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Declarations under Rule 4.17:

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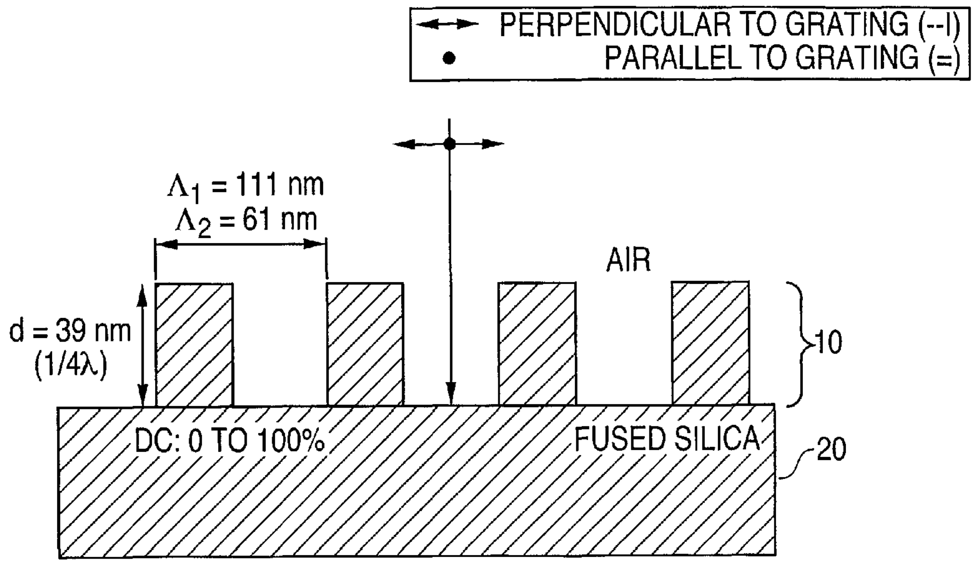
(54) **Title:** MONOLITHIC POLARIZATION CONTROLLED ANGLE DIFFUSERS AND ASSOCIATED METHODS



(57) **Abstract:** A monolithic polarization controlled angle diffuser includes a system having a first surface and a second surface, a controlled angle diffuser pattern for providing an angular distribution at an illumination plane, the controlled angle diffuser pattern being on one of the first and second surfaces of the substrate, and a polarizing pattern on one of the first and second surfaces of the substrate. The controlled angle diffuser pattern includes at least two controlled angle diffuser elements. Each controlled angle diffuser element outputs different angular distributions. The polarizing pattern includes at least two polarizing elements. Each polarizing element corresponds to a respective controlled angle diffuser element. The at least two polarizing elements output polarization's are rotated with respect to one another.

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MONOLITHIC POLARIZATION CONTROLLED ANGLE DIFFUSERS AND ASSOCIATED METHODS

1. Field of the Invention

[0001] The present invention is related to a polarization controlled angle diffuser and method of manufacturing such a polarization controlled angle diffuser. More particularly, the present invention is related to a monolithic polarization controlled angle diffuser and method of manufacturing such a polarization controlled angle diffuser.

2. Description of Related Art

[0002] Diffusers use diffractive elements to control an angle of illumination in a variety of systems, e.g., in a lithographic system. As a critical dimension in micro-lithography continues to be reduced, the effect of polarization on imaging performance in lithographic systems becomes more influential. If these effects are not accounted for, the imaging enhancement expected from using a higher numerical aperture (N.A.) lens system and/or immersion lithography may not be realized. If the polarization state of illumination could be optimized while controlling the angular distribution of the illumination, the adverse affects of the polarization may be minimized.

SUMMARY OF THE INVENTION

[0003] It is therefore a feature of the present invention to provide a polarization controlled angle diffuser and method of manufacturing such a polarization controlled angle diffuser, which substantially overcomes one or more of the problems noted above in connection with the related art.

[0004] It is a feature of the present invention to provide a polarization controlled angle diffuser that is monolithic. As used herein, "monolithic" is to mean that the elements of the controlled angle diffuser and the polarization control are each provided on a continuous surface. Thus, while the monolithic polarization controlled angle diffuser of the present invention may be realized on a single surface, it is not to be so limited, and the controlled angle diffuser elements and the polarization elements may be on different surfaces of a substrate or even on different substrates.

[0005] It is another feature of the present invention to provide a polarization controlled angle diffuser that maintains its efficiency.

[0006] It is yet another feature of the present invention to provide a polarization controlled angle diffuser that minimizes zero order light.

[0007] It is still another object of the present invention to provide a polarization controlled angle diffuser that may readily be interchanged with current diffusers.

[0008] It is yet another object of the present invention to provide a polarization controlled angle diffuser that may easily be manufactured.

[0009] At least one of the above and other features and advantages of the present invention may be realized by providing a monolithic polarizing controlled angle diffuser, including a system having at least two parallel, planar surfaces, a controlled angle diffuser pattern for providing an angular distribution at an illumination plane, the controlled angle diffuser pattern being on one of the at least two parallel surfaces, the controlled angle diffuser pattern including at least two controlled angle diffuser elements, each controlled diffuser element outputting different angular distributions, and a polarizing pattern on one of the at least two surfaces, the polarizing pattern including at least two polarizing elements, the at least two polarizing elements outputting polarizations rotated with respect to one another, each of the at least two polarizing elements corresponding to a respective one of the at least two controlled angle diffuser elements.

[0010] The system may include a substrate on which the polarizing pattern is formed. At least one of the at least two polarizing elements may be featureless. The polarizations of the at least two polarizing elements may be rotated by 90° with respect to one another.

[0011] The polarizing pattern may have a subwavelength structure. The polarizing pattern may have varied etch depths. The etch depth d may be determined by the equation:

$$d=\lambda/2\Delta n$$

where λ is a wavelength at which the diffuser is to be used and Δn is a difference between refractive indices of the substrate for orthogonal polarization states of the polarizing pattern. A period of the polarizing pattern may be selected to maximize Δn.

[0012] The substrate on which the polarizing pattern is formed may be birfringent. An etch depth may be determined in accordance with a difference between an ordinary refractive index and an extraordinary refractive index of the substrate. The period of the polarizing pattern may be selected to equal a size of one of the at least two controlled angle diffuser elements.

[0013] The controlled angle diffuser elements may be diffractive elements. The controlled angle diffuser elements may on the same substrate as the polarizing elements, either on the same side of the substrate or on opposite sides of the substrate. The controlled angle diffuser pattern may include an alternating array of x dipoles and y dipoles.

[0014] At least one of the above and other features and advantages of the present invention may be realized by providing a method of making a monolithic polarizing controlled angle diffuser including creating a controlled angle diffuser design having at least two controlled angle diffuser elements outputting different angular distributions, creating a polarizing pattern having at least two polarizing elements, the at least two polarizing elements outputting polarizations rotated with respect to one another, transferring the controlled angle diffuser design to a surface of a system having at least two surfaces, and transferring the polarizing pattern to one of the at least two surfaces, each of the at least two polarizing elements corresponding to a respective one of the at least two controlled angle diffuser elements.

[0015] The transferring the polarizing pattern may include etching a substrate of the system to an etch depth d determined by the equation:

$$d=\lambda/2\Delta n$$

where λ is a wavelength at which the diffuser is to be used and Δn is a different between refractive indices of the substrate for orthogonal polarization states of the polarizing pattern. The period of the polarizing pattern may be selected to maximize Δn.

[0016] The transferring the polarizing pattern may include etching a birefringent substrate to an etch depth determined in accordance with a difference between an ordinary refractive index and an extraordinary refractive index of the birefringent substrate. The period of the polarizing elements is selected to equal a size of one of the at least two controlled angle diffuser elements.

[0017] The at least two surfaces may be on a single substrate. The polarizing elements and the controlled angle diffuser elements may be on the same side or on opposite sides of the substrate. The transferring of the polarizing pattern may occur before transferring the controlled angle diffuser design.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The above and other features and advantages of the present invention will become more apparent to those of ordinary skill in the art by describing in detail exemplary embodiments thereof with reference to the attached drawings in which:

[0019] FIG. 1 illustrates a cross-sectional view of a model of a pattern in accordance with an embodiment of the present invention;

[0020] FIG. 2 is a plot of duty cycle versus index of refraction for both polarizations and both grating periods for the model of FIG. 1;

[0021] FIG. 3 illustrates a cross-sectional view of a half wave plate in accordance with an embodiment of the present invention;

[0022] FIG. 4 illustrates a schematic cross-sectional view of a half-wave plate in accordance with an embodiment of the present invention;

[0023] FIG. 5 illustrates a schematic top view of outputs of individual portions of an example of a controlled angle diffuser pattern;

[0024] FIG. 6 illustrates an output of the controlled angle diffuser pattern of FIG. 5 in conjunction with a polarizing pattern of an embodiment of the present invention; and

[0025] FIG. 7 illustrates a top view of the controlled angle diffuser pattern providing the outputs of FIG. 5.

DETAILED DESCRIPTION OF THE INVENTION

[0026] The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which exemplary embodiments of the invention are shown. The invention may, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the figures, the dimensions of layers and regions are exaggerated for clarity of illustration. Like reference numerals refer to like elements throughout.

[0027] In accordance with the present invention, the polarization of the diffuser is controlled in accordance with an etch depth of the material. This polarization control pattern may be on the same surface, on an opposite surface of the same substrate or even on different surfaces as the controlled angle diffuser pattern. The surfaces on which the controlled angle diffuser and the polarization pattern are to be formed may be parallel and planar to one another. Examples of appropriate controlled angle diffusers may be found in U.S. Patent No. 5,850,300, the entire contents of which are herein incorporated by reference for all purposes. If the polarization control pattern is on an opposite side of a substrate from the controlled angle diffuser pattern, then front to back alignment will be needed.

[0028] The polarization control may be realized in two manners. First, if the substrate is a non-birefringent material, e.g., fused silica, then a sub-wavelength structure will be designed to change or rotate the polarization state. A model for creating such a structure is shown in FIG. 1. The birefringent curves from this structure are shown in FIG. 2. A structure for a half-wave plate created based on this model is shown in FIG. 3.

[0029] In FIG. 1, the reflection of a diffractive pattern 10, here a binary pattern, in a fused silica substrate 20 was modeled for both parallel and perpendicular polarizations. A duty cycle of this pattern was varied from 0 to 100% at 1% increments for both polarizations. A period of this pattern was checked for 0.9 and 0.5 of the wavelength of interested in the substrate material. When the wavelength of interest is in the deep ultraviolet (DUV), e.g., 193 nm, and fused silica, have an index of refraction of about 1.56, is the substrate material, these wavelengths are about 111 nm and 61 nm, respectively. As can be seen from FIG. 2, the greatest birefringence occurs at about a 44% duty cycle using 111 nm as the grating period. Thus, these parameters are selected for creating a half-wave plate 30 shown in FIG. 3. The half-wave plate 30 includes a pattern 32 of depth d, a period of 111 nm and a duty cycle of 44%. For the half-wave plate 30, the depth d is set to be $\lambda/(2\Delta n)$, where Δn is the difference in refractive indices for the different polarization states. In fused silica, for the period of 111 nm, this difference is 0.16.

[0030] If the material of the substrate is birefringent, e.g., crystal quartz or calcium fluoride (CaF), such patterning is not needed. Instead, this material only needs to be selectively etched for every other part to an appropriate depth to realize the desired polarization rotation. No high resolution patterns are needed, as with the sub-wavelength pattern of the first embodiment. An example of this is shown in FIG. 4, in which a half-wave plate 40 includes etched portions 42 and unetched portions 44 to provide the different rotations. Thus, the unetched portions 44 may be featureless. While no pattern is required, the etch depth to realize the desired rotations are typically an order of magnitude higher than for the patterned approach, e.g., on the order of several microns. The etch depth is determined in accordance with the refractive index difference between the ordinary and extraordinary direction in the birefringent material.

[0031] As a specific example, polarized quadrupole illumination may be realized in accordance with an embodiment of the present invention. First, a dipole illuminator would be designed. Such a dipole illuminator may be designed using a diffractive approach, as set forth in U.S. Patent No. 5,850,300. As shown in FIG. 5, an output of each cell of an array of cells 50 includes a plurality of x dipole illumination cells 52, which are oriented along the x-axis, and a plurality of y dipole illumination cells 54, which are oriented along the y-axis. These x dipole illumination cells 52 and y dipole illumination cells 54 are arranged in a two-dimensional array of alternating x and y orientations.

[0032] If the substrate is not a birefringent material, and the input light is to be polarized, then a polarizing pattern rotating the polarization may be provided for every other illumination cell, i.e., all dipole illumination cells of the same orientation. The polarizing pattern would be created using the design technique of FIG. 3 and then transferred to a surface and aligned with the controlled angle diffuser pattern. Of course, if the incoming light is not polarized, the polarizing pattern may include a polarization element for each dipole illumination cell. If the substrate is birefringent, every other illumination cell, i.e., all dipole illumination cells of the same orientation, would have an etched portion as taught in connection with FIG. 4.

[0033] The composite output of a substrate having this controlled angle diffuser pattern therein would be a quadrupole 60 as shown in FIG. 6, without the arrows indicating polarization orientation in the quadrupole 60. In the particular example shown in FIG. 6, the polarization is rotated by 90° in the quadrupole 60. An x dipole illumination 62 and a y dipole illumination 64 have orthogonal polarizations, as indicated by the arrows therein.

[0034] An example of an actual mask 70 used to create the illumination shown in FIGS. 5 and 6 is illustrated in FIG. 7. Here, the mask 70 includes a plurality of x dipole illuminators 72, which are oriented along the x-axis, and a plurality of y dipole illuminators 74, which are oriented along the y-axis. Each dipole illuminator 72, 74 of this array would have the desired dimensions of the conventional individual elements, e.g., about 2 mm.

[0035] The controlled angle diffuser pattern of the mask 70 may then be transferred to a substrate, e.g., by lithography or replication, followed by etching. The polarization pattern in accordance with either embodiment of the present invention may be transferred to either the same or the opposite surface of the substrate, e.g., by lithography or replication, followed by etching. Alternatively, the transfer of the polarizing pattern may be transferred to another substrate. These substrates may be secured together. This securing may occur on a wafer level, after which the secured wafers may be vertically separated to form dies including at least two controlled angle diffuser elements and at least two polarizing elements. Each of the two controlled diffuser element outputs different angular distributions. Each polarizing element corresponds to a respective controlled angle diffuser element. Each of the two polarizing elements outputs polarizations rotated with respect to one another.

[0036] Exemplary embodiments of the present invention have been disclosed herein and, although specific terms are employed, they are used and are to be interpreted in a generic and descriptive sense only and not for purpose of limitation. For example, the polarizing pattern could be transferred to the substrate before the controlled angle diffuser pattern. Accordingly, it will be understood by those of ordinary skill in the art that various changes in form and details may be made without departing from the spirit and scope of the present invention as set forth in the following claims.

What is claimed is:

1. A monolithic polarizing controlled angle diffuser, comprising:

a system having at least two parallel, planar surfaces:

a controlled angle diffuser pattern for providing an angular distribution at an illumination plane, the controlled angle diffuser pattern being on one of the at least two parallel surfaces, the controlled angle diffuser pattern including at least two controlled angle diffuser elements, each controlled diffuser element outputting different angular distributions; and

a polarizing pattern on one of the at least two surfaces, the polarizing pattern including at least two polarizing elements, each polarizing element corresponding to a respective controlled angle diffuser element, the at least two polarizing elements outputting polarizations rotated with respect to one another.

2. The monolithic polarizing controlled angle diffuser as claimed in claim 1, wherein the system comprises a substrate on which the polarizing pattern is formed.

3. The monolithic polarizing controlled angle diffuser as claimed in claim 2, wherein the polarizing pattern comprises a subwavelength structure.

4. The monolithic polarizing controlled angle diffuser as claimed in claim 2, wherein the polarizing pattern comprises varied etch depths.

5. The monolithic polarizing controlled angle diffuser as claimed in claim 3, wherein an etch depth d is determined by the equation:

$d=\lambda/2\Delta n$

where λ is a wavelength at which the diffuser is to be used and Δn is a difference between refractive indices of the substrate for orthogonal polarization states of the polarizing pattern.

6. The monolithic polarizing controlled angle diffuser as claimed in claim 5, wherein a period of the polarizing pattern is selected to maximize Δn.

7. The monolithic polarizing controlled angle diffuser as claimed in claim 4, wherein an etch depth is determined in accordance with a difference between an ordinary refractive index and an extraordinary refractive index of the substrate.

8. The monolithic polarizing controlled angle diffuser as claimed in claim 7, wherein a period of the polarizing pattern is selected to equal a size of one of the at least two controlled angle diffuser elements.

9. The monolithic polarizing controlled angle diffuser as claimed in claim 1, wherein controlled angle diffuser elements are diffractive elements.

10. The monolithic polarizing controlled angle diffuser as claimed in claim 2, wherein the substrate is birefringent.

11. The monolithic polarizing controlled angle diffuser as claimed in claim 2, wherein the controlled angle diffuser elements are on the substrate.

12. The monolithic polarizing controlled angle diffuser as claimed in claim 11, wherein the polarizing pattern and the controlled angle diffuser elements are on a same side of the substrate.

13. The monolithic polarizing controlled angle diffuser as claimed in claim 11, wherein the polarizing pattern and the controlled angle diffuser elements are on different sides of the substrate.

14. The monolithic polarizing controlled angle diffuser as claimed in claim 1, wherein at least one of the at least two polarizing elements is featureless.

15. The monolithic polarizing controlled angle diffuser as claimed in claim 1, wherein the polarizations of the at least two polarizing elements are rotated by 90° with respect to one another.

16. The monolithic polarizing controlled angle diffuser as claimed in claim 1, wherein the controlled angle diffuser pattern comprises an alternating array of x dipoles and y dipoles.

17. A method of making a monolithic polarizing controlled angle diffuser comprising:

creating a controlled angle diffuser design having at least two controlled angle diffuser elements outputting different angular distributions;

creating a polarizing pattern having at least two polarizing elements, the at least two polarizing elements outputting polarizations rotated with respect to one another;

transferring the controlled angle diffuser design to a surface of a system having at least two surfaces; and

transferring the polarizing pattern to one of the at least two surfaces, each of the at least two polarizing elements corresponding to a respective one of the at least two controlled angle diffuser elements.

18. The method as claimed in claim 17, wherein transferring the polarizing pattern includes etching a substrate of the system to an etch depth d determined by the equation:

$d=\lambda/2\Delta n$

where λ is a wavelength at which the diffuser is to be used and Δn is a different between refractive indices of the substrate for orthogonal polarization states of the polarizing pattern.

19. The method as claimed in claim 18, further comprising selecting a period of the polarizing pattern to maximize Δn.

20. The method as claimed in claim 17, wherein transferring the polarizing pattern includes etching a birefringent substrate to an etch depth determined in accordance with a difference between an ordinary refractive index and an extraordinary refractive index of the birefringent substrate.

21. The method as claimed in claim 20, wherein a period of the polarizing elements is selected to equal a size of one of the at least two controlled angle diffuser elements.

22. The method as claimed in claim 17, wherein the at least two surfaces are on a substrate.

23. The method as claimed in claim 22, wherein the polarizing elements and the controlled angle diffuser elements are on a same side of the substrate.

24. The method as claimed in claim 22, wherein the polarizing elements and the controlled angle diffuser elements are on different sides of the substrate.

25. The method as claimed in claim 22, wherein transferring the polarizing pattern occurs before transferring the controlled angle diffuser design.

FIG. 1

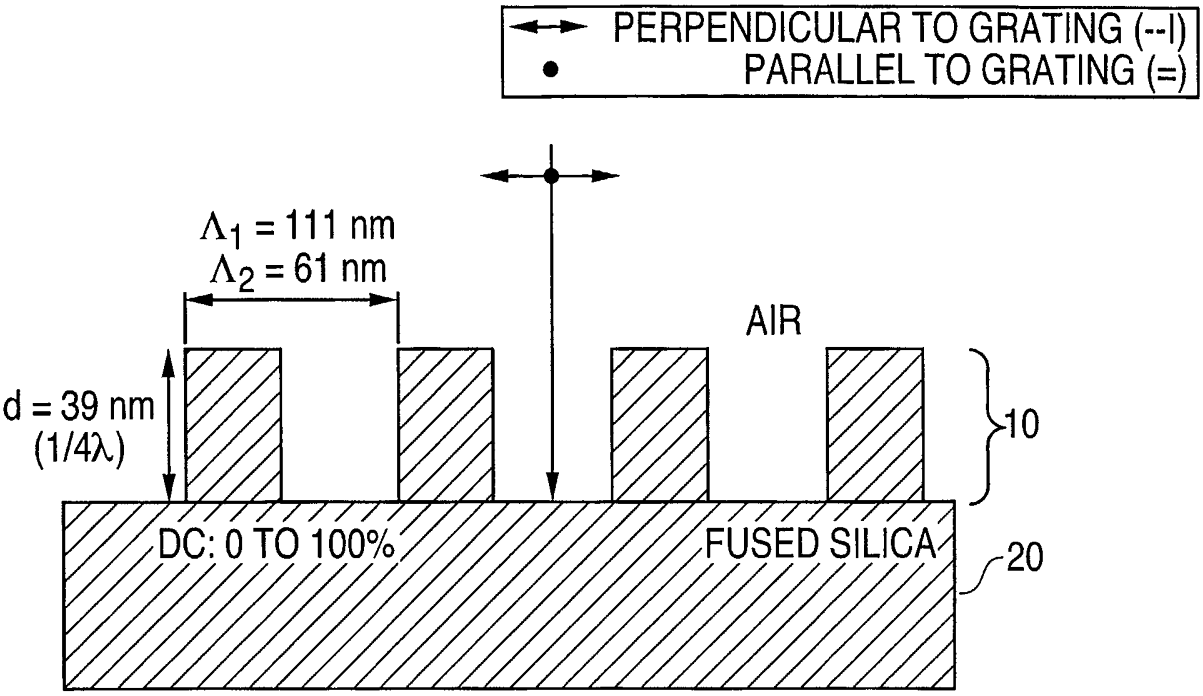

PERPENDICULAR TO GRATING (--I)
PARALLEL TO GRATING (=)
Λ1 = 111 nm
Λ2 = 61 nm
AIR
d = 39 nm
(1/4λ)
10
DC: 0 TO 100%
FUSED SILICA
20

FIG. 2

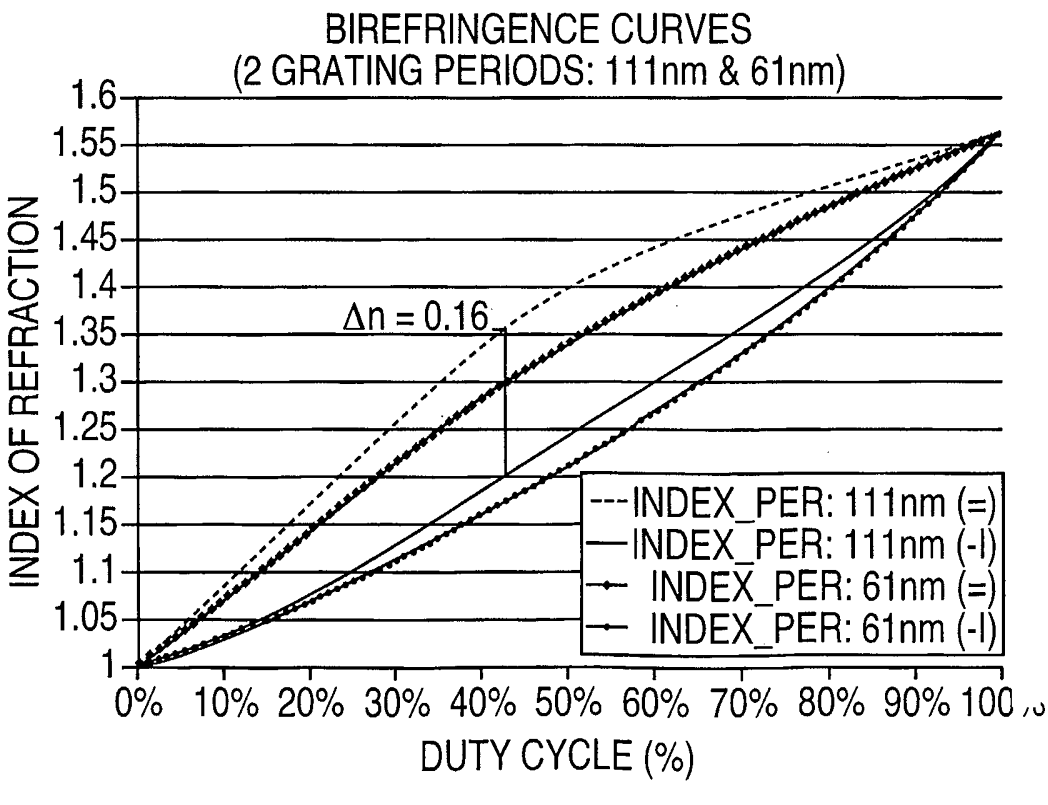
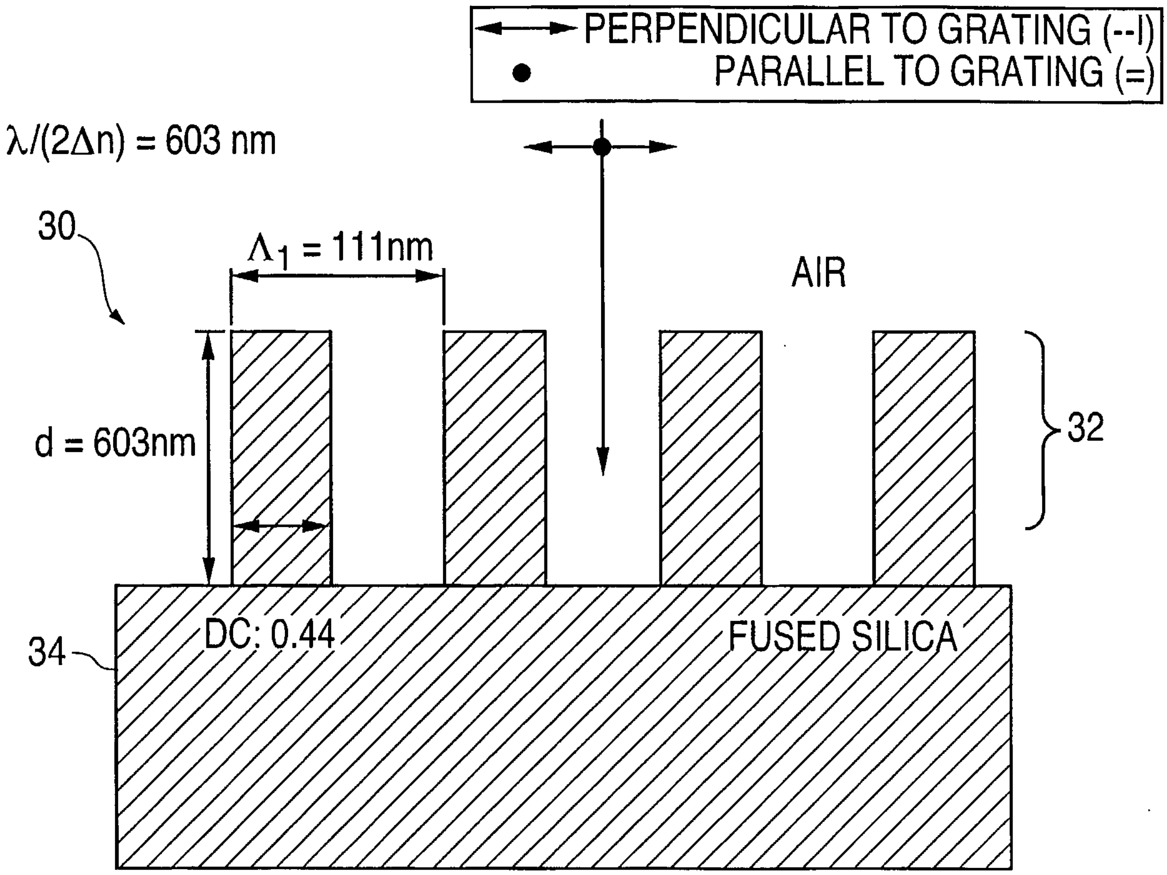

BIREFRINGENCE CURVES
(2 GRATING PERIODS: 111nm & 61nm)
INDEX OF REFRACTION
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
Δn = 0.16
INDEX_PER: 111nm (=)
INDEX_PER: 111nm (-I)
INDEX_PER: 61nm (=)
INDEX_PER: 61nm (-I)
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
DUTY CYCLE (%)

FIG. 3


PERPENDICULAR TO GRATING (--I)
PARALLEL TO GRATING (=)
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30
Λ1 = 111nm
AIR
d = 603nm
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34
DC: 0.44
FUSED SILICA

FIG. 4

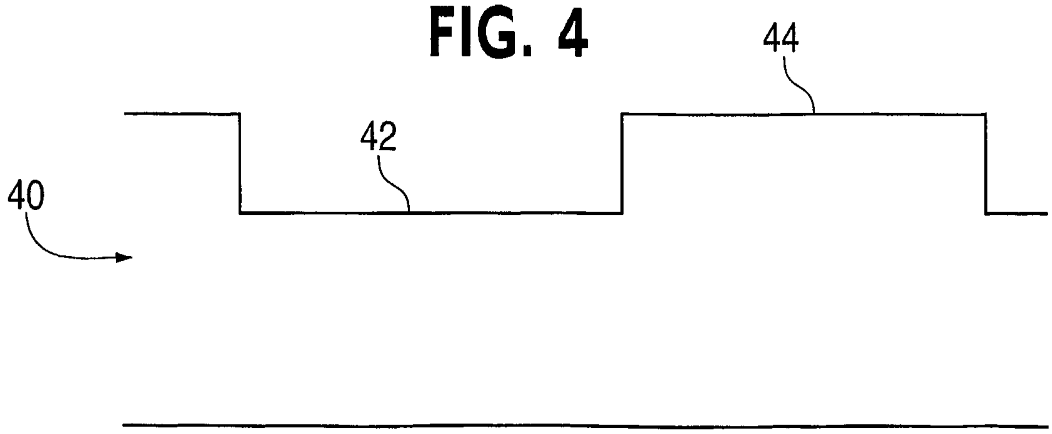
44
42
40

FIG. 5

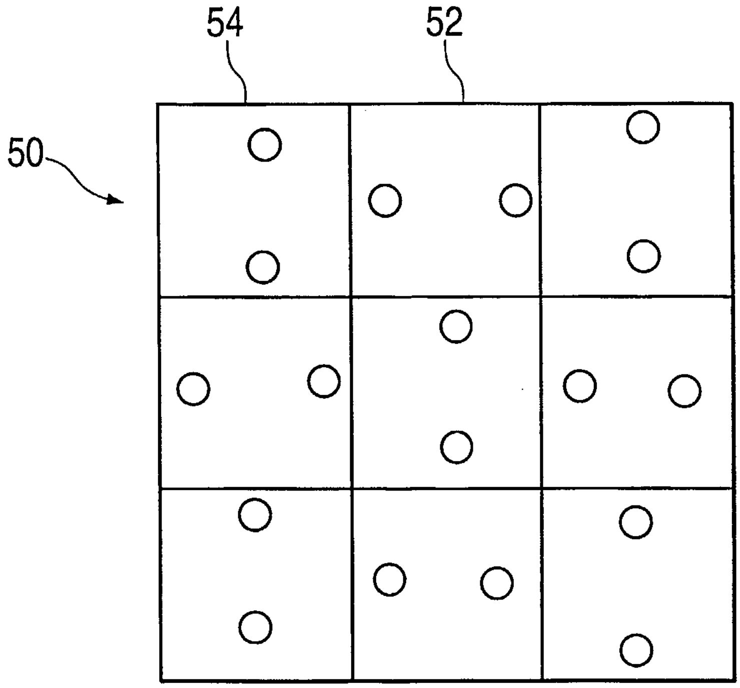

FIG. 6

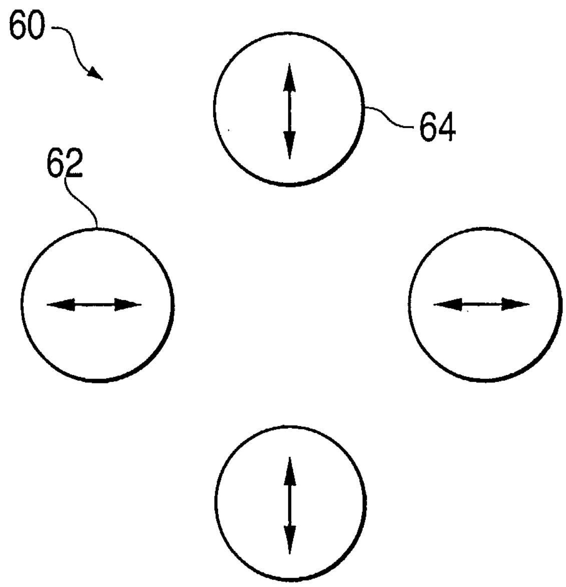

FIG. 7