Design Study of high reflectivity Birefringent mirrors

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Abstract— Multilayer mirrors that maintain or increase their reflectivity with increasing incidenceangle can be constructed using polymers that exhibit large birefringence in their indicesof refraction. The most important feature of these multilayer interference stacks is the indexdifference in the thickness direction (*z* axis) relative to the in-plane directions of the film. This *z*-axis refractive index difference provides a variable that determines the existence and value of the Brewster's angle at layer interfaces, and it controls both the interfacial Fresnelrefection coefficient and the phase relations that determine the optics of multilayer stacks. These films can yield optical results that are difficult or impossible to achieve withconventional multilayer optical designs. The materials and processes necessary to fabricate such films are amenable to large-scale manufacturing .In this research use the (MATLAP) to calculate and design this type of reflection surfaces then we study the main parameters effect on it .

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1 Theory

There are two conventional ways to create a mirror: using the surface of a layer of metal, or using a tuned interference stack composed of multiple layers of transparent dielectric materials Metal mirrors are inexpensive and perform robustly across a broad range of angles, wavelengths, and polarizations, but they exhibit limited reflectivity. Multilayer interference mirrors are routinely used for optical applications requiring high reflectivity and wavelength selectivity. Although they can be designed to achieve a wide range of optical characteristics, each design typically performs across a limited range of incidence angles,wavelengths, and polarizations. A key limitation of multilayer mirrors stems from Brewster's law, a nearly200-year-old maxim of optics, which predicts the decrease of reflection for p-polarized light at material interfaces with increasing incidence angle. Specifically, Brewster's law states that there is an angle of incidence (Brewster's angle) for which the reflectivity for p-polarized light vanishes at a material interface. As a result, a multilayer interference mirror that is designed to have a 1% loss for reflection of p-polarized light (99% reflectivity) at normal incidence can have many times that loss at high incidence angles Using highly birefringent polymers, we have found that multilayer mirrors can be constructed that maintain or increase their reflectivity with increasing reflective index. The reflective characteristics of these mirrors require a generalization of Brewster's law. This generalization has enabled the development of a new class of multilayer interference optics with design freedoms that can result in unprecedented means for transporting, filtering, andreflecting light. Optical birefringence describes the difference of a material's refractive index with direction. When birefringence is on the order of the change of the in-plane refractive index between adjacent material layers, surprising and useful optical effects occur.

We refer to these effects as giant birefringent optics (GBO). A central feature of GBO is improved control of the reflectivity of p-polarized light. With the additional design freedom allowed by GBO, Brewster's angle can be controlled to any angle from0° (normal incidence) to 90° (grazing incidence), to imaginary values for light incident from media of any index of refraction. For imaginary values of Brewster's angle, the reflectivity at material interfaces (referred to as Fresnel or interfacial reflectivity) for p-polarized light increases with angle of incidence in a similar or identical form to that for s-polarized light. By comparison, isotropic materials have no substantial optical birefringence; that is, their refractive index values are equal for all directions. Interfaces of these conventional isotropic materials exhibit a limited range of Brewster's angles because the optical effects presented are based on the fundamental physics of interfacial reflection and phase thickness and not on a particular multilayer interference stack design, new design freedoms are possible. For example, designs for wide-angle, broadband applications are simplified if optical elements with no Brewster's angle are used, particularly if immersed in a high-index medium such as a glass prism. Color filters can be designed that provide high color saturation at all incidence angles and polarizations. Alternatively, a mirror or reflecting polarizer can be designed to have a Brewster's angle that is accessible in air. Conventional polymer film-making processes have been enhanced to fabricate a wide array of GBO films from commercially available polymers and monomers for use in a range of applications. These applications include high efficiency mirrors for piping visible light over long distances or uniformly lighting small optical displays. GBO multilayer films have been used to create reflective polarizers that make liquid crystal displays brighter And easier to view. Other applications include decorative products, cosmetics, security films, optoelectronic components, and infrared solar control reflectors for architectural and automotive glazing. After a review of birefringent optics, we discuss the relations describing GBO and show the implications of GBO on optical film performance and applications.Background. Multilayer interference optics can generally be described as the use of the amplitudes and phases of light reflected at planar material boundaries to produce constructive and destructive interference effects. Pairs or groupings of adjacent layers (termed unit cells) can produce constructive interference effects when their thicknesses are properly scaled to the wavelengths of interest. These interference effects in multilayered structures result in the development of wavelength regions of high reflectivity (reflection bands) withadjacent wavelength regions of high transmission (pass bands) (1). Much of the design effort in multilayer interference optics is devoted to controlling the angular dependence of reflection bands, which is complicated by polarization effects. These effects have long been known, with publications dating to before the turn of the century [see, e.g., Drudge (2, 3). Sir David Brewster empirically deduced the law named for him by observing that light reflected from an air-glass interface is highly polarized at a specific angle (4). The same phenomenon occurs for all interfaces between isotropic materials. Aside from the well-knownMcNeill polarizing beam splitters (5) and magneto-optic materials (6), such polarization effects are typically undesirable, as they limit the angular performance of multilayer interference stacks. Various researchers (7–10) have developed a variety of limited solutions to the problem. In addition, modern computer optimization codes have dealt admirably with the problem. However, the basic phenomenon associated with Brewster's angle still continues to constrain the angular and wavelength performance of multilayer interference stacks fabricated from materials having isotropic indices of refraction .Multilayer polymeric interference mirrors were pioneered in the late 1960s (11), and even though the large birefringence of oriented polyethylene terephthalate (PET) was known at the time (12), the use of materials with large optical birefringence in a multilayer mirror (polymeric or otherwise) has not been reported. Numerous other works have been published on birefringent optical materials (13), but none of these discuss the use of birefringence to control(or eliminate) Brewster's angle effects and phase thickness relations among interface multilayer interference stacks.Using Eq. (8.10.6) and the TM and TE Snel's laws, Eqs. (1,2), we may rewrite the reflection coefficients in terms of the angle θ only:

$$\rho TM = \frac{nH1nH3\sqrt{n_{L3}^{2}N_{a}^{2}\ _{Sin^{2}}\theta_{a}}-nL1nL3\sqrt{n^{2}_{H3-N^{2}_{a\,SIN^{2}\theta a}}}}{nH1nH3\sqrt{n^{2}_{L3}-N_{a}^{2}SIN^{2}\theta a}+nL1nL3\sqrt{n^{2}_{H3-N^{2}_{a\,sin^{2}\theta a}}}}\ldots\ldots(1)$$

$$\rho TE = \frac{\sqrt{n^{2}_{H2-N^{2}_{a\,sin^{2}\theta a}}}-\sqrt{n^{2}_{L2-N^{2}_{asin^{2}\theta a}}}}{\sqrt{n^{2}_{H2-N^{2}_{asin^{2}\theta a}}}+\sqrt{n^{2}_{L2-N^{2}_{asin^{2}\theta a}}}}\ldots\ldots\ldots(2)$$

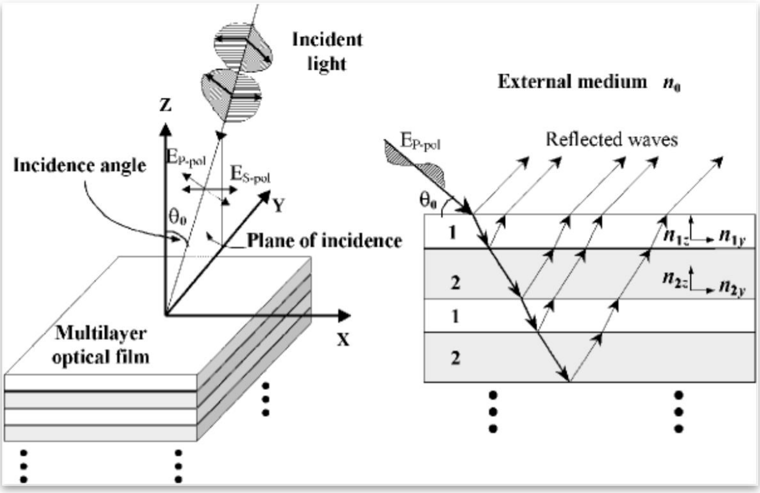
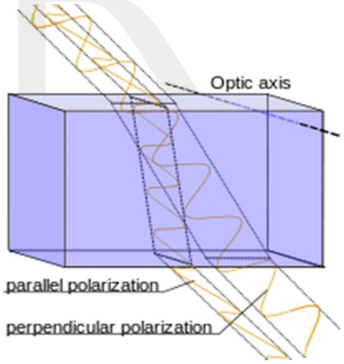


Figure .1. Oblique incidence on multilayer dielectric structural

Positive or negative



Rays passing through a positively birefringent material. The incident light has parallel and perpendicular polarization components (linear polarization at 45º the optic axis). The optical axis is perpendicular to the direction of the perpendicular component of incident ray, so the ray polarized parallel to the optic axis has a greater refractive index than the ray polarized perpendicular to it. Uniaxial birefringent materials are classified as positively (or negatively) birefringent when, for light (having parallel and perpendicular components) directed to the optic axis, the refractive of light polarized parallel to the optic axis is greater (or smaller, respectively) than light polarized perpendicularly to the optic axis. In other words, the polarization of the slow (or fast) wave is parallel to the optical axis when the birefringence of the crystal is positive (or negative, respectively).

2 Measurement

Birefringence and related optical effects (such as optical rotation and linear or circular dichroic) can be measured by measuring the changes in the polarization of light passing through the material. These measurements are known as polarimetry. Birefringence of lipid bilayers can be measured using dual polarization interferometry. This provides a measure of the degree of order within these fluid layers and how this order is disrupted when the layer interacts with other biomolecules. A common feature of optical microscopes is a pair of crossed polarizing filters. Between the crossed polarizers, a birefringent sample will appear bright against a dark (isotropic) background. For a fixed composition such as calcium carbonate, a crystal such as calcite or its polymorphs, the index of refraction depends on the direction of light through the crystal structure. The refraction also depends on composition, and can be calculated using the Gladstone–Dale relation .

3 Applications

A calcite crystal laid upon a paper with some letters showing the double refraction Birefringence is widely used in optical devices, such as liquid crystal displays, light modulators, color filters, wave plates, optical axis gratings, etc. It also plays an important role in second harmonic generation and many other nonlinear processes. Birefringent filters are also used as spatial low-pass filters in electronic cameras, where the thickness of the crystal is controlled to spread the image in one direction, thus increasing the spot-size. This is essential to the proper working of all television and electronic film cameras, to avoid spatial aliasing, the folding back of frequencies higher than can be sustained by the pixel matrix of the camera. Calcite is frequently used to produce twin beams of perpendicularly polarized light for use in quantum mechanical experiments.

Stress induced birefringence

Color pattern of a plastic box with "frozen in" mechanical stress placed between two crossed polarizers.Isotropic solids do not exhibit birefringence. However, when they are under mechanical stress, birefringence results. The stress can be applied externally or is ‘frozen’ in after a birefringent plastic ware is cooled after it is manufactured using injection molding. When such a sample is placed between two crossed polarizers, color patterns can be observed, because polarization of a light ray is rotated after passing through a birefingent material and the amount of rotation is dependent on wavelength. The experimental method called photo elasticity used for analyzing stress distribution in solids is based on the same principle.

4 The results and discussion

We consider a giant birefringent optics mirror of (30 and 35)bilayers of high and low index quarter-wave layers with refractive indices n_H=[1.8;1.8;1.5] and n_H=[3.4;3.4;1.9] n_L=[1.5;1.5;1.8]andn_L=[1.9;1.9;3.4].The surrounding media are air ,na=nb=1.4 .The layers are quarter wavelength at the normalization wavelengthλ0=700nm at oblique incidence, so that for both polarizations we take LH=LL=0.25.Because the high/low index layers are matched along the z-direction, nH3 = nL3, the TMreflection coefficient at the high/low interface will be constant, independent of the incident angle θ.In this research to compare the results between the articles of the refractive index is (3.4)higher and refractive index low is (1.9)with an example (8-13) are mentioned in the book of optics in chapter 8 of (Giant Birefringing Optics) is (1.8) higher refractive index and (1.5) for low refractive index under the same conditions of na = nb=1.4 and a different number of layers to wave length (700nm) and angle used 45 degrees .

The typical MATLAP code used to generate the graph
N:-number of layers
nH:-higher refractive index
nL:-low refractive index

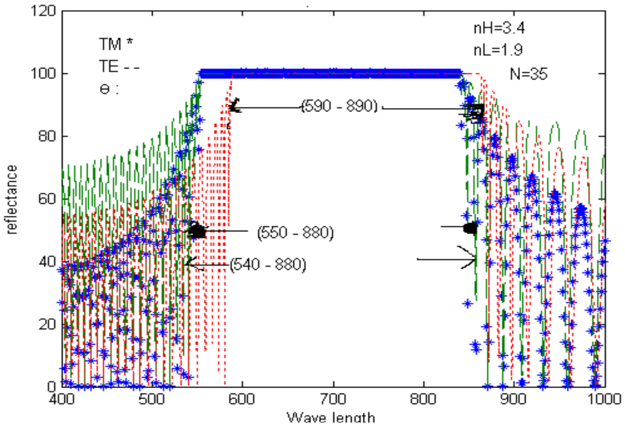


Figure.2.Birefringent mirrorwithidenticalTM an TE reflection bands.

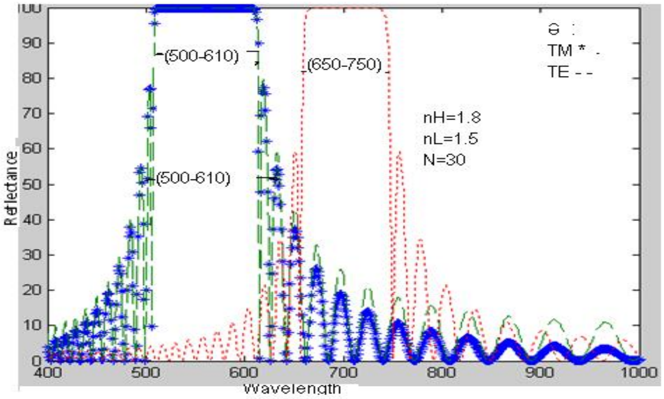


Figure.3. Birefringent mirror with identical TM anTE reflection bands.

4 .1 The results were as follows

1. Electric field (TE) in the figure (2)has period from (500-610) nm while in figure(3) we obtained period has limited from the (540-880) nm.
2. Magnate tic field (TM) in the figure (2)has period from (500-610) nm while in figure(3) we obtained period has limited from the (550-880) nm.
3. The angle which represents the (:)appear in the figure(2) period between (650-750) nm but we get inthe figure(3) period between (590-890)nm .

And the reasons for the difference in the returns results to the change of the refractive index and number of layers. Gave different results in the figure(3) depends two areas where the electric and magnetic field on the refractive index higher and refractive index low represent following equations.

5 References

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[13] AFM image and layer thickness analyses were provided by V. W. Jones of 3M Corporate Analytical Technology Center. 25 October 1999; accepted 15 February 2000 .