

Optical Grating

FIELD OF INVENTION

5 The invention relates generally to an optical grating.

BACKGROUND

10 It has been demonstrated that nanowire grid polarizers comprising a metal grating, traditionally fabricated on glass substrates, can also be fabricated on plastic films. Compared to glass, plastic is cheap, allows fabrication over a large area with high throughput and finds use in applications which need to be lightweight and flexible (e.g. printed electronics, wearable electronics).

15 For example, the publications "Large flexible nanowire grid visible polarizer made by nanoimprint lithography" (by Chen, L., Wang, J. J., Walters, F., Deng, X. G., Buonanno, M., Tai, S. & Liu, X. M. (2007) Applied Physics Letters, 90) and "Direct imprinting on a polycarbonate substrate with a compressed air press for polarizer applications" (by Lin, C. H., Lin, H. H., Chen, W. Y. & Cheng, T. C. (2011), Microelectronic Engineering, 88, 2026-2029) disclose optical element structures that
20 have non-flat spectral response of light over a visible wavelength range. This non-flat spectral response results in an undesirable reddish artifact for plastic nanowire grid polarizer operating in transmission mode. A further discussion on the operating principle of a nanowire grid polarizer is described further below, with reference to Figure 10A.

25 A need therefore exists to provide an optical element and its method of fabrication that can address the undesirable attributes, such as the associated reddish artifact, of optical element structure fabricated from existing plastic nanowire grid polarizers.

30 SUMMARY

 According to one aspect of the invention, there is provided an optical grating comprising a substrate comprising a plurality of protrusions with a space in between any two adjacent protrusions; and a cap provided on at least one of the plurality of
35 protrusions at an end that is furthest from the substrate, wherein the cap has a higher degree of optical attenuation compared to the substrate material and wherein the

combination of each protrusion and the respective cap thereon has a generally symmetric cross-sectional profile.

According to another aspect of the invention, there is provided a method of forming an optical grating, the method comprising providing a substrate; forming a plurality of protrusions on the substrate with a space in between any two adjacent protrusions, providing a cap on at least one of the plurality of protrusions at an end that is furthest from the substrate, wherein the cap has a higher degree of optical attenuation compared to the substrate material and wherein the combination of each protrusion and the respective cap thereon has a generally symmetric cross-sectional profile.

BRIEF DESCRIPTION OF THE DRAWINGS

Example embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention, in which:

Figure 1A shows the cross-sectional structure of an optical grating according to a first embodiment.

Figure 1B shows the cross-sectional structure of an optical grating having a non-symmetric cross-sectional profile.

Figure 2 shows the cross-sectional structure of an optical grating according to a preferred embodiment.

Figure 3 shows a flowchart of a method to fabricate an optical grating according to the first embodiment shown in Figure 2.

Figures 4A to 4C show an exemplary process to fabricate the preferred embodiment of an optical grating directly onto a substrate, with Figure 4D providing a schematic of the fabricated optical grating.

Figure 5A shows the cross-section of a structure of an optical grating fabricated using the method described with respect to Figures 4A to 4C.

Figures 5B and 5C show the cross-section of a conventional optical grating.

Figure 6A shows a plot of the measured transmission spectrum of TM polarized light (T_{TM}) against the visible light wavelength range from 400nm to 800nm for a fabricated optical grating in accordance to the preferred embodiment and the conventional optical grating shown in Figures 5A and 5C respectively.

Figure 6B shows a plot of the contrast ratio between transmitted TE polarized light and transmitted TM polarized light (T_{TM} / T_{TE}) against the visible light wavelength range from 400nm to 800nm for a fabricated optical grating in accordance to the preferred embodiment and a conventional optical grating.

5 Figure 7A shows a picture of a document viewed through an optical film fabricated from the structure of Figure 5A.

Figure 7B shows a picture of a document viewed through an optical film fabricated from the conventional nanowire grid polarizer shown in Figure 5C.

Figure 8 shows the trend of sub-pixel size between 2003 and 2012.

10 Figure 9A shows simulation results of a plot of the measured transmission spectrum of TM polarized light (T_{TM}) against the light wavelength range from 450nm to 650nm for an optical grating in accordance to the preferred embodiment.

Figure 9B shows simulation results of a plot of the contrast ratio between transmitted TE polarized light and transmitted TM polarized light (T_{TM} / T_{TE}) against the light wavelength range from 450nm to 650nm for an optical grating in accordance to the preferred embodiment.

Figures 10A and 10B each respectively illustrates the operating principle of a nanowire grid polarizer and a parallax barrier.

20 DEFINITIONS

The following provides sample, but not exhaustive, definitions for expressions used throughout various embodiments disclosed herein.

The phrase "optical grating" may mean an optical element which acts upon light passing through the optical element. Examples of optical elements include lenses, mirrors, prisms, nanowire grid polarizers and parallax barriers, whereby various embodiments of the optical grating disclosed herein function either as a nanowire grid polarizer or a parallax barrier. Accordingly, the phrases "optical grating" and "optical element" may be used interchangeably throughout the entire specification.

The operating principle of a nanowire grid polarizer and a parallax barrier is described with reference to Figures 10A and 10B respectively. Figure 10A shows a nanowire grid polarizer 1000. The nanowire grid polarizer 1000 has sub-wavelength metal gratings 1004 on a transparent substrate 1002 (e.g. glass, plastics). The submicron size metal gratings 1004 provide a series of alternate opaque and transparent slits. In principle, the optical characteristics of the polarizer 1000 enables incident light with polarization parallel to the metal grating

(TE-polarized light, denoted TE) to be reflected (denoted R_{TE}) with little amount of this incident TE-polarized light transmitted through the polarizer (the transmitted TE-polarized light is denoted T_{TE}), while enabling the incident light with perpendicular polarization (TM-polarized light, denoted TM) to be transmitted through the polarizer (the transmitted TM-polarized light is denoted T_{TM}). The spectra of T_{TM} and T_{TE} of the polarizer 1000 can be measured using a UV-vis Microspectrophotometer (such as "CRAIC QDI 2010") across the visible wavelength range from 400nm to 800nm. A contrast ratio is calculated from the ratio of (T_{TM}/T_{TE}). Transmission spectrum (T_{TM}) and the contrast ratio (T_{TM} / T_{TE}) are the two main optical performance parameters of polarizers. Figure 10B shows a system 1050 for creating a parallax barrier. The parallax barrier is created by placing an optical element 1040 in front of an image source (such as a liquid crystal display 1054), so that each eye 1042 sees a different sets of pixels through parallax brought about by the optical element 1040, thereby creating a sense of depth required for 3D imaging. The optical element 1040 provides a series of alternate opaque and transparent slits of micron-size gratings.

The term "protrusion" may mean a structure that extends from a surface of a substrate. In various embodiments, where the optical grating is referred to as an optical element, the term "grating" may be used to refer to the "protrusion". Accordingly, the terms "grating" and "protrusion" may be used interchangeably throughout the entire specification.

The phrase "cross-sectional arc profile" is to be understood in the context of a fabrication process performed at microscopic levels, whereby such a "cross-sectional arc profile" may refer to a profile with a deliberately fabricated curvature due to the process of fabrication.

DETAILED DESCRIPTION

In the following description, various embodiments are described with reference to the drawings, where like reference characters generally refer to the same parts throughout the different views.

Figure 1A shows the cross-sectional structure of an optical grating 100 according to a first embodiment.

The optical grating 100 includes a substrate 102 comprising a plurality of protrusions 104. A space 106 exists in between any two adjacent protrusions 104. A cap 118 is provided on at least one of the plurality of protrusions 104 at an end 103

that is furthest from the substrate 102. The cap 118 has a higher degree of optical attenuation compared to the substrate 102 material. The combination of each protrusion 104 and the respective cap 118 thereon has a generally symmetric cross-sectional profile.

5 The combination of each protrusion 104 and the respective cap 118 thereon is generally symmetric about a longitudinal axis 114 extending along a centre and intersecting a base 116 of the respective protrusion 104. This symmetry provides the optical grating 100 with a flat optical spectral response. Accordingly, an identical degree of symmetry is not required, but rather a degree of symmetry that allows the
10 optical grating 100 to provide a flat optical spectral response.

 It has been found that the symmetric profile such as those presented by the cross-sectional arc profile 112 of each protrusion 104 provides a flatter spectral response compared to the case where each protrusion 104 were to have non-symmetric structure (e.g. straight sidewalls with a cross-sectional linear profile, see
15 Figure 1B). While an arced cross-sectional profile is shown in Figure 1A, other profiles such as square shaped or round shaped are possible, as long as the overall cross-sectional profile of the cap 118 and the respective protrusion 104 has symmetry.

 The cap 118 is preferably opaque. Such an opaque overcap can be made
20 using metals or dielectric with light-absorbent additive molecules. The degree of opacity (i.e. degree of optical attenuation) in metals is controlled by the thickness of the metals. Using metals to realise the cap 118 provides the cap 118 with reflective properties. The degree of opacity (i.e. degree of optical attenuation) in a dielectric is controlled by the amount of light-absorbent additive molecules (e.g. pigments, dyes,
25 colorants and photosensitive emulsions, etc.) present in the dielectric. Using a dielectric to realise the cap 118 provides the cap 118 with non-reflective properties.

 The physical properties of the cap 118 imparted by the material used to fabricate the cap 118 determines whether the optical grating 100 functions as a parallax barrier or a nanowire grid polarizer. Given that a non-reflective overcap
30 does not reflect TE polarized light, an opaque and reflective overcap allows the optical grating 100 to function as a nanowire grid polarizer. An opaque and reflective overcap; or an opaque and non-reflective overcap allows the optical grating 100 to function as a parallax barrier. In the case where the cap 118 is opaque and reflective, the optical grating 100 will function as a parallax barrier when the optical
35 grating 100 is used under conditions allowing the optical grating 100 to function as a parallax barrier; or as a nanowire grid polarizer when the optical grating 100 is used under conditions allowing the optical grating 100 to function as a parallax barrier.

The optical grating 100 will function as a parallax barrier when it is placed in front of an image source, such as a liquid crystal display (LCD). The optical grating 100 will function as a nanowire grid polarizer when used in any linear polarization required equipment or techniques such as a flexible LCD or an optical filter.

5 The cap 118 has a shape such that both sidewalls 108, 110 of each of the plurality of protrusions 104 have a cross-sectional arc profile 112 along at least a portion of both of these sidewalls 108, 110.

10 The plurality of protrusions 104 are fabricated simultaneously with the substrate 102 and therefore are integral to and made of the same material as the substrate 102. The plurality of protrusions 104 may be arranged in an array. To achieve such an array, one embodiment has any two adjacent protrusions 104 spaced apart about equally (i.e. the space 106 between any two adjacent protrusions 104 is around the same). Each protrusion 104 may have a width from a range 10nm to 300nm, with a suitable width being for example 70nm. The distance
15 for the space 106 may be from a range 10nm to 300nm, with a suitable distance being for example 70nm. In another embodiment, the array may be realised by the optical grating 100 having a repetitive pattern, whereby two adjacent protrusions 104 are spaced 106 a first distance apart and another two adjacent protrusions 104 are spaced 106 a second distance apart, the size of the first distance being different from
20 that of the second distance.

 As shown in Figure 1A, the cross-sectional arc profile 112 is present along a portion of the entire sidewalls 108, 110. However, although not shown, the cross-sectional arc profile 112 can also extend over the entire surface of the sidewalls 108, 110. Also, although not shown, the cross-sectional arc profile 112 can
25 commence from the portions of both sidewalls 108, 110 that are adjacent to their respective base 116. Rather, the portion of both sidewalls 108, 110, having the cross-sectional arc profile 112, is proximate to the end 103 of each of the plurality of protrusions 104 that is furthest from the substrate 102.

 Figure 2 shows the cross-sectional structure of an optical grating 200
30 according to a preferred embodiment.

 The optical grating 200 of Figure 2 includes a substrate 202 comprising a plurality of protrusions 204. A space 206 exists in between any two adjacent protrusions 204. The cross-sectional profile 212 of each of the sidewalls 208, 210 has a convex shape relative to a longitudinal axis 214 extending along the centre
35 and intersecting the base 216 of the respective protrusion 204.

 Like the optical grating 100 of Figure 1A, the overall structure of each of the plurality of protrusions 204 and its respective cap 218 has a combined cross-

sectional profile that is generally symmetrical about a longitudinal axis 214 extending along a centre and intersecting a base 216 of each respective protrusion 104. The cap 218 also has a higher degree of optical attenuation compared to the substrate 202 material. However, while the optical grating 100 of Figure 1A has the cap 118 only provided on a selected number of the plurality of protrusions 104, the optical grating 200 of Figure 2 has the cap 218 provided on each of the plurality of protrusions 204 at an end 203 that is furthest from the substrate 202.

Similar to the optical grating 100 of Figure 1A, the plurality of protrusions 204 may be arranged in an array. The plurality of protrusions 204 are also fabricated simultaneously with the substrate 202 and therefore are integral to and made of the same material as the substrate 202. The substrate 202 may be made from direct imprinting onto a plastic sheet (which includes all types of thermoplastic films, e.g. polycarbonate (PC), polymethylmethacrylate (PMMA) and polyethylene so that the substrate 202 is flexible.

The cap 218 may comprise material that has a higher degree of optical attenuation, compared to the substrate 202 material. In various embodiments, the cap 218 may be opaque. The cap 218 may be made of the same materials as the cap 118 of Figure 1A. Thus, the cap 218 may be made of material that is both opaque and reflective (e.g. metals) whereby the cap 218 may comprise one or more of the following materials: aluminum, gold and chromium. Alternatively, the cap 218 may be made of material that is both opaque and non-reflective, whereby the cap 218 may comprise of dielectric with light-absorbent additive molecules (e.g. pigments, dyes, colorants and photosensitive emulsions etc.)

Figure 3 shows a flowchart 300 of a method to fabricate an optical grating according to the first embodiment shown in Figure 2

In step 302, a substrate is provided.

In step 304, a plurality of protrusions on the substrate is formed with a space in between any two adjacent protrusions.

In step 306, a cap is provided on at least one of the plurality of protrusions at an end that is furthest from the substrate, wherein the cap has a higher degree of optical attenuation compared to the substrate material and wherein the combination of each protrusion and the respective cap thereon has a generally symmetric cross-sectional profile.

In one implementation of the method of Figure 3 to fabricate an optical grating in accordance to the preferred embodiment (see Figure 2), the cap provides each of the plurality of protrusions with sidewalls having a cross-sectional arc profile along at

least a portion of the sidewalls. The cap may comprise different material from the substrate. The cap is preferably opaque. The cap may be made of material that is both opaque and reflective. It is also possible for the cap to be made of material that is opaque and non-reflective. The cap may be provided by a process which forms a portion of the cap on one sidewall of each protrusion and forms a remainder of the cap on the other sidewall, i.e. an opposite sidewall of the same protrusion. This process is described in greater detail below with reference to Figures 4A to 4C.

Figures 4A to 4C show an exemplary process of this implementation to fabricate the preferred embodiment of an optical grating 400 (see Figure 4D) directly onto a substrate 402, such as commercially available free-standing polycarbonate (PC) (Innox PC2151, thickness 0.25mm) sheet, through a two-step process. Other materials such as plastic, polycarbonate and polymethylmethacrylate are also usable.

Prior to performing a nanoimprint process shown in Figure 4A, a silicon mould 420 with topography (such as 70nm line, 70nm space, 300nm height grating), designed to provide a protrusion pattern on the substrate 402, was fabricated. The mould 420 was cleaned using oxygen plasma and silanized with an anti-stiction monolayer (FDTS, (1H,1H,2H,2H)-Perfluorodecyltrichlorosilane). The silanization treatment was used to reduce the surface energy of the mould 420 to facilitate easy demoulding of the mould 420 from the substrate 402.

In a first step 470 shown in Figure 4A, thermal nanoimprinting using a nanoimprinter (such as an "Obducat AB" Nanoimprinter) was employed to directly pattern the substrate 402 with the desired grating feature from the silicon mould 420. A batch or roll-to-roll processing can be used for the thermal nanoimprinting. The silicon mould 420 was placed in direct contact with the substrate 402 at an imprinting temperature of 180°C and at a pressure of 60 bar for a duration of 10 minutes. Following this, the temperature of the system was cooled down to 25°C and demoulding was performed at this temperature. The grating pattern feature from the silicon mold was thus imprinted onto the substrate 402.

In a second step 472 shown in Figures 4B and 4C, the protrusions 404 formed from the imprinted grating on the substrate 402 undergo a "dual-side coating" method to form a cap 418 on each of the protrusions 404. Equipment that can be used to coat the protrusions 404 with the cap 418 include a metal evaporator/coater/sputterer (such as an "Edwards Auto306 Ebeam Evaporation System"). The metal evaporator/coater/sputterer can be integrated with the nanoimprinter, described above, into a single system. Accordingly, the formation of

the plurality of protrusions 404 and the provision of the cap 418 may be performed in an integrated system where imprinting and metal evaporation/coating/sputtering occur.

A portion of the cap 418 is formed on one of the both sidewalls of each protrusion 404 by tilting θ the substrate 402 in a first direction 422 and forming the portion of the cap 418 on the one sidewall. The remainder of the cap 418 is formed on the other of the both sidewalls by tilting θ the substrate 402 in a second direction 424 that is opposite to the first direction and forming the remainder of the cap 418 on the other sidewall.

The angle θ at which the substrate 402 is tilted in the first direction 422 may be approximately the same as angle θ at which the substrate is tilted in the second direction 424. The angle θ may range from 1° to 89° , with an exemplary tilt angle θ being around 5 to 30° . The angle θ of tilting during cap formation will affect the light transmittance percentage of the resulting optical grating 400 (see Figure 4D). For cap 418 formation at a smaller tilt angle (such as $\theta = 1^\circ$), the optical grating 400 has higher light transmittance and less light blockage as compared to cap 418 formation done at a higher tilt angle (such as $\theta = 10^\circ$). If aluminum is evaporated onto the substrate 402 in Figures 4B and 4C, aluminum metal will be deposited onto the top of the grating 400, i.e. onto the two sidewalls of each protrusion 404 of the grating 400. Figure 4D shows a schematic illustration of the resulting optical grating 400 following this "dual-side coating".

The two-step process and the two pieces of equipment used to implement this two-step process (both described above) provide a simple way to fabricate an optical grating in accordance to an embodiment of the invention. In comparison to other optical gratings (such as: 1) "Fabrication of a 50 nm half-pitch wire grid polarizer using nanoimprint lithography" by Ahn, S. W., Lee, K. D., Kim, J. S., Kim, S. H., Park, J. D., Lee, S. H. and Yoon, P. W. (2005). Nanotechnology, 16, 1874-1877; and 2) "Wire Grid Polarizer and Manufacturing Method Thereof" by Ahn, S. W., Lee, K. D., Kim, J. S., Kim, S. H., Park, J. D., Lee, S. H. and Yoon, P. W. (2006)) that require at least five to six processing steps performed using four processing equipment, it is easier and cheaper to fabricate an optical gratings in accordance to an embodiment of the invention. The four processing equipment to manufacture such other optical gratings include a metal evaporator, a spin-coater, a nanoimprint system and a reactive ion etcher for metal etching/reactive ion etcher for resist etching. An exemplary six step process includes: (1) metal deposition onto a glass substrate; (2) spin-coating a resist onto the metal over the glass substrate; (3)

nanoimprinting to transfer the pattern from a mould onto the resist; (4) reactive ion etching to remove residual layer; (5) reactive ion etching to etch metal; and (6) resist stripping by reactive ion etching. An exemplary five step process includes: (1) spin-coating a resist onto a glass substrate; (2) nanoimprinting to transfer the pattern from a mould onto the resist; (3) reactive ion etching to etch residual layer resist; (4) metal evaporation; and (5) lift-off process using acetone solution.

Figure 5A shows the cross-section of a structure 500 of an optical grating fabricated using the "dual-side coating" method described with respect to Figures 4A to 4C. The cross-section view is obtained using transmission emission microscopy, such as by way of a "Phillips CM300".

The structure 500 comprises a grating having a plurality of protrusions 504, each having thickness of around 70nm, patterned on a plastic substrate 502. Adjacent protrusions 504 are spaced around 70nm apart, for a pitch distance 506 of around 140nm. Each protrusion 504 has a metal over-cap 518 of non-uniform thickness, such as a top thickness 520 of around 50nm (measured from the top of each protrusion 504) and a side thickness 522 of around 20nm thickness (measured from the sidewalls of each protrusion 504). The metal over-cap 520 provides at least a portion of both sidewalls of each of the plurality of protrusions 504 with a cross-sectional arc profile. Ideally, the metal deposition is desired to be symmetrical on both sides of each protrusion 504. However, this is not achieved in the fabricated structure 500 due to a slight tilt of the grating because of its high aspect ratio, and thus a slight shadow deposition effect on the fabricated structure 500.

Figure 6A shows a plot of the measured transmission spectrum of TM polarized light (T_{TM}) against the visible light wavelength range from 400nm to 800nm. Figure 6B shows a plot of the contrast ratio between transmitted TE polarized light and transmitted TM polarized light (T_{TM} / T_{TE}) against the same visible light wavelength range from 400nm to 800nm.

In both Figures 6A and 6B, each curve 600 represents the result obtained for the structure 500 of Figure 5A, while each curve 650 represents the result obtained for a conventional nanowire grid polarizer 540, schematically shown in Figure 5B, with a transmission emission microscopic image shown in Figure 5C. The results show that a flatter spectral response is achieved by the structure 500 (i.e. an optical grating according to the preferred embodiment) compared to the conventional structure. The contrast ratios for both the structure 500 and the conventional nanowire grid polarizer are comparable.

Figure 7A shows a picture of a document 730 viewed through an optical film 700 fabricated from the structure 500 of Figure 5A. Figure 7B shows a picture of the document 730 viewed through an optical film 750 fabricated from the nanowire grid polarizer of Figure 5C. Thus, in both Figures 7A and 7B, the optical films 700 and 750 are operated under transmission mode, i.e. viewing of the document 730 through the respective optical film 700, 750.

Figure 7B shows a reddish artifact for the document 730 viewed through the optical film 750. The reddish artifact is caused by the non-constant transmission intensity spectrum across the visible wavelength range (graphically represented by the curve 650 in Figure 6A), which is not desirable to the user. On the other hand, no such reddish artifact is present for the document 730 viewed through the optical film 700. The flatter spectral response (graphically represented by the curve 600 in Figure 6A) across the visible wavelength (400-800nm) eliminates the reddish artifact observed in the conventional nanowire grid polarizer operating in the transmission mode, allowing the structure 500 to be used in applications that require a nanowire grid polarizer.

The structure 500 of Figure 5A provides a series of alternate opaque and transparent slits of micron-size gratings. Due to its high resolution (brought about by each protrusion 504 having a width of 70nm) and sharing a similar structure to that of a parallax barrier (compare against the optical element 1040 of Figure 10), the structure 500 also functions as a high resolution plastic parallax barrier film, finding applications for auto-stereoscopic display with sub-pixel resolution below 1 μ m. Although present liquid crystal display (LCD) technology is still using sub-pixel resolution in the micrometer scale, the trend (see Figure 8) between 2003 and 2012 to improve LCD sub-pixel resolution is to reduce sub-pixel size below the micrometer scale. Thus, the optical film 700 shown in Figure 7A can thus function as a parallax barrier for auto-stereoscopic display for future displays with sub-pixel resolution below 1 μ m.

From the above, an optical grating according to various embodiments allow for an optical element with a structure fabricated on a substrate to function either as a nanowire grid polarizer or as a high resolution parallax barrier (PB) film for auto-stereoscopic display. Applications of such an optical grating include placement into an auto-stereoscopic display and optical films.

Figure 9A shows a plot of the simulated transmission spectrum of TM polarized light (T_{TM}) against the light wavelength range from 450nm to 650nm. Figure 9B shows a plot of the simulated curve of the contrast ratio between the

transmitted TE polarized light and transmitted TM polarized light (T_{TM} / T_{TE}) against the same light wavelength range from 450nm to 650nm.

In both Figures 9A and 9B, each curve 900 represents simulated results obtained using the optical grating 200 of Figure 2. The simulated results were generated using software from FDTD SolutionsTM. The results obtained from the fabricated structure 500 of Figure 5A verify the simulation results, as seen from comparing the curves 600 shown in Figures 6A and 6B against the curves 900 shown in Figures 9A and 9B.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the embodiments without departing from a spirit or scope of the invention as broadly described. The embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. An optical grating comprising
a substrate comprising
5 a plurality of protrusions with a space in between any two adjacent protrusions; and
a cap provided on at least one of the plurality of protrusions at an end that is furthest from the substrate, wherein the cap has a higher degree of optical attenuation compared to the substrate material and
10 wherein the combination of each protrusion and the respective cap thereon has a generally symmetric cross-sectional profile.
2. The optical grating of claim 1, wherein the combination of each protrusion and the respective cap thereon is generally symmetric about a longitudinal axis extending
15 along a centre and intersecting a base of the respective protrusion.
3. The optical grating of claim 1 or 2, wherein the plurality of protrusions are arranged in an array.
- 20 4. The optical grating of any one of the preceding claims, wherein the cap provides each of the plurality of protrusions with sidewalls having a cross-sectional arc profile along at least a portion of the sidewalls
5. The optical grating of claim 4, wherein the cross-sectional arc profile of each of
25 the sidewalls has a convex shape relative to a longitudinal axis extending along a centre and intersecting a base of the respective protrusion.
6. The optical grating of any one of the preceding claims, wherein the cap comprises different material from the substrate.
- 30 7. The optical grating of any one of the preceding claims, wherein the cap is opaque.
8. The optical grating of any one of the claims 1 to 7, wherein the cap comprises
35 one or more metals.

9. The optical grating of any one of the claims 1 to 7, wherein the cap comprises dielectric materials with a light-absorbent additive.

5 10. A method of forming an optical grating, the method comprising
providing a substrate;
forming a plurality of protrusions on the substrate with a space in between any two adjacent protrusions,
providing a cap on at least one of the plurality of protrusions at an end that is furthest from the substrate, wherein the cap has a higher degree of optical
10 attenuation compared to the substrate material and wherein the combination of each protrusion and the respective cap thereon has a generally symmetric cross-sectional profile.

11. The method of claim 10, wherein the cap provides each of the plurality of
15 protrusions with sidewalls having a cross-sectional arc profile along at least a portion of the sidewalls.

12. The method of claim 10 or 11, wherein the cap comprises different material
from the substrate.

20 13. The method of any one of claims 10 to 12, wherein the cap is opaque.

14. The method of any one of claims 10 to 13, wherein the cap is provided by
forming a portion of the cap on one sidewall of each protrusion and forming a
25 remainder of the cap on an opposite sidewall of the same protrusion.

15. The method of claim 14, wherein forming the cap on the sidewalls comprises
tilting the substrate in a first direction; and
forming the portion of the cap on the one sidewall;
30 and forming the remainder of the cap on the opposite sidewalls comprises
tilting the substrate in a second direction that is opposite to the first
direction; and
forming the remainder of the cap on the opposite sidewall.

35 16. The method of claim 15, wherein an angle at which the substrate is tilted in the first direction is approximately the same as angle at which the substrate is tilted in the second direction.

17. The method of any one of claims 14 to 16, wherein the cap is formed by any one or more of the following techniques: evaporation, deposition and sputter.

5 18. The method of claim 16 or 17, wherein the angle of tilt ranges from 1° to 89°.

19. The method of any one of claims 10 to 18, wherein the substrate is fabricated from flexible material.

10 20. The method of any one of claims 10 to 19, wherein the substrate comprises any one or more of the following materials: plastic, polymethylmethacrylate, polycarbonate and polyethylene.

15 21. The method of any one of claims 10 to 20, wherein the plurality of protrusions is formed by any one or more of the following techniques: imprinting and nanopatterning.

22. The method of any one of claims 10 to 21, wherein the formation of the plurality of protrusions and the provision of the cap is performed in an integrated system.

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23. An auto-stereoscopic display comprising the optical grating of any one of claims 1 to 9.

24. An optical film comprising the optical grating of any one of claims 1 to 9.

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