'' that is second most distant from the substrate.

Figure 3 shows a schematic illustration of a further mirror 1c according to the invention for the EUV wavelength range comprising a substrate S and a layer arrangement. In this case, the layer arrangement comprises a plurality of layer subsystems P'' and P''' each consisting of a periodic sequence of at least two periods P_2 and P_3 of individual layers, wherein the periods P_2 and P_3 comprise two individual layers composed of different materials for a high refractive index layer H'' and H''' and a low refractive index layer L'' and L''' and have within each layer subsystem P'' and P''' a constant thickness d_2 and d_3 that deviates from a thickness of the periods of an adjacent layer subsystem. In this case, in a fourth exemplary embodiment in accordance with the description concerning figures 15 and 16, the layer subsystem P''' that is most distant from the substrate has a number N_3 of periods P_3 that is greater than the number N_2 of periods P_2 for the layer subsystem P'' that is second most distant from the substrate. This fourth exemplary embodiment also comprises, as a variant with respect to the illustration of the mirror 1c in figure 3 corresponding to mirror 1a, the reversed order of the layers in the layer subsystem P'' that is second most distant from the substrate S, such that this fourth exemplary embodiment also has the feature that the first high refractive index layer H''' of the layer subsystem P''' that is most distant from the substrate optically actively succeeds the last low refractive index layer L'' of the layer subsystem P'' that is second most distant from the substrate.

Particularly in the case of a small number of layer subsystems of, for example, just two layer subsystems it is found that high reflectivity values are obtained if the period P_3 for the layer subsystem P''' that is most distant from the substrate has a thickness of the high refractive index layer H''' which amounts to more than 120% of the thickness, in particular more than double the thickness, of the high refractive index layer H'' of the period P_2 for the layer subsystem P'' that is second most distant from the substrate.

The layer subsystems of the layer arrangement of the mirrors according to the invention with respect to figures 1 to 4 succeed one another directly and are not separated by a further layer system. However, separation of the layer subsystems by an individual intermediate layer is conceivable for adapting the layer subsystems to one another or for optimizing the optical properties of the layer arrangement. This last does not apply, however, to the two layer subsystems P'' and P''' of the first exemplary embodiment with respect to figure 1 and the fourth exemplary embodiment as a variant with respect to figure 3 since the desired optical effect would thereby be prevented by the reversal of the sequence of the layers in P''.

The layers designated by H, H', H'' and H''' in figures 1 to 4 are layers composed of materials which, in the EUV wavelength range, can be designated as high refractive index layers in comparison with the layers of the same layer subsystem which are designated as L, L', L'' and L''', see the complex refractive indices of the materials in table 2. Conversely, the layers designated by L, L', L'' and L''' in figures 1 to 4 are layers composed of materials which, in the EUV wavelength range, can be designated as low refractive index layers in comparison with the layers of the same layer subsystem which are designated as H, H', H'' and H'''. Consequently, the terms high refractive index and low refractive index in the EUV wavelength range are relative terms with regard to the respective partner layer in a period of a layer subsystem. Layer subsystems function in the EUV wavelength range generally only if a layer that acts optically with a high refractive index is combined with a layer that optically has a lower refractive index relative thereto, as main constituent of a period of the layer subsystem. The material silicon is generally used for high refractive index layers. In combination with silicon, the materials molybdenum and ruthenium should be designated as low refractive index layers, see the complex refractive indices of the materials in table 2.

The layers L_{ASL} and H_{ASL} of the layer subsystem ASL having oxygen doping in figure 4 can be correspondingly low and high refractive index layers in the EUV wavelength range. However, this is not absolutely necessary, since the layers of the layer subsystem ASL are provided for the stress compensation of the layer arrangement and, consequently, do not necessarily contribute to the reflectivity of the layer arrangement.

In figures 1 to 4, a barrier layer B is in each case situated between the individual layers of a period, either composed of silicon and molybdenum or composed of silicon and ruthenium, said barrier layer consisting of a material which is selected or made up as a compound from the group of materials: B_4C, C, Si nitride, Si carbide, Si boride, Mo nitride, Mo carbide, Mo boride, Ru nitride, Ru carbide and Ru boride. Such a barrier layer suppresses the interdiffusion between the two individual layers of a period, thereby increasing the optical contrast in the transition of the two individual layers. With the use of the materials molybdenum and silicon for the two individual layers of a period, one barrier layer above the silicon layer, as viewed from the substrate, suffices in order to provide for a sufficient contrast. The second barrier layer above the molybdenum layer can be dispensed with in this case. In this respect, at least one barrier layer for separating the two individual layers of a period should be provided, wherein the at least one barrier layer may perfectly well be constructed from various ones of the above-indicated materials or the compounds thereof and may in this case also exhibit a layered construction of different materials or compounds. These statements correspondingly apply to the barrier layers in the further layer subsystem ASL having oxygen doping in figure 4.

Barrier layers which comprise the material B_4C and have a thickness of between 0.35 nm and 0.8 nm, preferably between 0.4 nm and 0.6 nm, lead in practice to high reflectivity values of the layer arrangement. Particularly in the case of layer subsystems composed of ruthenium and silicon, barrier layers composed of B_4C exhibit a maximum of reflectivity in the case of values of between 0.4 nm and 0.6 nm for the thickness of the barrier layer.

In the case of the mirrors 1a, 1b, 1c and 1d according to the invention, the number N_1, N_2 and N_3 of periods P_1, P_2 and P_3 of the layer subsystems P', P'' and P''' can comprise in each case up to 100 periods of the individual periods P_1, P_2 and P_3 illustrated in figures 1 to 4. Furthermore, the layer arrangements illustrated in figures 1 to 3 can comprise a layer subsystem ASL having oxygen doping between the layer subsystems P', P'' and P''' and the substrate, which layer subsystem is illustrated in accordance with figure 4 and, on account of its tensile stress, compensates for the compressive stress of the layer subsystems P', P'' and P'''.

Figure 4 shows a layer subsystem ASL having oxygen doping having the total thickness D_{ASL} having a number N_{ASL} of periods P_{ASL} of individual layers L_{ASL}, B, H_{ASL} having a period thickness d_{ASL}, which layer subsystem is situated between the layer subsystem P''' and the substrate S and compensates for the compressive stress of the layer subsystem P''' by means of its tensile stress in such a way that the resulting total layer stress of the layer arrangement is less than 100 MPa, in particular less than 50 MPa, particularly preferably less than 20 MPa. This layer subsystem ASL having oxygen doping has a doping of between 10 ppb and 0.1% oxygen, in particular between 50 ppb and 50 ppm oxygen, and a higher stress in the sense of higher tensile stress than an identically constructed layer subsystem without such a doping. Such a layer subsystem ASL can also be used expediently between the layer subsystems P', P'', P''' illustrated in figures 1 to 3 and the substrate S for the purpose of stress compensation. Furthermore, one of the layer subsystem P' and P'' in figures 1 to 3 can also be such a layer subsystem ASL having oxygen doping. In this case, it is important that, during the production of the layer subsystem ASL with oxygen doping, a doping with oxygen is effected and, in association therewith, the tensile stress is increased, thus resulting in a tensile stress of more than +240 MPa, in particular of more than +400 MPa, given a total thickness D_{ASL} of less than 200 nm and/or given a number N_{ASL} of 50 periods or less; in this respect, also see the discussion of the experimental results of samples 1 to 5 in table 7.

The layer arrangements of the mirrors 1a, 1b, 1c and 1d according to the invention are terminated toward the vacuum in figures 1 to 4 by a covering layer system C comprising at least one layer composed of a chemically inert material such as e.g. Rh, Pt, Ru, Pd, Au, SiO2 etc. as a terminating layer M. Said terminating layer M thus prevents the chemical alteration of the mirror surface on account of ambient influences. The covering layer system C in figures 1 to 4 consists, besides the terminating layer M, of a high refractive index layer H, a low refractive index layer L and a barrier layer B.

The thickness of one of the periods P_{ASL}, P_1, P_2 and P_3 results from figures 1 to 4 as the sum of the thicknesses of the individual layers of the corresponding period, that is to say from the thickness of the high refractive index layer, the thickness of the low refractive index layer and the thickness of two barrier layers. Consequently, the layer subsystems ASL, P', P'' and P''' in figures 1 to 4 can be distinguished from one another by virtue of the fact that their periods P_{ASL}, P_1, P_2 and P_3 have a different thickness d_{ASL}, d_1, d_2 and d_3. Consequently, in the context of the present invention, different layer subsystems ASL, P', P'' and P''' are understood to be layer subsystems whose periods P_{ASL}, P_1, P_2 and P_3 differ by more than 0.1 nm in their thicknesses d_{ASL}, d_1, d_2 and d_3, since a different optical effect of the layer subsystems can no longer be assumed below a difference of 0.1 nm given otherwise identical division of the periods between high and low refractive index layers. Furthermore, inherently identical layer subsystems can fluctuate by this absolute value in their period thicknesses during their production on different production apparatuses. For the case of a layer subsystem ASL, P', P'' and P''' having a period composed of molybdenum and silicon, it is also possible, as already described above, to dispense with the second barrier layer within the period P_{ASL}, P_1, P_2 and P_3, such that in this case the thickness of the periods P_{ASL}, P_1, P_2 and P_3 results from the thickness of the high refractive index layer, the thickness of the low refractive index layer and the thickness of a barrier layer.

Figure 5 shows a schematic illustration of a projection lens 2 according to the invention for a projection exposure apparatus for microlithography having six mirrors 1, 11, including at least one mirror 1 configured on the basis of the mirrors 1a, 1b, 1c or 1d according to the invention in accordance with the exemplary embodiments with respect to figures 9 to 16. The task of a projection exposure apparatus for microlithography is to image the structures of a mask, which is also referred to as a reticle, lithographically onto a so-called wafer in an image plane. For this purpose, a projection lens 2 according to the invention in figure 5 images an object field 3, which is arranged in the object plane 5, into an image field in the image plane 7. The structure-bearing mask, which is not illustrated in the drawing for the sake of clarity, can be arranged at the location of the object field 3 in the object plane 5. For orientation purposes, figure 5 illustrates a system of Cartesian coordinates, the x-axis of which points into the plane of the figure. In this case, the x-y coordinate plane coincides with the object plane 5, the z-axis being perpendicular to the object plane 5 and pointing downward. The projection lens has an optical axis 9, which does not run through the object field 3. The mirrors 1, 11 of the projection lens 2 have a design surface that is rotationally symmetrical with respect to the optical axis. In this case, said design surface must not be confused with the physical surface of a finished mirror, since the latter surface is trimmed relative to the design surface in order to ensure passages of light past the mirror. In this exemplary embodiment, the aperture stop 13 is arranged on the second mirror 11 in the light path from the object plane 5 to the image plane 7. The effect of the projection lens 2 is illustrated with the aid of three rays, the principal ray 15 and the two aperture marginal rays 17 and 19, all of which originate in the center of the object field 3. The principal ray 15, which runs at an angle of 6° with respect to the perpendicular to the object plane, intersects the optical axis 9 in the plane of the aperture stop 13. As viewed from the object plane 5, the principal ray 15 appears to intersect the optical axis in the entrance pupil plane 21. This is indicated in figure 5 by the dashed extension of the principal ray 15 through the first mirror 11. Consequently, the virtual image of the aperture stop 13, the entrance pupil, lies in the entrance pupil plane 21. The exit pupil of the projection lens could likewise be found with the same construction in the backward extension of the principal ray 15 proceeding from the image plane 7. However, in the image plane 7 the principal ray 15 is parallel to the optical axis 9, and from this it follows that the backward projection of these two rays produces a point of intersection at infinity in front of the projection lens 2 and the exit pupil of the projection lens 2 is thus at infinity. Therefore, this projection lens 2 is a so-called objective that is telecentric on the image side. The center of the object field 3 is at a distance R from the optical axis 9 and the center of the image field 7 is at a distance r from the optical axis 9, in order that no undesirable vignetting of the radiation emerging from the object field occurs in the case of the reflective configuration of the projection lens.

Figure 6 shows a plan view of an arcuate image field 7a such as occurs in the projection lens 2 illustrated in figure 5, and a system of Cartesian coordinates, the axes of which correspond to those from figure 5. The image field 7a is a sector from an annulus, the center of which is given by the point of intersection of the optical axis 9 with the object plane. The average radius r is 34 mm in the case illustrated. The width of the field in the y-direction d is 2 mm here. The central field point of the image field 7a is marked as a small circle within the image field 7a. As an alternative, a curved image field can also be delimited by two circle arcs which have the same radius and are displaced relative to one another in the y-direction. If the projection exposure apparatus is operated as a scanner, then the scanning direction runs in the direction of the shorter extent of the object field, that is to say in the direction of the y-direction.

Figure 7 shows an exemplary illustration of the maximum angles of incidence (rectangles) and of the interval lengths of the angle of incidence intervals (circles) in the unit degrees [°] against different radii or distances between the locations of the mirror surface and the optical axis, indicated in the unit [mm], of the penultimate mirror 1 in the light path from the object plane 5 to the image plane 7 of the projection lens 2 from figure 5. Said mirror 1, in the case of a projection lens 2 for microlithography which has six mirrors 1, 11 for the EUV wavelength range, is generally that mirror which has to ensure the largest angles of incidence and the largest angle of incidence intervals or the greatest variation of angles of incidence. In the context of this application, the interval length of an angle of incidence interval as a measure of the variation of angles of incidence is understood to be the number of angular degrees of that angular range in degrees between the maximum and minimum angles of incidence which the coating of the mirror has to ensure for a given distance from the optical axis on account of the requirements of the optical design. The angle of incidence interval will also be abbreviated to AOI interval.

The optical data of the projection lens in accordance with table 1 are applicable in the case of the mirror 1 taken as a basis in figure 7. In this case, the aspheres of the mirrors 1, 11 of the optical design are specified as rotationally symmetrical surfaces by means of the perpendicular distance Z(h) of an asphere point relative to the tangential plane in the asphere vertex as a function of the perpendicular distance h of the asphere point with respect to the normal in the asphere vertex in accordance with the following asphere equation:

$$Z(h) = (rho * h^2) / (1 + [1 - (1 + k_y) * (rho * h)^2]^{0.5}) +$$
$$+ c_1 * h^4 + c_2 * h^6 + c_3 * h^8 + c_4 * h^{10} + c_5 * h^{12} + c_6 * h^{14}$$

with the radius R =1/rho of the mirror and the parameters k_y, c_1, c_2, c_3, c_4, c_5, and c_6 in the unit [mm]. In this case, said parameters c_n are normalized with regard to the unit [mm] in accordance with [$1/mm^{2n+2}$] in such a way as to result in the asphere Z(h) as a function of the distance h also in the unit [mm].

Designation of the surface in accordance with figure 2	Radius R in [mm]	Distance from the nearest surface in [mm]	Asphere parameters with the unit [$1/mm^{2n+2}$] for c_n
Object plane 5	Infinity	697.657821079643	
1st mirror 11	-3060.189398512395	494.429629463009	
			k_y = 0.00000000000000E+00
			c_1 = 8.46747658600840E-10
			c_2 = -6.38829035308911E-15
			c_3 = 2.99297298249148E-20
			c_4 = 4.89923345704506E-25
			c_5 = -2.62811636654902E-29
			c_6 = 4.29534493103729E-34
2nd mirror 11 -- diaphragm --	-1237.831140064837	716.403660000000	
			k_y = 3.05349335818189E+00
			c_1 = 3.01069673080653E-10
			c_2 = 3.09241275151742E-16
			c_3 = 2.71009214786939E-20
			c_4 = -5.04344434347305E-24
			c_5 = 4.22176379615477E-28
			c_6 = -1.41314914233702E-32
3rd mirror 11	318.277985359899	218.770165786534	
			k_y = -7.80082610035452E-01
			c_1 = 3.12944645776932E-10
			c_2 = -1.32434614339199E-14
			c_3 = 9.56932396033676E-19
			c_4 = -3.13223523243916E-23
			c_5 = 4.73030659773901E-28
			c_6 = -2.70237216494288E-33
4th mirror 11	-513.327287349838	892.674538915941	
			k_y = -1.05007411819774E-01
			c_1 = -1.33355977877878E-12
			c_2 = -1.71866358951357E-16
			c_3 = 6.69985430179187E-22

			c_4 = 5.40777151247246E-27
			c_5 = -1.16662974927332E-31
			c_6 = 4.19572235940121E-37
Mirror 1	378.800274177878	285.840721874570	
			k_y = 0.00000000000000E+00
			c_1 = 9.27754883183223E-09
			c_2 = 5.96362556484499E-13
			c_3 = 1.56339572303953E-17
			c_4 = -1.41168321383233E-21
			c_5 = 5.98677250336455E-25
			c_6 = -6.30124060830317E-29
5th Mirror 11	-367.938526548613	325.746354374172	
			k_y = 1.07407597789597E-01
			c_1 = 3.87917960004046E-11
			c_2 = -3.43420257078373E-17
			c_3 = 2.26996395088275E-21
			c_4 = -2.71360350994977E-25
			c_5 = 9.23791176750829E-30
			c_6 = -1.37746833100643E-34
Image plane 7	Infinity		

Table 1: Data of the optical design regarding the angles of incidence of the mirror 1 in figure 7 in accordance with the schematic illustration of the design on the basis of figure 5.

It can be discerned from figure 7 that maximum angles of incidence of 24° and interval lengths of 11° occur at different locations of the mirror 1. Consequently, the layer arrangement of the mirror 1 has to yield high and uniform reflectivity values at these different locations for different angles of incidence and different angle of incidence intervals, since otherwise a high total transmission and an acceptable pupil apodization of the projection lens 2 cannot be ensured.

The so-called PV value is used as a measure of the variation of the reflectivity of a mirror over the angles of incidence. In this case, the PV value is defined as the difference between the maximum reflectivity R_{max} and the minimum reflectivity R_{min} in the angle of incidence interval under consideration divided by the average reflectivity $R_{average}$ in the angle of incidence interval under consideration. Consequently, $PV = (R_{max} - R_{min}) / R_{average}$ holds true.

In this case, it should be taken into consideration that high PV values for a mirror 1 of the projection lens 2 as penultimate mirror before the image plane 7 in accordance with figure 5 and the design in table 1 lead to high values for the pupil apodization. In this case, there is a correlation between the PV value of the mirror 1 and the imaging aberration of the pupil apodization of the projection lens 2 for high PV values of greater than 0.25 since, starting from this value, the PV value dominates the pupil apodization relative to other causes of aberration.

In figure 7, a bar 23 is used to mark by way of example a specific radius or a specific distance of the locations of the mirror 1 having the associated maximum angle of incidence of approximately 21° and the associated interval length of 11° with respect to the optical axis. Said marked radius correspond in figure 8, described below, to the locations on the circle 23a – illustrated in dashed fashion – within the hatched region 20, which represents the optically used region 20 of the mirror 1.

Figure 8 shows the substrate S of the penultimate mirror 1 in the light path from the object plane 5 to the image plane 7 of the projection lens 2 from figure 5 as a circle centered with respect to the optical axis 9 in plan view. In this case, the optical axis 9 of the projection lens 2 corresponds to the axis 9 of symmetry of the substrate. Furthermore, in figure 8, the optically used region 20 of the mirror 1, said region being offset with respect to the optical axis, is depicted in hatched fashion and a circle 23a is depicted in dashed fashion.

In this case, the part of the dashed circle 23a within the optically used region corresponds to the locations of the mirror 1 which are identified by the depicted bar 23 in figure 7. Consequently, the layer arrangement of the mirror 1 along the partial region of the dashed circle 23a within the optically used region 20, in accordance with the data from figure 7, has to ensure high reflectivity values both for a maximum angle of incidence of 21° and for a minimum angle of incidence of approximately 10°. In this case, the minimum angle of incidence of approximately 10° results from the maximum angle of incidence of 21° from figure 7 on account of the interval length of 11°. The locations on the dashed circle at which the two abovementioned extreme values of the angles of incidence occur are emphasized in figure 8 by the tip of the arrow 26 for the angle of incidence of 10° and by the tip of the arrow 25 for the angle of incidence of 21°.

Since a layer arrangement cannot be varied locally over the locations of a substrate S without high technological outlay and layer arrangements are generally applied rotationally symmetrically with respect to the axis 9 of symmetry of the substrate, the layer arrangement along the locations of the dashed circle 23a in figure 8 comprises one and the same layer arrangement such as is shown in its basic construction in figures 1 to 4 and is explained in the form of specific exemplary embodiments with reference to figures 9 to 16. In this case, it should be taken into consideration that a rotationally symmetrical coating of the substrate S with respect to the axis 9 of symmetry of the substrate S with the layer arrangement has the effect that the periodic sequence of the layer subsystems P_{ASL}, P', P'' and P''' of the layer arrangement is maintained at all locations of the mirror and only the thickness of the periods of the layer arrangement depending on the distance from the axis 9 of symmetry acquires a rotationally symmetrical profile over the substrate S, the layer arrangement correspondingly being thinner or thicker at the edge of the substrate S than in the center of the substrate S at the axis 9 of symmetry.

It should be taken into consideration that it is possible by means of a suitable coating technology, for example by the use of distribution diaphragms, to adapt the rotationally symmetrical radial profile of the thickness of a coating over the substrate. Consequently, in addition to the design of the coating per se, with the radial profile of the so-called thickness factor of the coating design over the substrate, a further degree of freedom is available for optimizing the coating design.

The reflectivity values illustrated in figures 9 to 16 were calculated using the complex refractive indices ñ = n – i*k indicated in table 2 for the used materials at the wavelength of 13.5 nm. In this case, it should be taken into consideration that reflectivity values of real mirrors can turn out to be lower than the theoretical reflectivity values illustrated in figures 9 to 16, since in particular the refractive indices of real thin layers can deviate from the literature values mentioned in table 2.

Material	Chemical symbol	Layer design symbol	n	k
Substrate			0.973713	0.0129764
Silicon	Si	H_{ASL}, H, H', H'', H'''	0.999362	0.00171609
Boron carbide	B_4C	B	0.963773	0.0051462
Molybdenum	Mo	L_{ASL}, L, L', L'', L'''	0.921252	0.0064143
Ruthenium	Ru	M, L, L', L'', L'''	0.889034	0.0171107
Vacuum			1	0

Table 2: Employed refractive indices ñ = n – i*k for 13.5 nm

Moreover, the following short notation in accordance with the layer sequence with respect to figures 1 to 3 is declared for the layer designs associated with figures 9 to 16:

Substrate / ... / $(P_1) * N_1$ / $(P_2) * N_2$ / $(P_3) * N_3$ / covering layer system C

where

P1 = H' B L' B; P2 = H'' B L'' B; P3 = H''' B L''' B; C = H B L M;

for figures 2 and 3 and where

P1 = B H' B L'; **P2 = B L'' B H''**; P3 = H''' B L''' B; C = H B L M;

for figure 1 and for the fourth exemplary embodiment as a variant with respect to figure 3.

In this case, the letters H symbolically represent the thickness of high refractive index layers, the letters L represent the thickness of low refractive index layers, the letter B represents the thickness of the barrier layer and the letter M represents the thickness of the chemically inert terminating layer in accordance with table 2 and the description concerning figures 1 to 3.

In this case, the unit [nm] applies to the thicknesses of the individual layers that are specified between the parentheses. The layer design used with respect to figures 9 and 10 can thus be specified as follows in the short notation:

Substrate /.../ (0.4 **B_4C** 2.921 **Si** 0.4 **B_4C** 4.931 **Mo**) * 8 / (0.4 **B_4C** 4.145 **Mo** 0.4 **B_4C** 2.911 **Si**) * 5 / (3.509 **Si** 0.4 **B_4C** 3.216 **Mo** 0.4 **B_4C**) * 16 / 2.975 **Si** 0.4 **B_4C** 2 **Mo** 1.5 **Ru**

Since the barrier layer B_4C in this example is always 0.4 nm thick, it can also be omitted for illustrating the basic construction of the layer arrangement, such that the layer design with respect to figures 9 and 10 can be specified in a manner shortened as follows:

Substrate /.../ (2.921 **Si** 4.931 **Mo**) * 8 / (4.145 **Mo** 2.911 **Si**) * 5 / (3.509 **Si** 3.216 **Mo**) * 16 / 2.975 **Si** 2 **Mo** 1.5 **Ru**

It should be recognized from this first exemplary embodiment according to figure 1 that the order of the high refractive index layer Si and the low refractive index layer Mo in the second layer subsystem, comprising five periods, has been reversed relative to the other layer subsystems, such that the first high refractive index layer of the layer subsystem that is most distant from the substrate, with a thickness of 3.509 nm, directly succeeds the last high refractive index layer of the layer subsystem that is second most distant from the substrate, with a thickness of 2.911 nm.

Correspondingly, it is possible to specify the layer design used with respect to figures 11 and 12 as second exemplary embodiment in accordance with figure 2 in the short notation as:

Substrate /.../ (4.737 **Si** 0.4 **B_4C** 2.342 **Mo** 0.4 **B_4C**) * 28 / (3.443 **Si** 0.4 **B_4C** 2.153 **Mo** 0.4 **B_4C**) * 5 / (3.523 **Si** 0.4 **B_4C** 3.193 **Mo** 0.4 **B_4C**) * 15 / 2.918 **Si** 0.4 **B_4C** 2 **Mo** 1.5 **Ru**

Since the barrier layer B_4C in this example is in turn always 0.4 nm thick, it can also be omitted for illustrating this layer arrangement, such that the layer design with respect to figures 11 and 12 can be specified in a manner shortened as follows:

Substrate /.../ (4.737 **Si** 2.342 **Mo**) * 28 / (3.443 **Si** 2.153 **Mo**) * 5 / (3.523 **Si** 3.193 **Mo**) * 15 / 2.918 **Si** 2 **Mo** 1.5 **Ru**

Accordingly, it is possible to specify the layer design used with respect to figures 13 and 14 as third exemplary embodiment in accordance with figure 3 in the short notation as:

Substrate /.../ (1.678 **Si** 0.4 **B_4C** 5.665 **Mo** 0.4 **B_4C**) * 27 / (3.798 **Si** 0.4 **B_4C** 2.855 **Mo** 0.4 **B_4C**) * 14 / 1.499 **Si** 0.4 **B_4C** 2 **Mo** 1.5 **Ru**

and, disregarding the barrier layer B_4C for illustration purposes, as:

Substrate /.../ (1.678 **Si** 5.665 **Mo**) * 27 / (3.798 **Si** 2.855 **Mo**) * 14 / 1.499 **Si** 2 **Mo** 1.5 **Ru**

Likewise, it is possible to specify the layer design used with respect to figures 15 and 16 as fourth exemplary embodiment in accordance with a variant with respect to figure 3 in the short notation as:

Substrate /.../ (0.4 **B_4C** 4.132 **Mo** 0.4 **B_4C** 2.78 **Si**) * 6 / (3.608 **Si** 0.4 **B_4C** 3.142 **Mo** 0.4 **B_4C**) * 16 / 2.027 **Si** 0.4 **B_4C** 2 **Mo** 1.5 **Ru**

and, disregarding the barrier layer B_4C for illustration purposes, as:

Substrate /.../ (4.132 **Mo** 2.78 **Si**) * 6 / (3.609 **Si** 3.142 **Mo**) * 16 / 2.027 **Si** 2 **Mo** 1.5 **Ru**

It should be recognized from this fourth exemplary embodiment that the order of the high refractive index layer Si and the low refractive index layer Mo in the layer subsystem P'', comprising six periods, has been reversed relative to the other layer subsystem P''' having 16 periods, such that the first high refractive index layer of the layer subsystem P''' that is most distant from the substrate, with a thickness of 3.609 nm, directly succeeds the last high refractive index layer of the layer subsystem P'' that is second most distant from the substrate, with a thickness of 2.78 nm.

This fourth exemplary embodiment is therefore a variant of the third exemplary embodiment in which the order of the high and low refractive index layers in the layer subsystem P'' that is second most distant from the substrate has been reversed according to the first exemplary embodiment with respect to figure 1.

Figure 9 shows reflectivity values for unpolarized radiation in the unit [%] of the first exemplary embodiment of a mirror 1a according to the invention in accordance with figure 1 plotted against the angle of incidence in the unit [°]. In this case, the first layer subsystem P' of the layer arrangement of the mirror 1a consists of $N_1 = 8$ periods P_1, wherein the period P_1 consists of 2.921 nm Si as high refractive index layer and 4.931 nm Mo as low refractive index layer, and also of two barrier layers each comprising 0.4 nm B_4C. The period P_1 consequently has a thickness d_1 of 8.652 nm. The second layer subsystem P'' of the layer arrangement of the mirror 1a having the reversed order of the layers Mo and Si consists of $N_2 = 5$ periods P_2, wherein the period P_2 consists of 2.911 nm Si as high refractive index layer and 4.145 nm Mo as low refractive index layer, and also of two barrier layers each comprising 0.4 nm B_4C. The period P_2 consequently has a thickness d_2 of 7.856 nm. The third layer subsystem P''' of the layer arrangement of the mirror 1a consists of $N_3 = 16$ periods P_3, wherein the period P_3 consists of 3.509 nm Si as high refractive index layer and 3.216 nm Mo as low refractive index layer, and also of two barrier layers each comprising 0.4 nm B_4C. The period P_3 consequently has a thickness d_3 of 7.525 nm. The layer arrangement of the mirror 1a is terminated by a covering layer system C consisting of 2.975 nm Si, 0.4 nm B_4C, 2 nm Mo and 1.5 nm Ru in the order specified. Consequently, the layer subsystem P''' that is most distant from the substrate has a number N_3 of periods P_3 that is greater than the number N_2 of periods P_2 for the layer subsystem P'' that is second most distant from the substrate and the first high refractive index layer H''' of the layer subsystem P''' that is most distant from the substrate directly succeeds the last high refractive index layer H'' of the layer subsystem P'' that is second most distant from the substrate.

The reflectivity values of this nominal layer design with the thickness factor 1 in the unit [%] at a wavelength of 13.5 nm are illustrated as a solid line against the angle of incidence in the unit [°] in figure 9. Moreover, the average reflectivity of this nominal layer design for the angle of incidence interval of 14.1° to 25.7° is depicted as a solid horizontal bar. Furthermore, figure 9 correspondingly specifies, at a wavelength of 13.5 nm and given a thickness factor of 0.933, as a dashed line the reflectivity values against the angles of incidence and as a dashed bar the average reflectivity of the above-specified layer design for the angle of incidence interval of 2.5° to 7.3°. Consequently, the thicknesses of the periods of the layer arrangement with respect to the reflectivity values illustrated as a dashed line in figure 9 amount to only 93.3% of the corresponding thicknesses of the periods of the nominal layer design. In other words, the layer arrangement is thinner than the nominal layer design by 6.7% at the mirror surface of the mirror 1a at the locations at which angles of incidence of between 2.5° and 7.3° have to be ensured.

Figure 10 shows, at a wavelength of 13.5 nm and given a thickness factor of 1.018, in a manner corresponding to figure 9, as a thin line the reflectivity values against the angles of incidence and as a thin bar the average reflectivity of the above-specified layer design for the angle of incidence interval of 17.8° to 27.2°, and also, given a thickness factor of 0.972, in a corresponding manner, as a thick line the reflectivity values against the angles of incidence and as a thick bar the average reflectivity of the above-specified layer design for the angle of incidence interval of 8.7° to 21.4°. Consequently, the layer arrangement is thicker than the nominal layer design by 1.8% at the mirror surface of the mirror 1a at the locations at which angles of incidence of between 17.8° and 27.2° have to be ensured and is correspondingly thinner than the nominal layer design by 2.8% at the locations at which angles of incidence of between 8.7° and 21.4° have to be ensured.

The average reflectivity and PV values which can be achieved by means of the layer arrangement with respect to figure 9 and figure 10 are compiled relative to the angle of incidence intervals and the thickness factors in table 3. It can be discerned that the mirror 1a comprising the layer arrangement specified above, at a wavelength of 13.5 nm for angles of incidence of between 2.5° and 27.2°, has an average reflectivity of more than 43% and a variation of the reflectivity as PV value of less than or equal to 0.21.

AOI-Interval [°]	Thickness factor	R_average [%]	PV
17.8 – 27.2	1.018	43.9	0.14
14.1 – 25.7	1	44.3	0.21
8.7 – 21.4	0.972	46.4	0.07
2.5 – 7.3	0.933	46.5	0.01

Table 3: Average reflectivity and PV values of the layer design with respect to figure 9 and figure 10 relative to the angle of incidence interval in degrees and the thickness factor chosen.

Figure 11 shows reflectivity values for unpolarized radiation in the unit [%] of the second exemplary embodiment of a mirror 1b according to the invention in accordance with figure 2 plotted against the angle of incidence in the unit [°]. In this case, the first layer subsystem P' of the layer arrangement of the mirror 1b consists of $N_1 = 28$ periods P_1, wherein the period P_1 consists of 4.737 nm Si as high refractive index layer and 2.342 nm Mo as low refractive index layer, and also of two barrier layers each comprising 0.4 nm B_4C. The period P_1 consequently has a thickness d_1 of 7.879 nm. The second layer subsystem P'' of the layer arrangement of the mirror 1b consists of $N_2 = 5$ periods P_2, wherein the period P_2 consists of 3.443 nm Si as high refractive index layer and 2.153 nm Mo as low refractive index layer, and also of two barrier layers each comprising 0.4 nm B_4C. The period P_2 consequently has a thickness d_2 of 6.396 nm. The third layer subsystem P''' of the layer arrangement of the mirror 1b consists of $N_3 = 15$ periods P_3, wherein the period P_3 consists of 3.523 nm Si as high refractive index layer and 3.193 nm Mo as low refractive index layer, and also of two barrier layers each comprising 0.4 nm B_4C. The period P_3 consequently has a thickness d_3 of 7.516 nm. The layer arrangement of the mirror 1b is terminated by a covering layer system C consisting of 2.918 nm Si, 0.4 nm B_4C, 2 nm Mo and 1.5 nm Ru in the order specified. Consequently, the layer subsystem P''' that is most distant from the substrate has a number N_3 of periods P_3 that is greater than the number N_2 of periods P_2 for the layer subsystem P'' that is second most distant from the substrate.

The reflectivity values of this nominal layer design with the thickness factor 1 in the unit [%] at a wavelength of 13.5 nm are illustrated as a solid line against the angle of incidence in the unit [°] in figure 11. Moreover, the average reflectivity of this nominal layer design for the angle of incidence interval of 14.1° to 25.7° is depicted as a solid horizontal bar. Furthermore, figure 11 correspondingly specifies, at a wavelength of 13.5 nm and given a thickness factor of 0.933, as a dashed line the reflectivity values against the angles of incidence and as a dashed bar the average reflectivity of the above-specified layer design for the angle of incidence interval of 2.5° to 7.3°. Consequently, the thicknesses of the periods of the layer arrangement with respect to the reflectivity values illustrated as a dashed line in figure 11 amount to only 93.3% of the corresponding thicknesses of the periods of the nominal layer design. In other words, the layer arrangement is thinner than the nominal layer design by 6.7% at the mirror surface of the mirror 1b at the locations at which angles of incidence of between 2.5° and 7.3° have to be ensured.

Figure 12 shows, at a wavelength of 13.5 nm and given a thickness factor of 1.018, in a manner corresponding to figure 11, as a thin line the reflectivity values against the angles of incidence and as a thin bar the average reflectivity of the above-specified layer design for the angle of incidence interval of 17.8° to 27.2°, and also, given a thickness factor of 0.972, in a corresponding manner, as a thick line the reflectivity values against the angles of incidence and as a thick bar the average reflectivity of the above-specified layer design for the angle of incidence interval of 8.7° to 21.4°. Consequently, the layer arrangement is thicker than the nominal layer design by 1.8% at the mirror surface of the mirror 1b at the locations at which angles of incidence of between 17.8° and 27.2° have to be ensured and is correspondingly thinner than the nominal layer design by 2.8% at the locations at which angles of incidence of between 8.7° and 21.4° have to be ensured.

The average reflectivity and PV values which can be achieved by means of the layer arrangement with respect to figure 11 and figure 12 are compiled relative to the angle of incidence intervals and the thickness factors in table 4. It can be discerned that the mirror 1b comprising the layer arrangement specified above, at a wavelength of 13.5 nm for angles of incidence of between 2.5° and 27.2°, has an average reflectivity of more than 45% and a variation of the reflectivity as PV value of less than or equal to 0.23.

AOI Interval [°]	Thickness factor	R_average [%]	PV
17.8 – 27.2	1.018	45.2	0.17
14.1 – 25.7	1	45.7	0.23
8.7 – 21.4	0.972	47.8	0.18

2.5 – 7.3	0.933	45.5	0.11

Table 4: Average reflectivity and PV values of the layer design with respect to figure 11 and figure 12 relative to the angle of incidence interval in degrees and the thickness factor chosen.

Figure 13 shows reflectivity values for unpolarized radiation in the unit [%] of the third exemplary embodiment of a mirror 1c according to the invention in accordance with figure 3 plotted against the angle of incidence in the unit [°]. In this case, the layer subsystem P'' of the layer arrangement of the mirror 1c consists of $N_2 = 27$ periods P_2, wherein the period P_2 consists of 1.678 nm Si as high refractive index layer and 5.665 nm Mo as low refractive index layer, and also of two barrier layers each comprising 0.4 nm B_4C. The period P_2 consequently has a thickness d_2 of 8.143 nm. The layer subsystem P''' of the layer arrangement of the mirror 1c consists of $N_3 = 14$ periods P_3, wherein the period P_3 consists of 3.798 nm Si as high refractive index layer and 2.855 nm Mo as low refractive index layer, and also of two barrier layers each comprising 0.4 nm B_4C. Consequently, the period P_3 has a thickness d_3 of 7.453 nm. The layer arrangement of the mirror 1c is terminated by a covering layer system C consisting of 1.499 nm Si, 0.4 nm B_4C, 2 nm Mo and 1.5 nm Ru in the order specified. Consequently, the layer subsystem P''' that is most distant from the substrate has a thickness of the high refractive index layer H''' that amounts to more than double the thickness of the high refractive index layer H'' of the layer subsystem P'' that is second most distant from the substrate.

The reflectivity values of this nominal layer design with the thickness factor 1 in the unit [%] at a wavelength of 13.5 nm are illustrated as a solid line against the angle of incidence in the unit [°] in figure 13. Moreover, the average reflectivity of this nominal layer design for the angle of incidence interval of 14.1° to 25.7° is depicted as a solid horizontal bar. Furthermore, figure 13 correspondingly specifies, at a wavelength of 13.5 nm and given a thickness factor of 0.933, as a dashed line the reflectivity values against the angles of incidence and as a dashed bar the average reflectivity of the above-specified layer design for the angle of incidence interval of 2.5° to 7.3°. Consequently, the thicknesses of the periods of the layer arrangement with respect to the reflectivity values illustrated as a dashed line in figure 13 amount to only 93.3% of the corresponding thicknesses of the periods of the nominal layer design. In other words, the layer arrangement is thinner than the nominal layer design by 6.7% at the mirror surface of the mirror 1c at the locations at which angles of incidence of between 2.5° and 7.3° have to be ensured.

Figure 14 shows in a manner corresponding to figure 13, at a wavelength of 13.5 nm and given a thickness factor of 1.018, as a thin line the reflectivity values against the angles of incidence and as a thin bar the average reflectivity of the above-specified layer design for the angle of incidence interval of 17.8° to 27.2°, and also, given a thickness factor of 0.972, in a corresponding manner, as a thick line the reflectivity values against the angles of incidence and as a thick bar the average reflectivity of the above-specified layer design for the angle of incidence interval of 8.7° to 21.4°. Consequently, the layer arrangement is thicker than the nominal layer design by 1.8% at the mirror surface of the mirror 1c at the locations at which angles of incidence of between 17.8° and 27.2° have to be ensured and is correspondingly thinner than the nominal layer design by 2.8% at the locations at which angles of incidence of between 8.7° and 21.4° have to be ensured.

The average reflectivity and PV values which can be achieved by means of the layer arrangement with respect to figure 13 and figure 14 are compiled relative to the angle of incidence intervals and the thickness factors in table 5. It can be discerned that the mirror 1c comprising the layer arrangement specified above, at a wavelength of 13.5 nm for angles of incidence of between 2.5° and 27.2°, has an average reflectivity of more than 39% and a variation of the reflectivity as PV value of less than or equal to 0.22.

AOI Interval [°]	Thickness factor	R_average [%]	PV
17.8 – 27.2	1.018	39.2	0.19
14.1 – 25.7	1	39.5	0.22
8.7 – 21.4	0.972	41.4	0.17
2.5 – 7.3	0.933	43.9	0.04

Table 5: Average reflectivity and PV values of the layer design with respect to figure 13 and figure 14 relative to the angle of incidence interval in degrees and the thickness factor chosen.

Figure 15 shows reflectivity values for unpolarized radiation in the unit [%] of the fourth exemplary embodiment of a mirror according to the invention as a variant of the mirror 1c in which the order of the layers in the layer subsystem P'' has been reversed, plotted against the angle of incidence in the unit [°]. In this case, the layer subsystem P'' of the layer arrangement of the mirror consists of $N_2 = 6$ periods P_2, wherein the period P_2 consists of 2.78 nm Si as high refractive index layer and 4.132 nm Mo as low refractive index layer, and also of two barrier layers each comprising 0.4 nm B_4C. The period P_2 consequently has a thickness d_2 of 7.712 nm. The layer subsystem P''' of the layer arrangement of the mirror consists of $N_3 = 16$ periods P_3, wherein the period P_3 consists of 3.608 nm Si as high refractive index layer and 3.142 nm Mo as low refractive index layer, and also of two barrier layers each comprising 0.4 nm B_4C. The period P_3 consequently has a thickness d_3 of 7.55 nm. The layer arrangement of the mirror is terminated by a covering layer system C consisting of 2.027 nm Si, 0.4 nm B_4C, 2 nm Mo and 1.5 nm Ru in the order specified. Consequently, the layer subsystem P''' that is most distant from the substrate has a thickness of the high refractive index layer H''' which amounts to more than 120 % of the thickness of the high refractive index layer H'' of the layer subsystem P'' that is second most distant from the substrate. Furthermore, the layer subsystem P''' that is most distant from the substrate has a number N_3 of periods P_3 that is greater than the number N_2 of periods P_2 for the layer subsystem P'' that is second most distant from the substrate, and the first high refractive index layer H''' of the layer subsystem P''' that is most distant from the substrate directly succeeds the last high refractive index layer H'' of the layer subsystem P'' that is second most distant from the substrate.

The reflectivity values of this nominal layer design with the thickness factor 1 in the unit [%] at a wavelength of 13.5 nm are illustrated as a solid line against the angle of incidence in the unit [°] in figure 15. Moreover, the average reflectivity of this nominal layer design for the angle of incidence interval of 14.1° to 25.7° is depicted as a solid horizontal bar. Furthermore, figure 15 correspondingly specifies, at a wavelength of 13.5 nm and given a thickness factor of 0.933, as a dashed line the reflectivity values against the angles of incidence and as a dashed bar the average reflectivity of the above-specified layer design for the angle of incidence interval of 2.5° to 7.3°. Consequently, the thicknesses of the periods of the layer arrangement with respect to the reflectivity values illustrated as a dashed line in figure 15 amount to only 93.3% of the corresponding thicknesses of the periods of the nominal layer design. In other words, the layer arrangement is thinner than the nominal layer design by 6.7% at the mirror surface of the mirror according to the invention at the locations at which angles of incidence of between 2.5° and 7.3° have to be ensured.

Figure 16 shows, at a wavelength of 13.5 nm and given a thickness factor of 1.018, in a manner corresponding to figure 15, as a thin line the reflectivity values against the angles of incidence and as a thin bar the average reflectivity of the above-specified layer design for the angle of incidence interval of 17.8° to 27.2°, and also, given a thickness factor of 0.972, in a corresponding manner, as a thick line the reflectivity values against the angles of incidence and as a thick bar the average reflectivity of the above-specified layer design for the angle of incidence interval of 8.7° to 21.4°. Consequently, the layer arrangement is thicker than the nominal layer design by 1.8% at the mirror surface of this mirror according to the invention at the locations at which angles of incidence of between 17.8° and 27.2° have to be ensured and is correspondingly thinner than the nominal layer design by 2.8% at the locations at which angles of incidence of between 8.7° and 21.4° have to be ensured.

The average reflectivity and PV values which can be achieved by means of the layer arrangement with respect to figure 15 and figure 16 are compiled relative to the angle of incidence intervals and the thickness factors in table 6. It can be discerned that the mirror according to the invention comprising the layer arrangement specified above, at a wavelength of 13.5 nm for angles of incidence of between 2.5° and 27.2°, has an average reflectivity of more than 42% and a variation of the reflectivity as PV value of less than or equal to 0.24.

AOI Interval [°]	Thickness factor	R_average [%]	PV
17.8 – 27.2	1.018	42.4	0.18
14.1 – 25.7	1	42.8	0.24
8.7 – 21.4	0.972	44.9	0.15
2.5 – 7.3	0.933	42.3	0.04

Table 6: Average reflectivity and PV values of the layer design with respect to figure 15 and figure 16 relative to the angle of incidence interval in degrees and the thickness factor chosen.

In all four exemplary embodiments shown in accordance with figures 1 to 3, it is also possible to use layer subsystems ASL having oxygen doping for stress compensation between the layer subsystems in figures 1 to 3 and the substrate S, which themselves do not have high reflectivities for the EUV wavelength range on account of a high molybdenum proportion required for the stress compensation or on account of a different material selection for the layer subsystem ASL.

By way of example, in the case of the layer design used with respect to figures 11 and 12 as second exemplary embodiment in accordance with figure 2 with the layer sequence:

Substrate /…/ (4.737 **Si** 0.4 **B_4C** 2.342 **Mo** 0.4 **B_4C**) * 28 / (3.443 **Si** 0.4 **B_4C** 2.153 **Mo** 0.4 **B_4C**) * 5 / (3.523 **Si** 0.4 **B_4C** 3.193 **Mo** 0.4 **B_4C**) * 15 / 2.918 **Si** 0.4 **B_4C** 2 **Mo** 1.5 **Ru**

it is possible to use a layer subsystem ASL having oxygen doping which has 10 to 15 periods of the layer sequence (1 Si 0.5 C 2 Mo) with numerical indications in the unit [nm], as follows:

Substrate / … / (1 **Si** 0.5 **C** 2 **Mo**) * 10 / (4.737 **Si** 0.4 **B_4C** 2.342 **Mo** 0.4 **B_4C**) * 28 / (3.443 **Si** 0.4 **B_4C** 2.153 **Mo** 0.4 **B_4C**) * 5 / (3.523 **Si** 0.4 **B_4C** 3.193 **Mo** 0.4 **B_4C**) * 15 / 2.918 **Si** 0.4 **B_4C** 2 **Mo** 1.5 **Ru**

Correspondingly, it is possible to specify the layer design used with respect to figures 13 and 14 as third exemplary embodiment in accordance with figure 3 with a further layer subsystem ASL as:

Substrate / … /(1 **Si** 0.5 **C** 2 **Mo**) * 10 / (1.678 **Si** 0.4 **B_4C** 5.665 **Mo** 0.4 **B_4C**) * 27 / (3.798 **Si** 0.4 **B_4C** 2.855 **Mo** 0.4 **B_4C**) * 14 / 1.499 **Si** 0.4 **B_4C** 2 **Mo** 1.5 **Ru**

While, in the case of these two broadband coatings mentioned, 10 to 15 periods of a layer subsystem ASL having oxygen doping already suffice to compensate for the compressive stresses of the broadband coatings by the tensile stresses of the layer subsystem ASL that are intensified by means of oxygen doping, by contrast it is necessary to use approximately 20 to 25 periods of such a layer subsystem ASL in the case of a narrowband coating optimized for angles of incidence of 0° to approximately 10°. This is owing to the fact that such narrowband coatings are generally embodied as so-called "monostacks" having many periods of a specific layer sequence with a small molybdenum proportion and therefore have a high compressive stress as a result of the many periods.

Table 7 gives an overview of such narrowband coatings with different layer subsystems ASL having oxygen doping in comparison with a layer subsystem ASL from the prior art (sample 1) without such a doping. In this case, the narrowband coatings each comprise a layer subsystem P''' consisting of 50 periods P_3 in accordance with figure 4 with the layer sequence (3.8 Si 0.5 C 2.2 Mo 0.5 C) with numerical indications in the unit [nm] and have a reflectivity of more than 60% for the EUV wavelength range at an angle of incidence of 0°. All of samples 1 to 5 comprise, in accordance with figure 4, a layer subsystem ASL having 50 periods of the layer sequence (1 Si 0.5 C 2 Mo) with numerical indications in the unit [nm]. During the coating of samples 2 to 5, a different oxygen partial pressure of between $1*10^{-7}$ mbar and $1*10^{-5}$ mbar was set by adding oxygen into the coating apparatus. The different layer subsystem ASL of samples 2 to 5 are thereby doped with oxygen between 10 ppb and 0.1%, in particular between 50 ppb and 50 ppm. By contrast, the layer subsystem ASL of sample 1 was coated at a normal residual gas pressure of a coating apparatus in accordance with an oxygen partial pressure of less than 10^{-9} mbar. Therefore, this layer system ASL of sample 1 is regarded as a known layer system from the prior art since the period thicknesses and the molybdenum proportion of this layer system do not differ from known layer systems ASL for stress compensation. In this case, all samples 1 to 5 were coated by magnetron sputtering at a working pressure of $4*10^{-4}$ mbar of the working gas krypton.

The total layer stress of the layer arrangement as specified in table 7 and the reflectivity were measured after the coating of each individual sample. The specified tensile stress of the layer subsystem ASL results from this measured total layer stress, taking account of the theoretical compressive stress of the respective layer subsystem P'''. In this case, all of the specified stresses are normalized to 1 nm period thickness of the respective period for comparison. On the basis of this calculated tensile stress of the layer subsystem ASL in table 7 it can clearly be discerned that in the case of an inherently identical layer subsystem ASL having the same number of periods and the same layer sequence, as a result of the addition of oxygen during the coating, on account of the doping taking place in this case, the respective tensile stress is established within the layer subsystem ASL. Consequently, the tensile stress can be increased by oxygen doping within the further layer subsystem ASL in such a way that a virtually stress-free layer arrangement already results in the case of a total thickness D_{ASL} of the layer subsystem of less than 200 nm. Without such a doping, approximately 70-80 periods of the specified layer subsystem ASL with a total thickness of 245-280 nm are necessary for this purpose. Besides reducing the number of periods or the total thickness of the further layer subsystem ASL, it is also possible, therefore, for the roughness of the further layer subsystem to be reduced on account of thin or fewer periods, such that the surface roughness of the layer terminating the layer arrangement is less than 0.2 nm rms HSFR, in particular less than 0.1 nm rms HSFR. In this case, the thickness of the periods of the layer subsystem ASL can be limited to 5 nm or less, in particular to 3.5 nm or less, as a result of which thick and thus rough molybdenum layers are avoided. The tensile stress of the layer subsystem ASL having the 50 periods specified can be increased by the doping from a slight compressive stress of sample 1 at -12 MPa to tensile stresses of +241 MPa in the case of sample 2 through to 760 MPa in the case of sample 5. Accordingly, it is possible to produce layer subsystem ASL having oxygen doping whose normalized stress, depending on the molybdenum proportion, lies above a linear stress characteristic curve resulting from the corner point of -300 MPa given a molybdenum proportion of 0.3 and a gradient of 80 MPa per increase of 0.1 in the molybdenum proportion.

Sample No.	**1 Prior art**	**2**	**3**	**4**	**5**
O_2 Partial pressure	<1E-9 mbar	1E-7 mbar	5E-7 mbar	1E-6 mbar	1E-5 mbar
P''' = 50 x P_3 P_3 d_3 [nm]	Si / C / Mo / C 3.8 / 0.5 / 2.2 / 0.5	Si / C / Mo / C 3.8 / 0.5 / 2.2 / 0.5	Si / C / Mo / C 3.8 / 0.5 / 2.2 / 0.5	Si / C / Mo / C 3.8 / 0.5 / 2.2 / 0.5	Si / C / Mo / C 3.8 / 0.5 / 2.2 / 0.5
ASL = 50 x P_{ASL} P_{ASL} d_{ASL} [nm]	Si / C / Mo 1 / 0.5 / 2	Si / C / Mo 1 / 0.5 / 2	Si / C / Mo 1 / 0.5 / 2	Si / C / Mo 1 / 0.5 / 2	Si / C / Mo 1 / 0.5 / 2
Stress total [MPa]	-307	-224	-170	-100	-47
Stress P''' [MPa]	-450	-450	-450	-450	-450
Calculated stress ASL [MPa]	-12	+241	+406	+600	+760
Reflectivity at 0°	67.4 %	66.7 %	66.7 %	66.5 %	66.4%

Table 7: Overview of samples 2 to 5 of narrowband coatings with different layer subsystems ASL having oxygen doping on account of different addition of oxygen in comparison with the prior art (sample 1).

In principle, it is also conceivable to dope the layer subsystem P''' with oxygen in order to decrease its compressive stress. However, this leads to high reflectivity losses, which are undesirable for a mirror for an EUV projection exposure apparatus.

Furthermore, it is possible, within a layer subsystem P''' that contributes to the high reflectivity of an EUV mirror, to realize an e.g. graded transition of the oxygen doping, such that the layers of the layer subsystem P''' which are situated closest to the substrate have a higher oxygen doping than the layers situated most distant from the substrate. In this case, the layers of the layer subsystem P''' which are doped with oxygen and are situated closest to the substrate form the layer subsystem ASL within the meaning of this application, provided that the oxygen doping of these layers is more than 10 ppb and less than 0.1%, in particular more than 50 ppb and less than 50 ppm.

Patent claims:

1. A mirror (1a; 1b; 1c; 1d) for the EUV wavelength range having a reflectivity of greater than 40% for at least one angle of incidence of between 0° and 25°, comprising a substrate (S) and a layer arrangement, wherein the layer arrangement comprises at least one layer subsystem (ASL) consisting of a periodic sequence of at least two periods (P_{ASL}) of individual layers (L_{ASL}, B, H_{ASL}) composed of different materials, **wherein** the layer subsystem (ASL) has an oxygen doping of between 10 ppb and 0.1%, in particular between 50 ppb and 50 ppm.

2. The mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 1, wherein the layer arrangement comprises at least one additional layer subsystem (P', P'', P''') which consists of a periodic sequence of at least two periods (P_1, P_2, P_3) of individual layers, wherein the periods (P_1, P_2, P_3) comprise two individual layers composed of different materials for a high refractive index layer (H', H'', H''') and a low refractive index layer (L', L'', L''').

3. The mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 1, wherein the layer subsystem (ASL) having oxygen doping has a total thickness (D_{ASL}) of less than 200 nm.

4. The mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 1, wherein the layer subsystem (ASL) having oxygen doping has a stress which, depending on the molybdenum proportion, lies above a linear stress characteristic curve resulting from the corner point of -300 MPa given a molybdenum proportion of 0.3 and a gradient of 80 MPa per increase of 0.1 in the molybdenum proportion.

5. The mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 1, wherein the absolute value of the total layer stress of the layer arrangement is less than 100 MPa, in particular less than 50 MPa, particularly preferably less than 20 MPa.

6. The mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 1, wherein the absolute value of the tensile stress of the layer subsystem (ASL) having oxygen doping is more than 240 MPa, in particular more than 400 MPa, particularly preferably

more than 600 MPa.

7. The mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 1, wherein the number (N_{ASL}) of periods (P_{ASL}) of the layer subsystem (ASL) having oxygen doping is 50 or less.

8. The mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 1, wherein the layer subsystem (ASL) having oxygen doping has a thickness (d_{ASL}) of the periods (P_{ASL}) of 5 nm or less, in particular of 3.5 nm or less.

9. The mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 1, wherein the individual layers of the layer subsystem (ASL) having oxygen doping consist of materials which are selected or made up as a compound from the group of materials: molybdenum, silicon, B_4C, C, Si nitride, Si carbide, Si boride, Mo nitride, Mo carbide, Mo boride, Ru nitride, Ru carbide and Ru boride.

10. The mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 1, wherein the reflectivity given normal incidence is more than 60% and the number (N_{ASL}) of periods (P_{ASL}) of the layer subsystem (ASL) having oxygen doping is more than 20, in particular more than 25.

11. The mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 1, wherein an average reflectivity given an angle of incidence interval of 4.8° or greater and given a maximum angle of incidence of 27.2° is more than 39.2%, and the number (N_{ASL}) of periods (P_{ASL}) of the layer subsystem (ASL) having oxygen doping is more than 15, in particular more than 20.

12. The mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 2, wherein the materials of the two individual layers (L', H', L'', H'', L''', H''') of the at least one layer subsystem (P', P'', P''') that form the periods (P_1, P_2, P_3) are either molybdenum and silicon or ruthenium and silicon, and wherein the individual layers are separated by at least one barrier layer (B) and the barrier layer (B) consists of a material which is selected or made up as a compound from the group of materials: B_4C, C, Si nitride, Si carbide, Si boride, Mo nitride, Mo carbide, Mo boride, Ru nitride, Ru carbide and Ru

boride.

13. The mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 2, wherein the layer subsystem (ASL) having oxygen doping is arranged between the substrate and the at least one layer subsystem (P', P'', P''').

14. The mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 1 or 2, wherein the surface roughness of the layer terminating the layer arrangement is less than 0.2 nm rms HSFR, in particular less than 0.1 nm rms HSFR.

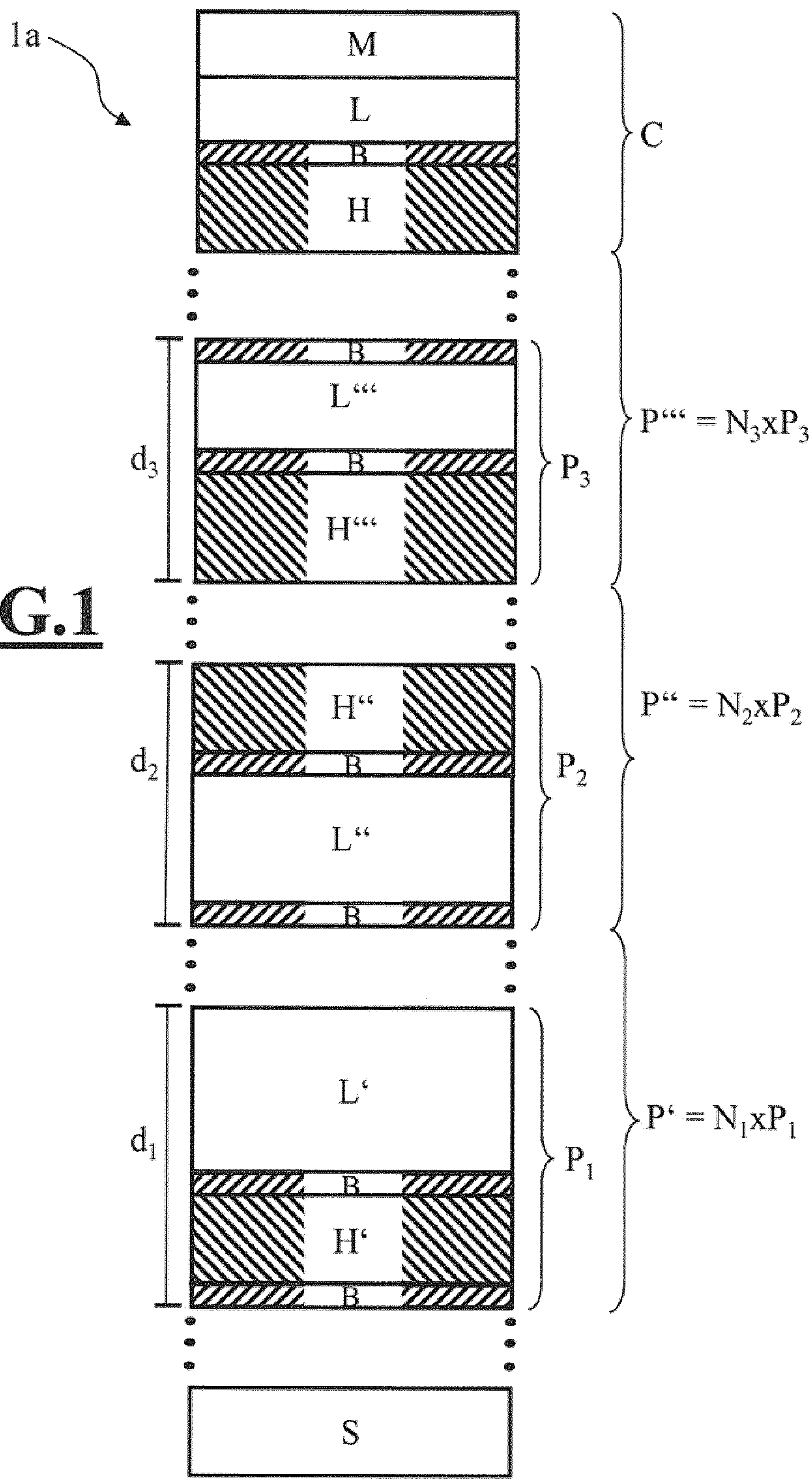
15. A method for coating a mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in any of the preceding claims, **wherein** an oxygen partial pressure of greater than 10^{-9} mbar, in particular of greater than 10^{-7} mbar, is present during the coating of the layer subsystem (ASL) with oxygen doping.

16. The method for coating a mirror (1a; 1b; 1c; 1d) for the EUV wavelength range as claimed in claim 15, wherein the coating of the layer subsystem (ASL) with oxygen doping is performed by magnetron sputtering at a working gas pressure of at least 10^{-4} mbar.

17. A projection lens for microlithography comprising a mirror (1a; 1b; 1c; 1d) as claimed in any of claims 1 to 14, and also a mirror (1a; 1b; 1c; 1d) produced by a method as claimed in claims 15 to 16.

18. A projection exposure apparatus for microlithography comprising a projection lens as claimed in claim 17.

FIG.1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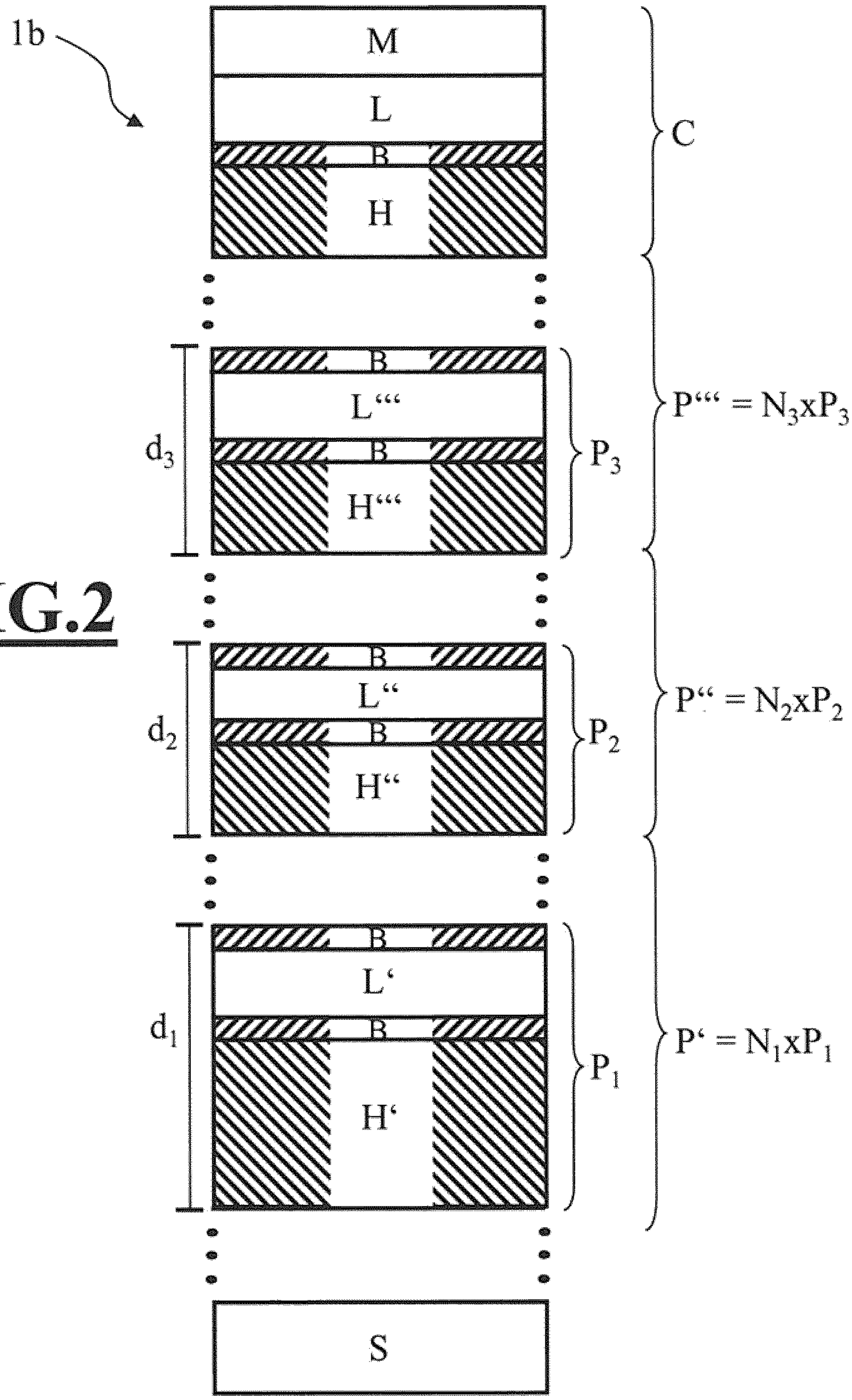
M
L
B
H
C
B
L‘‘‘
B
H‘‘‘
d3
P3
P‘‘‘ = N3xP3
H‘‘
B
L‘‘
B
d2
P2
P‘‘ = N2xP2
L‘
B
H‘
B
d1
P1
P‘ = N1xP1
S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B
H
C
B
L'''
B
H'''
d3
P3
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B
L''
B
H''
d2
P2
P'' = N2xP2
B
L'
B
H'
d1
P1
P' = N1xP1
S

FIG.2

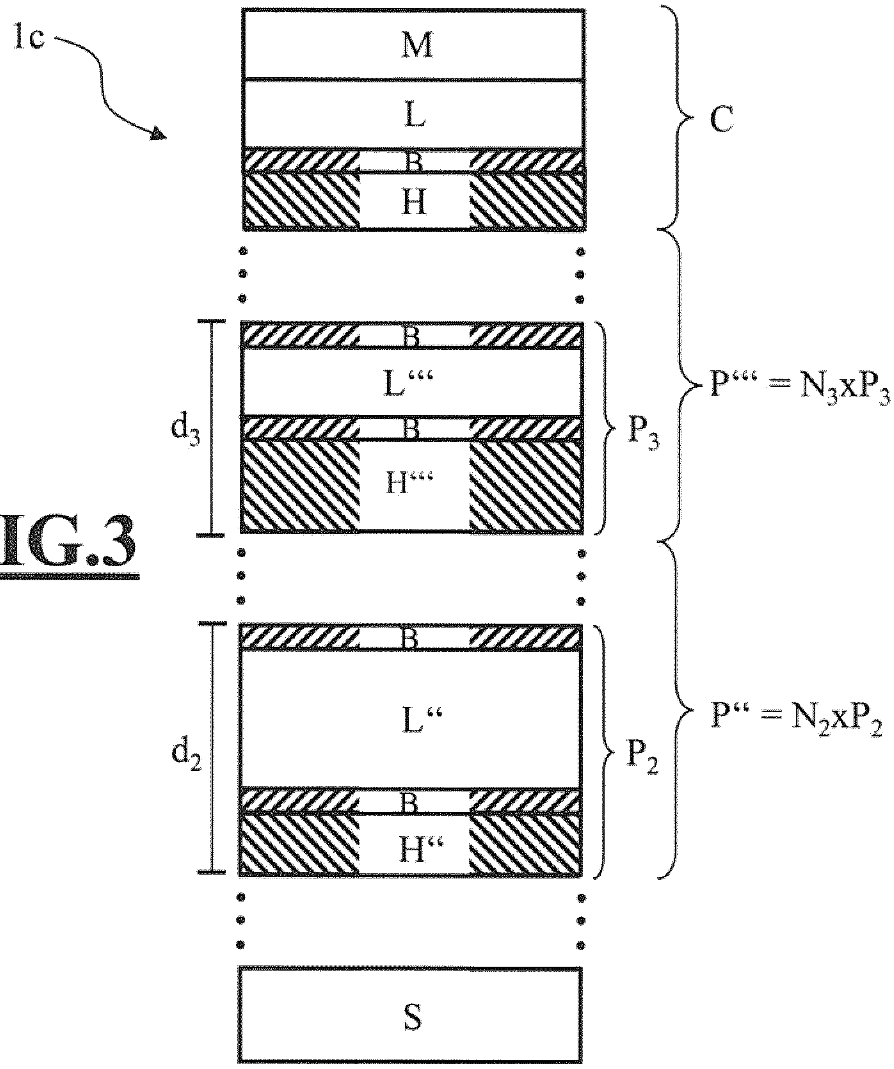
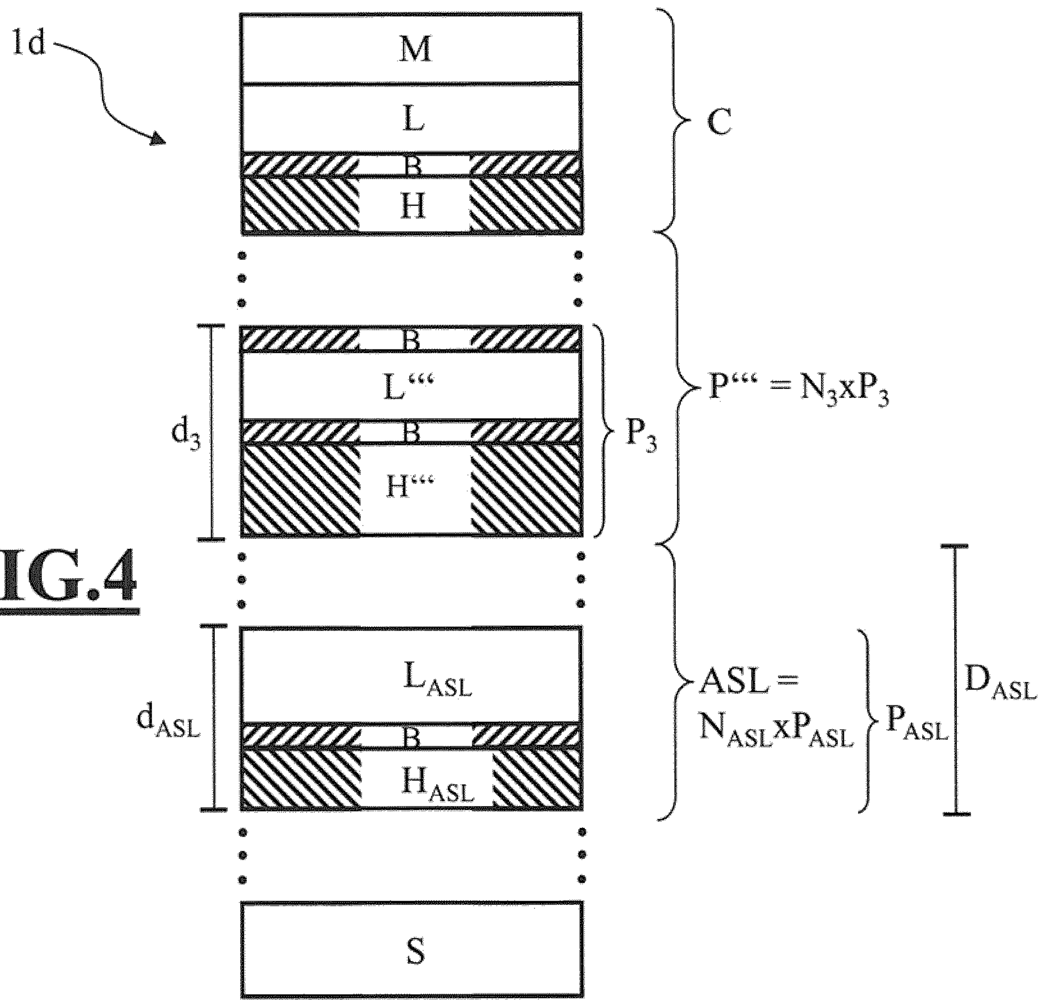


FIG.3



1d
M
L
B
H
C
B
L'''
B
H'''
d3
P3
P''' = N3xP3
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B
HASL
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ASL =
NASLxPASL
PASL
DASL
S

FIG.4

FIG.5

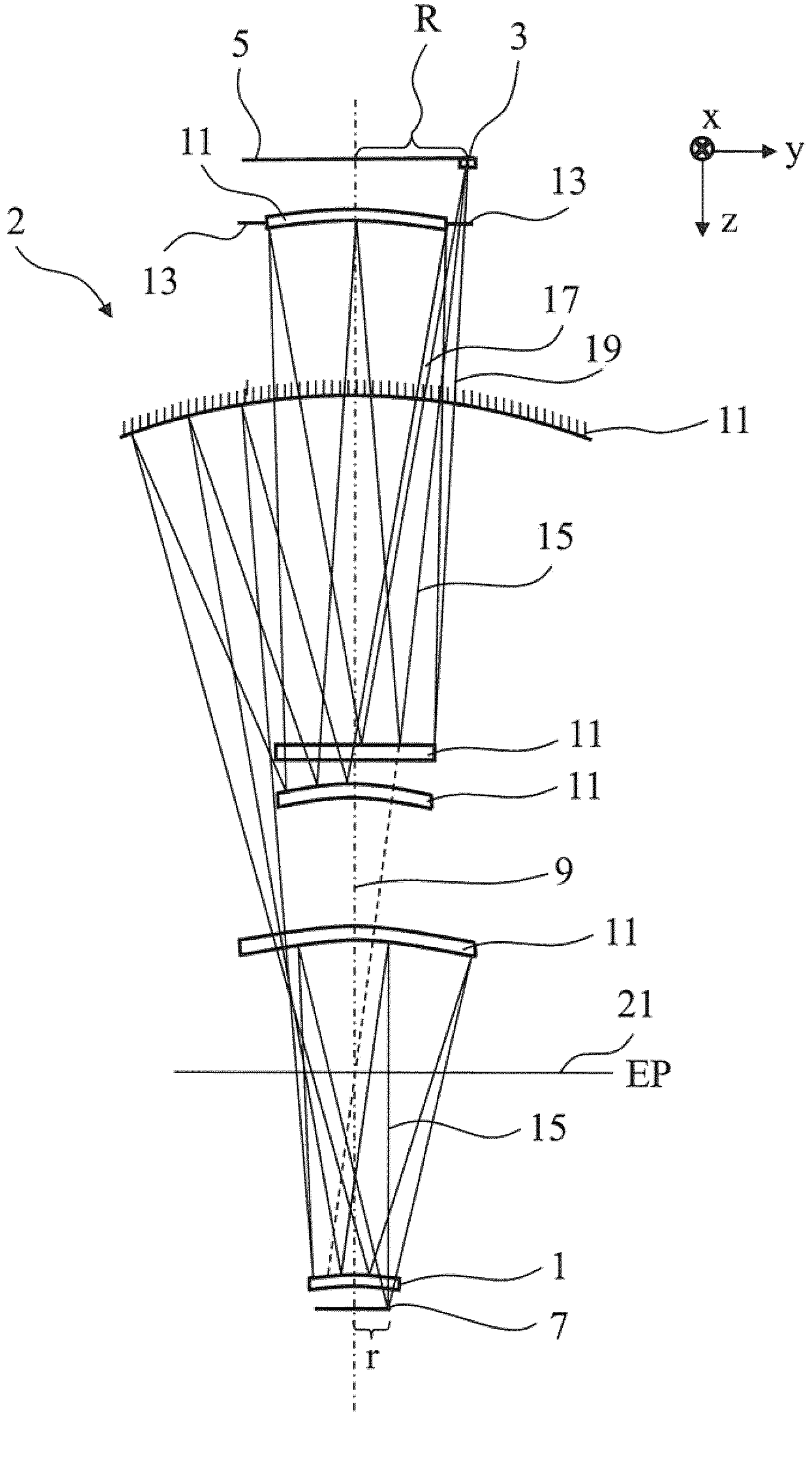


FIG.6

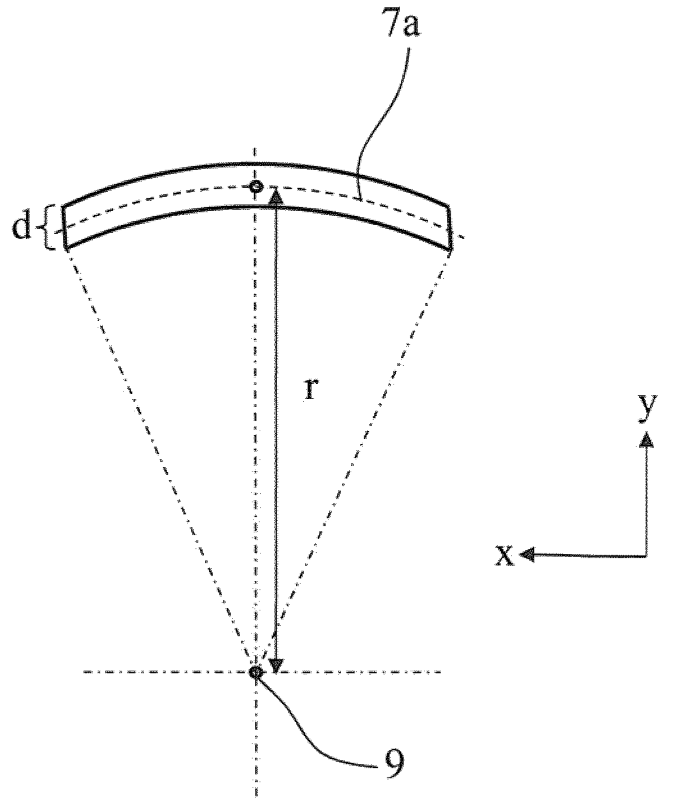
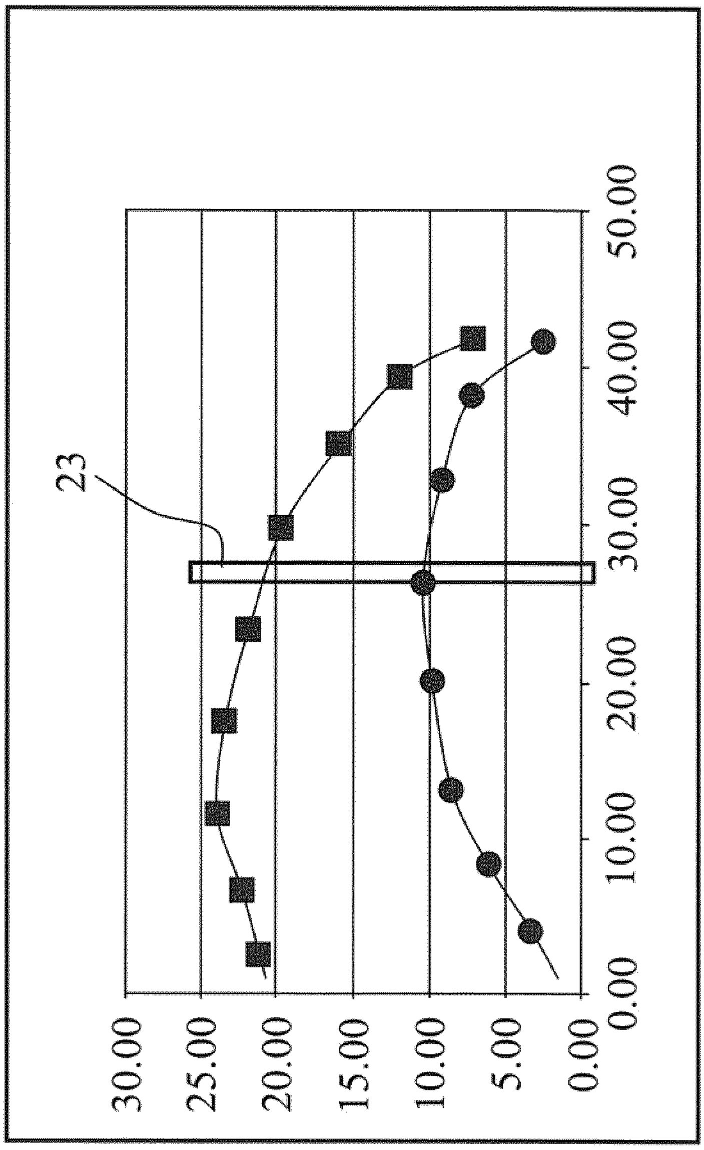


FIG.7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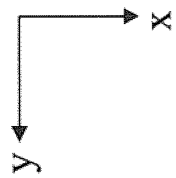
50.00



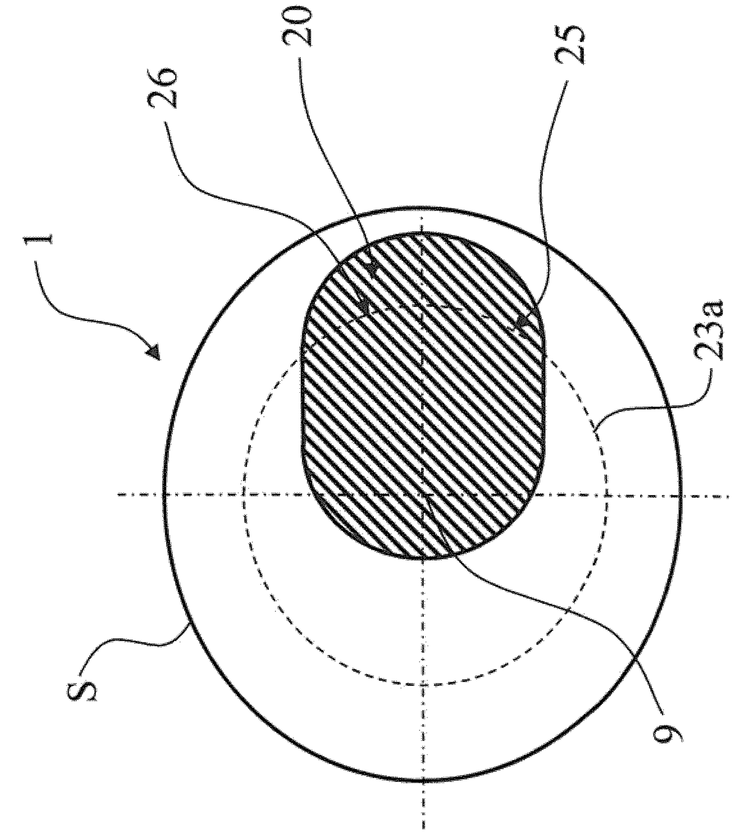


FIG.8

FIG.9

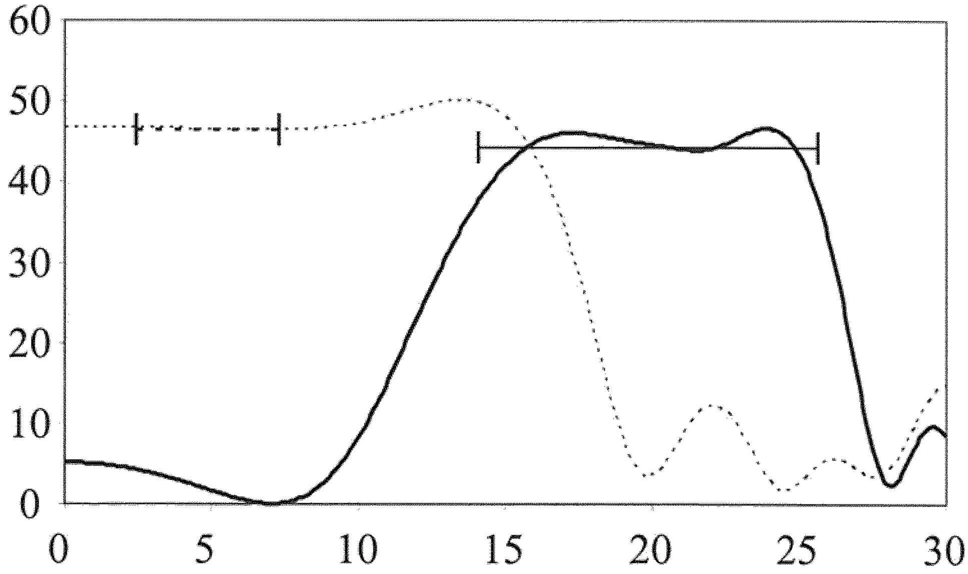

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FIG.10

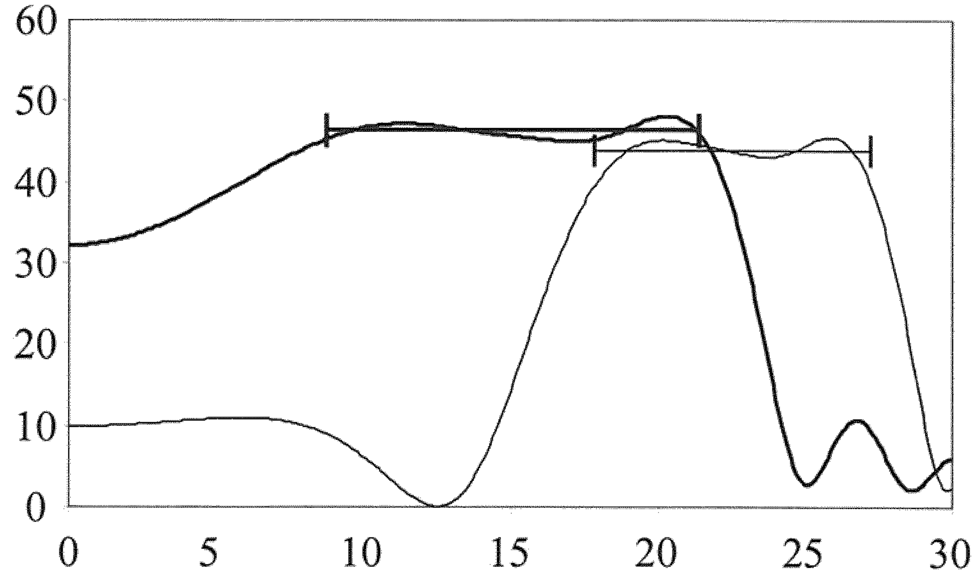
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FIG.11

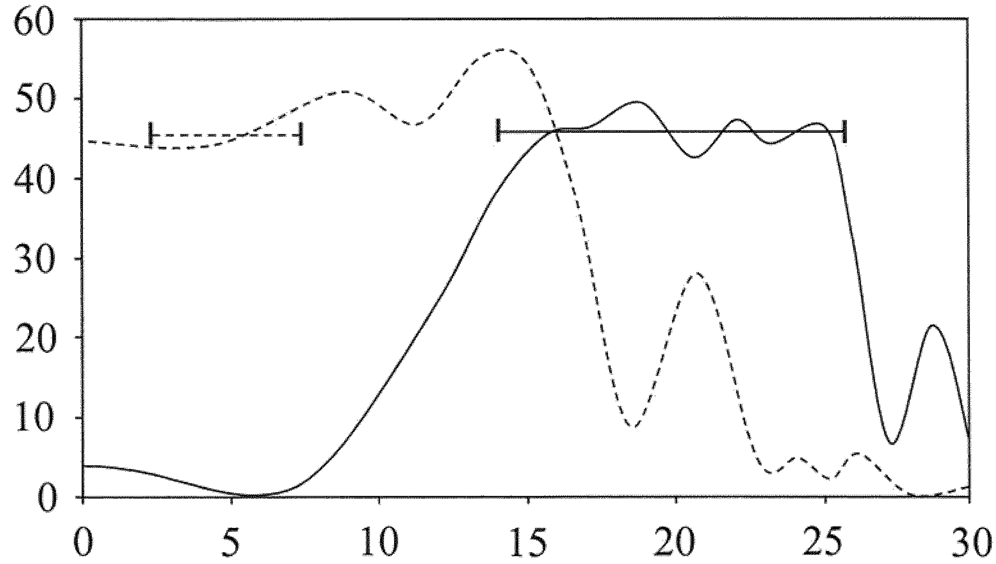
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FIG.12

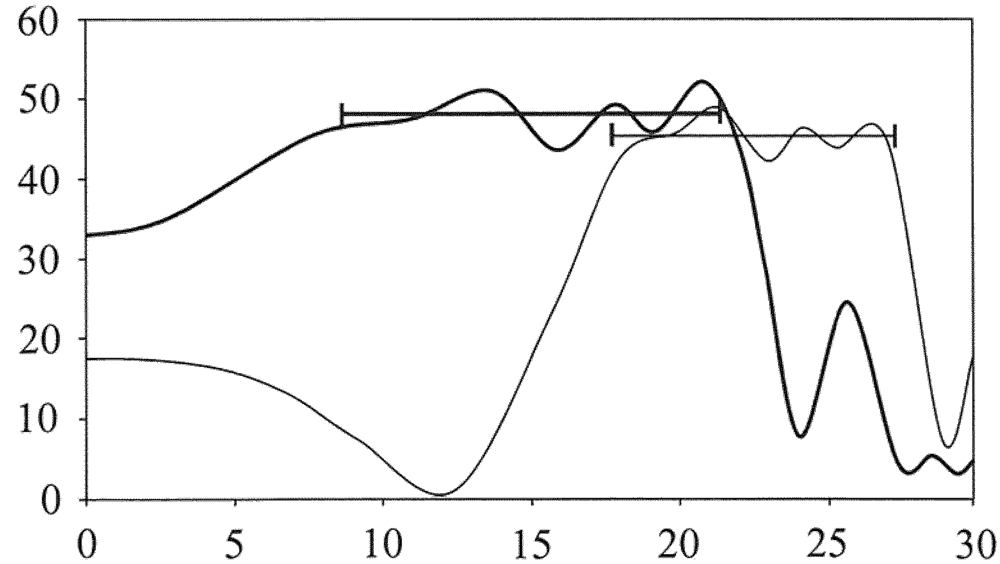
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FIG.13

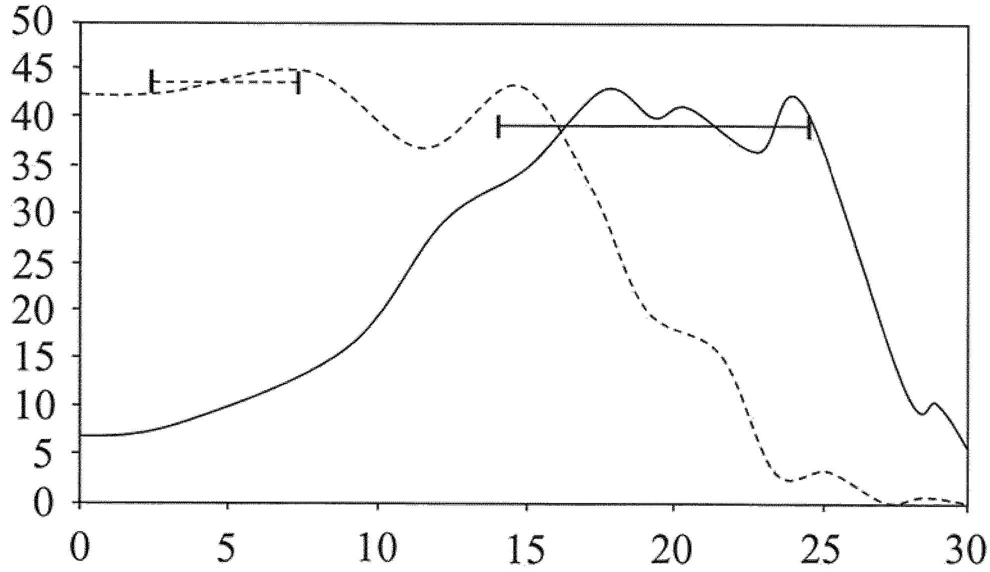
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FIG.14

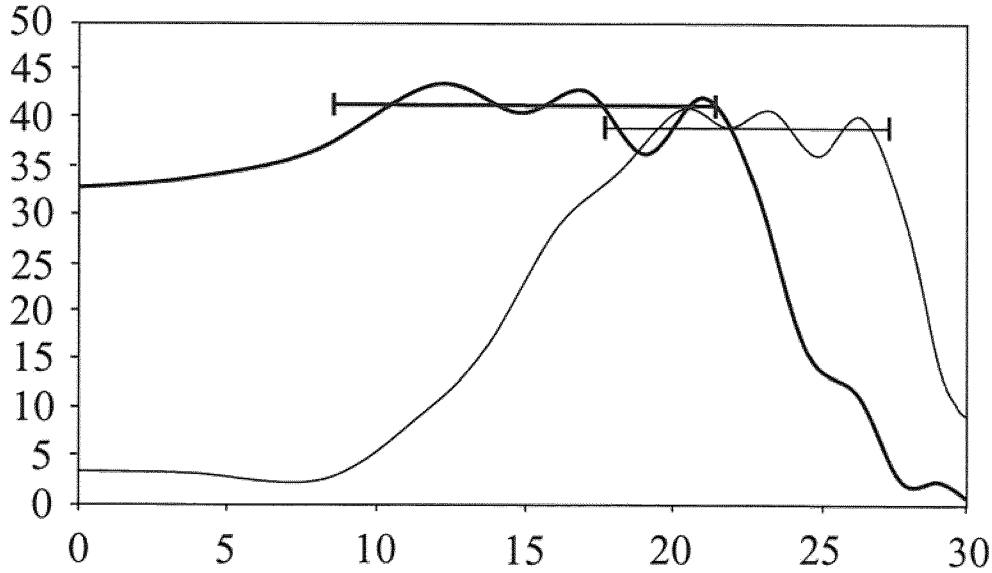
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FIG.15

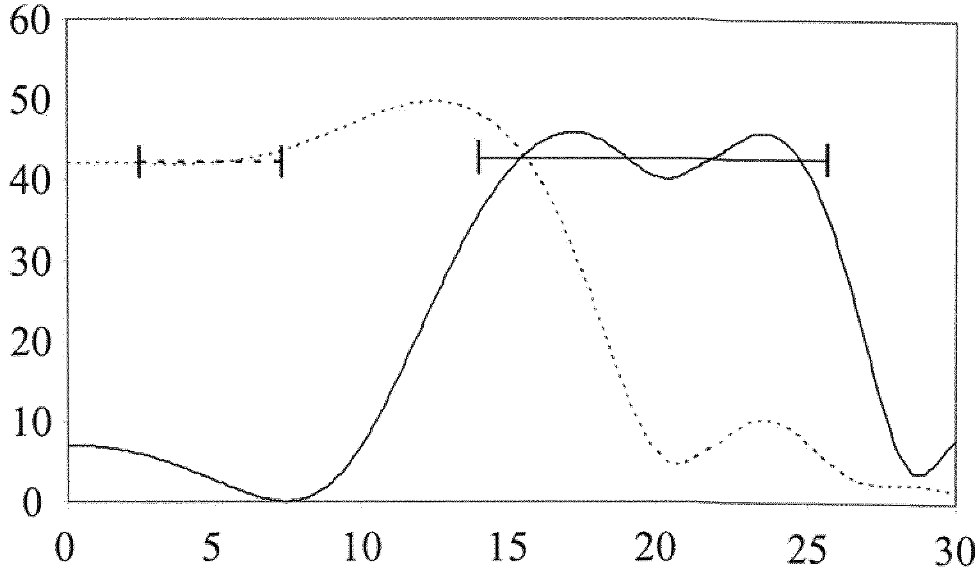
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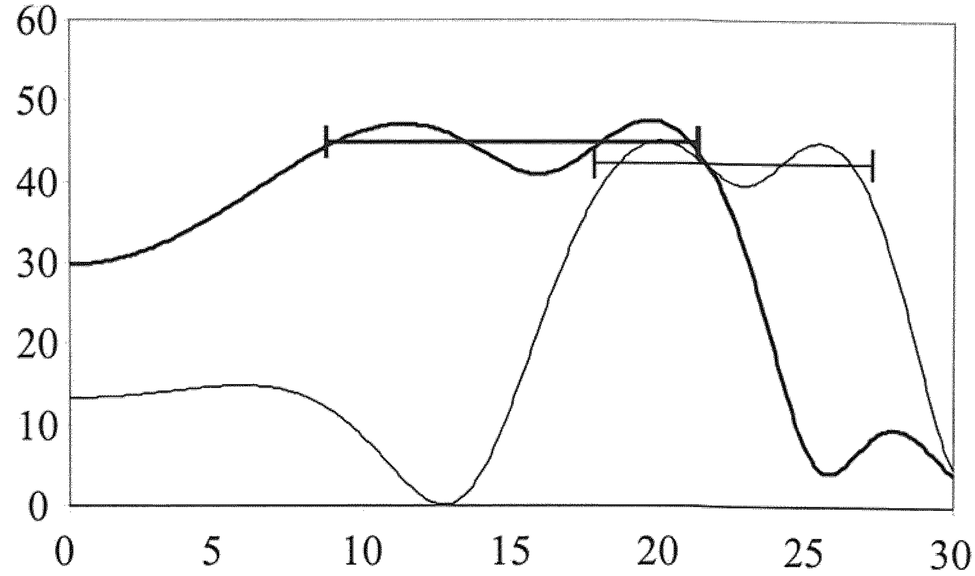
FIG.16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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/050573

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B17/06 G02B5/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G02B

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	MASAYUKI SHIRAISHI: "Effect of argon and non-argon ion impingement on the stress reduction of multilayers for extreme-ultraviolet lithography", PROCEEDINGS OF SPIE, vol. 4688, 1 January 2002 (2002-01-01), pages 516-526, XP55021266, ISSN: 0277-786X, DOI: 10.1117/12.472329 abstract Chapter I; page 517 page 518, paragraph 3.1 - page 521, last line ----- -/--	1 2-18

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

[ ] See patent family annex.

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

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 March 2012	05/04/2012

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

2

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	SASA BAJT ET AL: "Improved reflectance and stability of Mo-Si multilayers", OPTICAL ENGINEERING, vol. 41, no. 8, 1 January 2002 (2002-01-01), page 1797, XP55022439, ISSN: 0091-3286, DOI: 10.1117/1.1489426 Chapter 3: Interface-Engineered Multilayers Chapter 3.1: Experimental results figures 2-4 -----	2-18
A	WU BANQIU ET AL: "Extreme ultraviolet lithography: A review", JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY: PART B, AVS / AIP, MELVILLE, NEW YORK, NY, US, vol. 25, no. 6, 11 October 2007 (2007-10-11), pages 1743-1761, XP012105364, ISSN: 1071-1023, DOI: 10.1116/1.2794048 Chapter IV: Multilayer Coating; page 1748, right-hand column - page 1750, right-hand column figure 7 -----	1-18

2