Chapter 1

Introduction

1.1 Introduction of Polarizer

As the modern science evolves, polarized light is widely applied to many systems in different fields, including engineering, physics, biology, etc., because it exhibits the ultimate in delicacy and convenience; and is the simplest kind of light which is easier to deal with than ordinary light. Polarizer is the most common optical device, when supplied only with unpolarized light, can produce an appreciably polarized beam. Depending on whether the polarization type is linear, circular, or elliptical, the polarizer is called a *linear*, *circular*, or *elliptical* polarizer. Nevertheless, the conventional polarizers are either inefficienct or bulky which cause some troubles in applications. There are several methods of producing polarized light directly in addition to polarizers. These methods involve the Stark effect, the Zeeman effect, grazing emergence, biemissivity, bifluorescence, the Cherenkov effect, and various other effects [1]. However, few of the methods are of practical importance in the production of polarized light.

Some polarizers consist of a single uniform layer, and are so called homogeneous. Others employ several different layers and are called inhomogeneous, or multilayer. Inhomogeneous polarizers consist of two different classes, depending on which side the light emerges from. The commercially produced CP-HN-38 circular polarizer consists of two layers：(*a*) a linearly polarizing layer, and (*b*) a linearly retarding layer (having a certain retardance and orientation), as shown in Fig. 1.1. If the light is incident on layer *a* and emerges from layer *b*, it emerges circularly polarized; incident on layer *b* and emerges from layer *a*, it emerges linearly polarized. In addition to this linear-circular combination, other two-layer, dual-function polarizers can be constructed, for example, a linear-elliptical combination. Using three layers one can make, for example, a right-circular-left-circular combination (ambidextrous polarizer, as shown in Fig. 1.2), or a linear 0°-linear 45° combination.

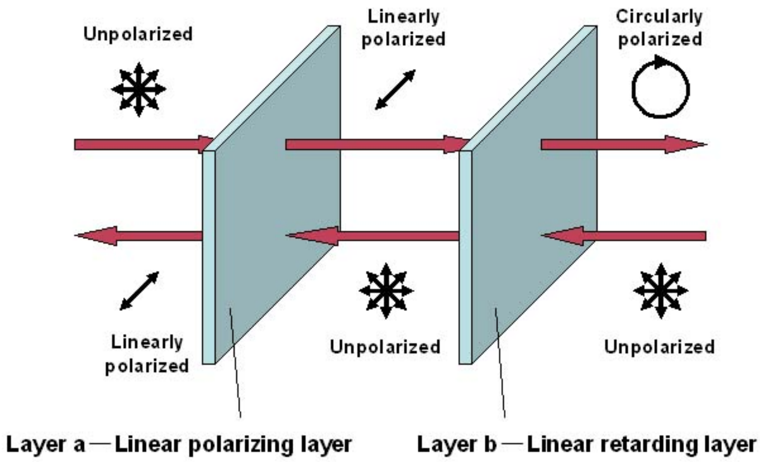

Fig. 1.1 CP-HN-38 circular polarizer.

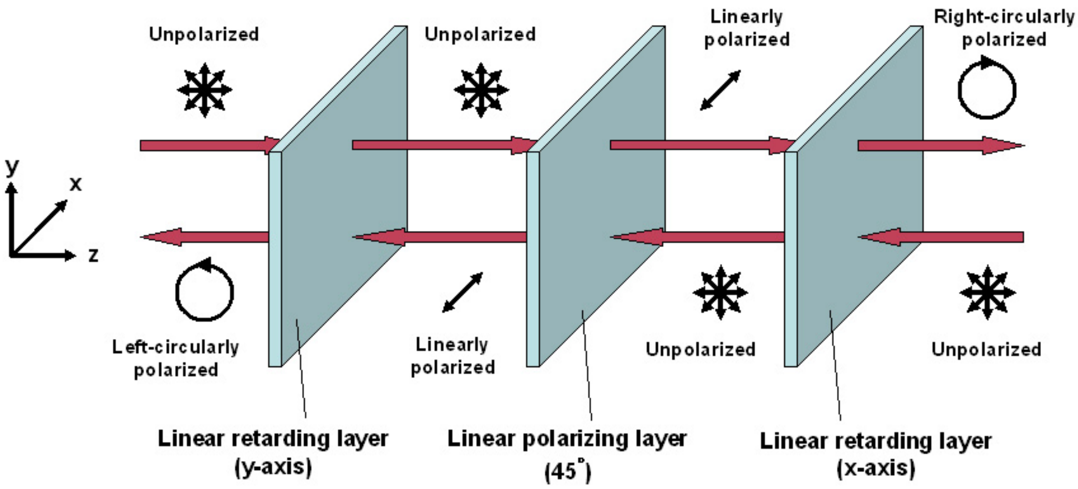

Fig. 1.2 Ambidextrous polarizer.

Most polarizers exhibit some depolarization, which is caused from scattering, oblique reflections, edge effects, and internal strains. Though a depolarizing polarizer is capable of increasing the degree of polarization of a beam that is initially polarized, it will unavoidably reduce the degree of polarization of an incident beam that is already 100-percent polarized. Nevertheless, the depolarization of most high-quality polarizers is so small enough to be negligible in nearly all types of applications. (Many of the laws governing polarizers are valid only if the depolarization is negligible.) [2]

Polarizers can be utilized in many applications. For example, we can use polarized sunglass lenses to selectively eliminate glare which is undesirable light and is reflected from horizontal surfaces such as water, sand, snow or road surfaces. Video camera polarizer filter eliminates over exposure of film by reducing the amount of light entering the lens. The applications we are interested the most are in display applications, where a polarized light is an essential light source to display images. The backlight system which is able to produce polarized light source for liquid crystal display (LCD) illumination and other applications where a polarizer is needed will be described more detailed in chapter 6.

1.2 Dichroic Polarizers

The majority of commercially produced polarizers are dichroic polarizer which itself is physically anisotropic, producing a strong asymmetric or preferential absorption of one field component while is essentially transparent to the other. It should be emphasized that the extent of absorption of a component depends on its vibration direction. Propagation direction is not the basic consideration: beams having the same propagation direction may be absorbed to different extents if their vibration directions differ; but if the vibration directions are the same, the absorptions will be the same even when the propagation directions differ [3].

The simplest device of this sort is a grid of parallel conducting wires, as shown in Fig. 1.3. Imaging that an unpolarized electromagnetic wave impinges on the grid from the right. The electric field can be decomposed into two orthogonal components, one is parallel to the wires and the other perpendicular to them. The y-component of the field drives the conduction electrons along the length of each wire, thus generating a current. The electrons impart energy to lattice atoms and thereby heating the wires. In this manner, energy is transferred from the field to the grid. In contrast, the electrons are not free to move very far in the x-direction, and the corresponding field component of the wave is then propagating through the grid.

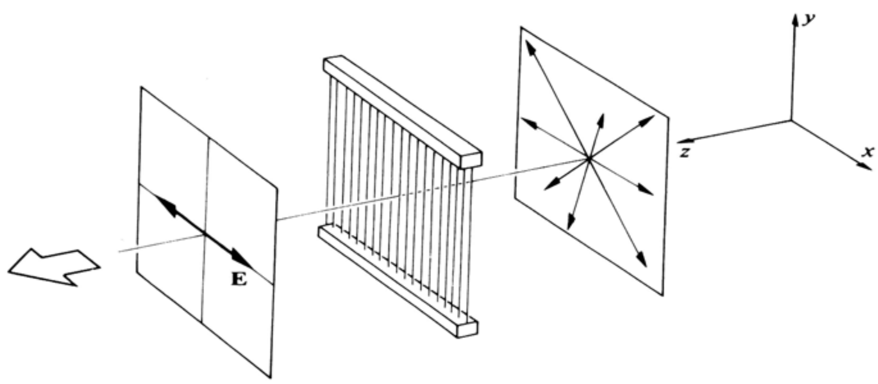

Fig. 1.3 Wire-grid Polarizer.

Another familiar dichroic polarizer is Polaroid, developed by Edwin Land, which is now probably the most widely used linear polarizer. It is a molecular analogue of the wire grid. A sheet of clear polyvinyl alcohol is heated and stretched in a given direction, which make its long hydrocarbon molecules aligned in the process. The sheet is then dipped into an ink solution rich in iodine. The iodine impregnates the plastic and attaches to the straight long-chain polymeric molecules, effectively forming a chain of its own. The conduction electrons associated with the iodine can move along the chains as if they were long thin wires. The component of E in an incident wave that is parallel to the molecules drives the electron and is strongly absorbed. The transmission axis of the polarizer is therefore perpendicular to the direction in which the film was stretched [4]. Because over 50% of incident light are absorbed by this sort of polarizer, it is not very efficient.

1.3 Birefringent Polarizers

Birefringent polarizers operate by dividing the incident beam into two completely and orthogonally polarized components, separating them physically, and eliminating one of them. Ideally, the transmitted component is completely polarized and suffers no decrease in intensity. In practical, various effects of reflection, obliquity, and astigmatism degrade the performance. Also, the linear and angular apertures are small, the thickness and weight are great, the cross-sectional shape (a rectangle) is inconvenient, and the cost is high. Consequently, such polarizers have been largely superseded by dichroic sheet-type polarizers, though they continue to be used in certain applications, such as those involving ultraviolet light.

An ideal polarizing birefringent beam splitter is a biprism that separates the ordinary and extraordinary beams by introducing a discontinuity in the refractive index. The birefringent materials that are used are often uniaxial and they must have a high transparency in the spectral band of their use and be stain-free. Among the most used polarizing beam splitters (PBS) is the Wollaston prism, as shown in Fig. 1.4. A Wollaston polarizing beam splitter has the optical axis of its first prism parallel to the surface to produce ordinary and extraordinary beams that see the second prism's optical axis rotated π/2 along the beam axis to produce a maximum birefringence and deviation for both beams. The incident unpolarized light is then separated into two outputs with perpendicular polarizations. The Wollaston prism yields both perpendicularly polarized beam with at least 99.9% polarization and large angular separation (i.e. up to 45°) between the two beams. The advantage of Wollaston prism is that it is suitable for broad band applications. There are other birefringent polarizers, include Rochon polarizer, Ahrens polarizer, Glan-Foucault polarizer, Nicol polarizer..., which are introduced in detail in reference [5][6][7].

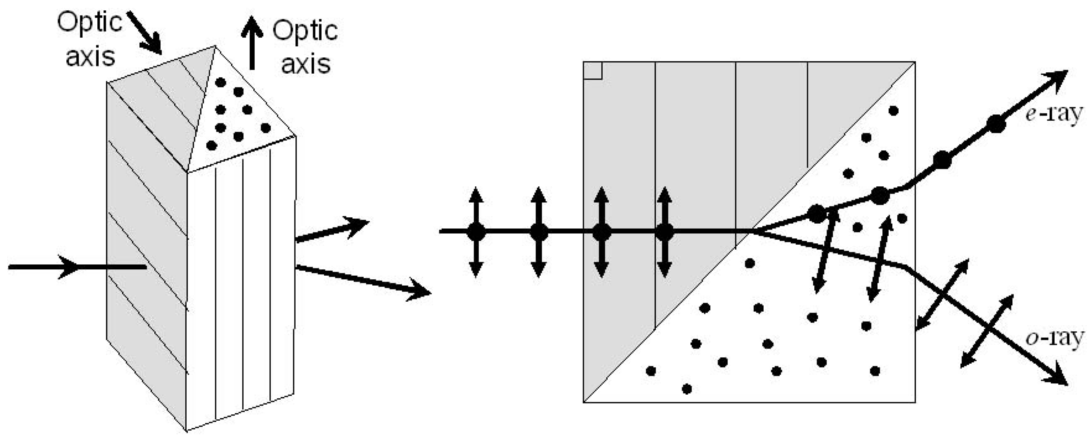

Fig. 1.4 Wollaston Prism.

1.4 MacNeille Polarizer

MacNeille polarizer is a thin-film polarizing beam splitter (PBS) cube which divides the incident beam into s and p polarization states, transmitting the p-polarized component and reflecting the s-polarized component. The MacNeille polarizing beam splitter is constructed by coating the hypotenuse face of an isosceles right-angled prism with multilayered thin films (alternating layers of materials of high and low refraction indices) and then cementing it to an identical prism, as shown in Fig. 1.5. The principle of MacNeille polarizer is that it is always possible to find an angle of incidence so that the Brewster condition for an interface of two materials with different refractive index is satisfied. The reflectance for the p-polarized component vanishes; the s-polarized light is partially reflected and transmitted at the angle of incidence. To increase the s-reflectance and to purify the polarization of transmitted light, the number of interface can be multiplied by a multi-film structure composed of the two materials with a quarter-wave optical thickness [8][9]. MacNeille polarizer can be used over a large spectral range, which depends on the film materials. However, the incident angle tolerance is only about $\pm 2^{\circ}$ [10]. This shortcoming can be resolved by optimizing multifilm thickness, yet, resulting in a narrower bandwidth.

However, dichroic polarizers are in a low efficiency due to the absorption of over 50% of light energy and the performance of birefringent polarizer and MacNeille polarizer are limited by their inherent nature. Therefore, we need a more efficient and small-sized PBS to satisfy the critical requirements of applications.

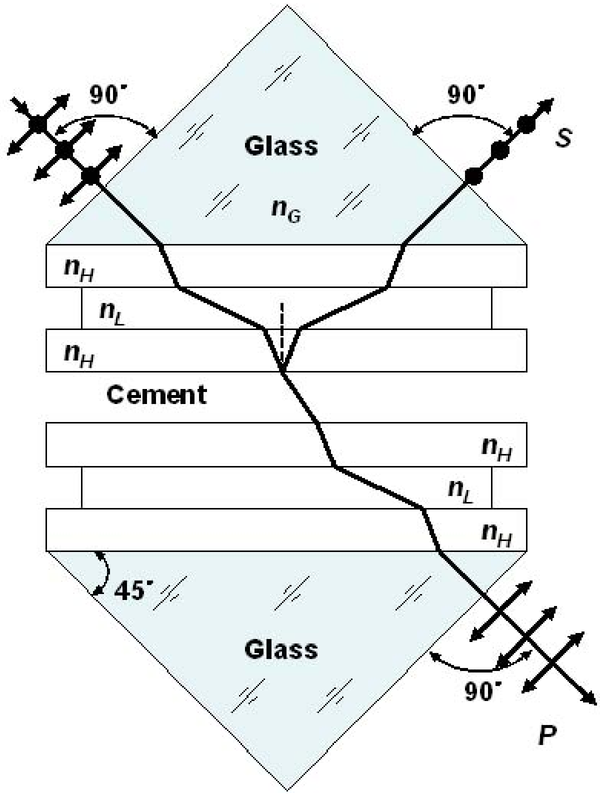

Fig. 1.5 MacNeille polarizing beam splitter cube.

1.5 Sub-Wavelength Grating (Zero-Order Grating)

In addition to asymmetry of material or incident angle, variation of interface profile is another way to produce asymmetry. In a surface relief grating, for example, it is obviously that TE and TM wave encounter different boundary conditions at the interface.

Sub-wavelength grating is a special case of gratings, which produces polarization effect. The relationship between the period of diffraction grating and wavelength of incident light is given by the following equation

$$p(n_i \sin\theta_i + n_d \sin\theta_d) = m\lambda \qquad 1.4.1$$

where p is the period of grating; n_i and n_d are the refractive indices of media where incident light and diffraction light exist; θ_i and θ_d correspond to the incident angle and diffraction angle, respectively; *m* is the diffraction order and is an integer [11]. When the condition:

$$p < \frac{\lambda}{\left(n_i \sin\theta_i + n_d\right)} \qquad 1.4.2$$

is satisfied, we find that all diffraction orders but the zeroth order are evanescent, i.e., they yield diffraction angle $\theta_d > 90°$. Hence the grating is also called zero-order grating [12][13].

Limited by the condition above, the sub-wavelength grating behaves no more as a grating, but as an effective dielectric medium with corresponding refractive indices, $n_{//}$ and $n_{\perp}$, which will be derived in chapter 2. As shown in Fig. 1.6, for a grating with period smaller than wavelength of incident light, the unpolarized light will be separated, i.e., P-rays transmitted and S-rays reflected.

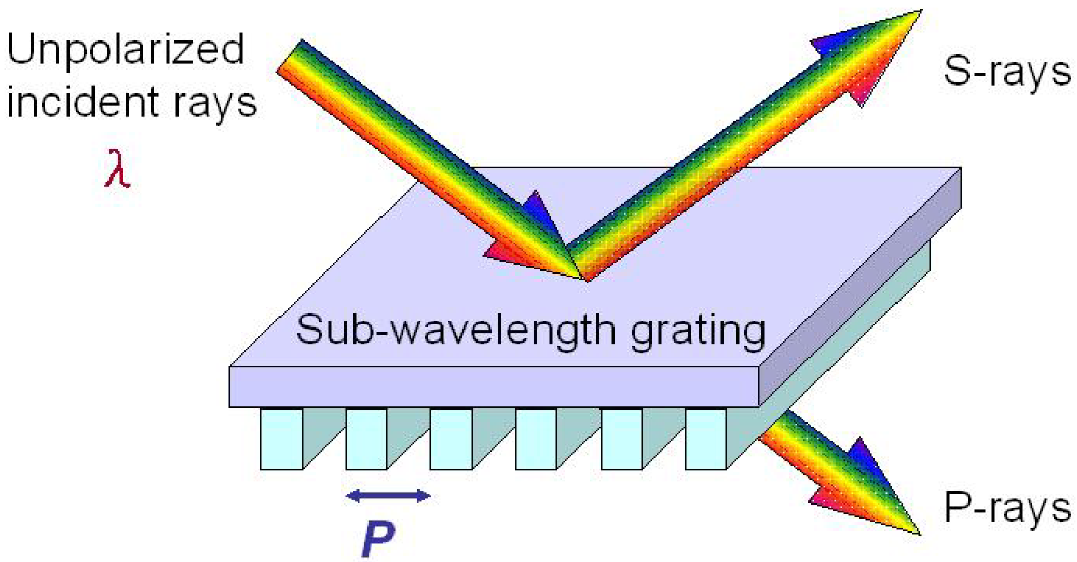

Fig. 1.6 Polarized light separation of a sub-wavelength grating.

As a result, these gratings can be used in applications such as in high-power lasers, antireflection surface, filters similar to thin-film coatings, wave plates, and polarization-selective mirrors with advantages of less in weight, thinner in thickness, and compactness. However, the bandwidth of a sub-wavelength grating is narrow. Tyan used multi-layer structure to broaden the bandwidth [14], but the proposed model seems to be a special case of the selected materials.

1.6 Motivation and Objective of this Thesis

Polarized light has been widely used in display technology applications. However, there are neither thin nor compact optical devices that can efficiently produce polarized light. Therefore, one of the objectives is to propose a multi-layered sub-wavelength grating which can efficiently separates two mutually orthogonally polarized lights. Because the proposed sub-wavelength grating is mainly used in display applications, the period of such a grating requires to be smaller than visible spectral, i.e. smaller than 0.4 μm. And the fine line-width of sub-wavelength grating is difficult to fabricate by semiconductor process. Thus, the other objective in this thesis is to fabricate and evaluate the proposed sub-wavelength grating.

1.7 Organization of this Thesis

The thesis is organized as following: The principle of sub-wavelength grating is presented in **Chapter 2**. In **Chapter 3**, the processes to fabricate sub-wavelength grating are summarized, and the major instruments used to characterize the diffractive component are described. The simulated results are presented in **Chapter 4**. The experimental results, including the fabricated sub-wavelength grating and the evaluated results, will be in **Chapter 5**. Moreover, the applications of sub-wavelength grating will be proposed in **Chapter 6**. Finally, the summary of this thesis and future works will be presented in **Chapter 7**.