Chapter 1

Introduction

1.1 Introduction of Polarizing Beam Splitter (PBS)

Polarizing Beam Splitter (PBS) can be utilized to separate an unpolarized light into two mutually perpendicular polarizations for diverse polarization with different optical path length. Since PBS produces polarized light not by means of light absorption, PBS has less thermal issues than Polaroid polarizer does. In other words, PBS is more suitable for high power system. In addition, the polarization efficiency of PBS may be greater than 0.5 if the polarization of the other output is transformed by a polarization converter system. Two types of traditional PBSs, Wollaston Prism and MacNeille Polarizer, will be briefly introduced in the following two sections.

1.1.1 Wollaston Prism

Wollaston Prism can be made of calcite or quartz employed two uniaxial prisms with mutually orthogonal optical axis, as shown in Fig. 1.1. The two prisms are fastened together by index matching optical glue. At the diagonal interface, the unpolarized light is separated into two outputs with perpendicular polarization owing to the nature of birefringence [1][2]. The advantage of Wollaston prism is that it is suitable for broad band applications. However, the device encounters an inherent size limitation because the dimension of Wollaston prism is proportional to the requirement of separation of two outputs.

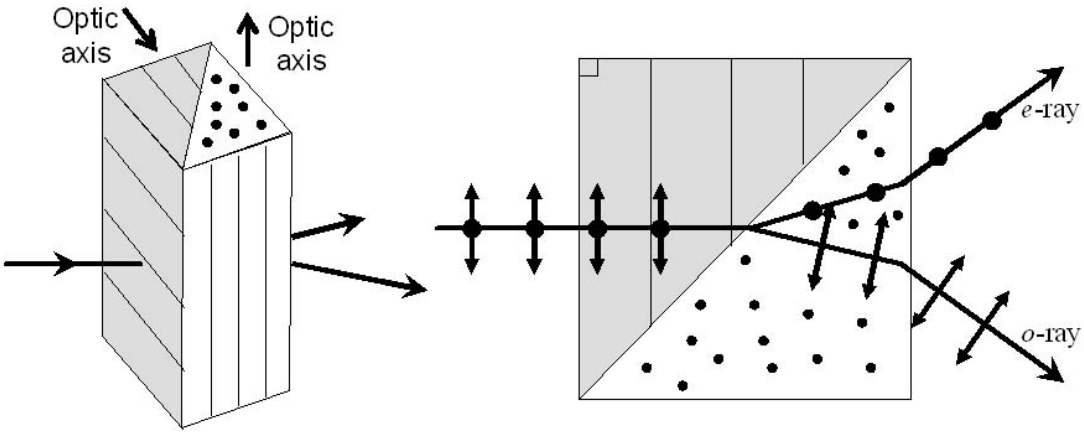

Fig. 1.1 Wollaston Prism

1.1.2 MacNeille Polarizer

The principle of MacNeille polarizer is using Brewster angle to separate TE wave from TM wave. At the interface between two materials of different refractive indices, it is always possible to find an incident angle, the Brewster angle, such that the reflectance of TM wave is zero, and TE wave is partially reflected and transmitted; therefore, the reflected light is linear polarized. For increasing the reflectance of TE wave and to purify the polarization of transmitted light, the number of interface can be multiplied by a multifilm structure composed of the two materials with a quarter-wave optical thickness. A schematic diagram of a MacNeille polarizer is shown in Fig. 1.2. The films are coated on the hypotenuse face of two 45-90 prisms and then cementing it to form a cube [3]. MacNeille polarizer can be used over a large spectral range, which depends on the film materials. However, the incident angle tolerance is only about ± 2° [4]. This drawback can be resolved by optimizing multifilm thickness, yet, resulting in a narrower bandwidth.

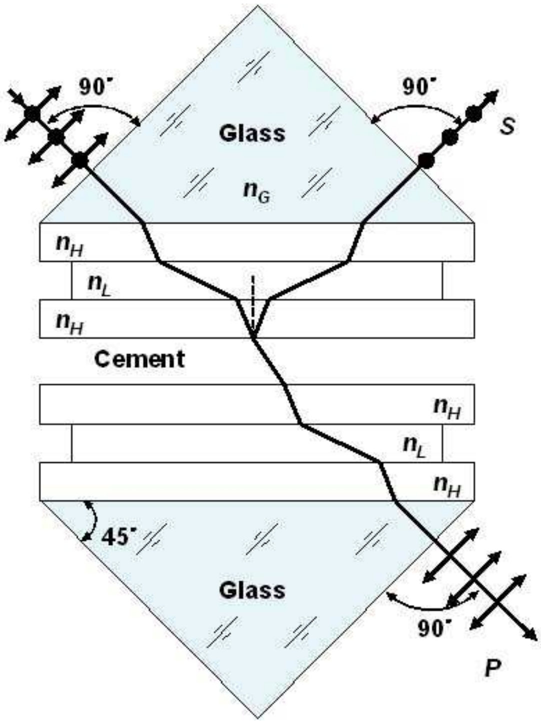

Fig. 1.2 MacNeille polarizing beam splitter cube

Wollaston prism and MasNeille polarizer use the asymmetric mechanism of birefringence and oblique reflection, respectively. However, the performances of these PBSs are limited by their inherent nature. Therefore, we need a new type of PBS to satisfy the critical requirements of applications.

1.2 Brief Review of Sub-wavelength Grating (Zero-Order Grating)

In addition to asymmetry of material or incident angle, interface profile between two materials is another way that can produce asymmetry. In a surface relief grating, for example, it is obvious that TE wave 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

$$p(n_i \sin\theta_i + n_d \sin\theta_d) = m\lambda \qquad 1.2.1$$

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 [5]. When the condition:

$$p < \frac{\lambda}{(n_i \sin\theta_i + n_d)} \qquad 1.2.2$$

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 [6][7].

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_{TE} and n_{TM}, which will be derived in chapter 2. As shown in Fig. 1.3, for a grating with period smaller than wavelength of incident light, two mutually perpendicular polarized lights will be separated.

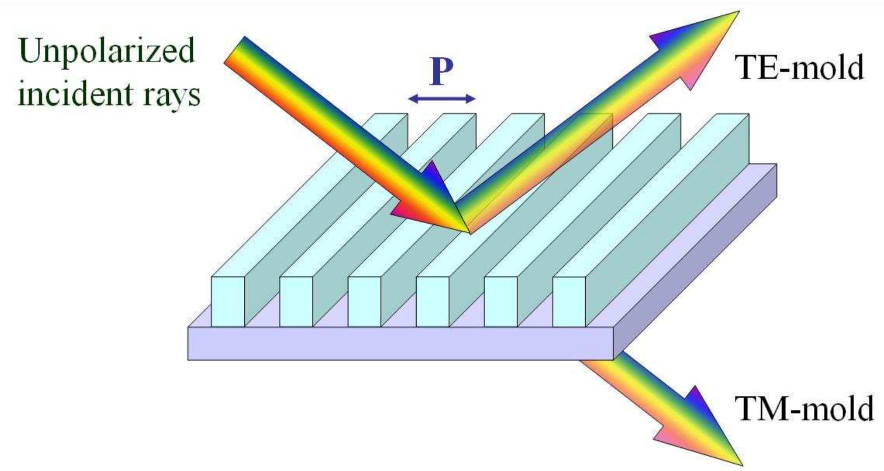

Fig. 1.3 Polarized light separation of a sub-wavelength grating

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 [8], but the proposed model seems to be a special case of the selected materials.

1.3 Brief Review of Nanoimprint Technology

Miniaturization and performance improvements are driving the electronics industry to shrink the feature size of semiconductor devices. Because of its diffraction limit, conventional optical or ultraviolet photolithography is becoming increasingly inadequate. In order to continuously reduce the feature size to nanometer scale, different forms of radiation is developed, for instance, extreme UV, x-ray, electron beams, and ion beams. Electron beam lithography is one of the best methods to produce nanometer-scale pattern by its superior high resolution and focus ability. But these lithographies are costly processes and relying on a serial fabrication paradigm, making the time needed to produce structures too long for practical industrial use.

In the few years, the development of nanoimprint lithography not only can reduce the fabrication time and the manufacturing cost, but also can achieve mass production. Besides, the line-width of the structure can reach about 10 nm by nanoimprint lithography. According to the report of Technology Review in 2003, nanoimprint lithography is one of the fabrication technologies with well developing potential recently [9].

Nano-imprint lithography process involves four key steps：making a mold inscribed with the complement of the desired nano-structure, impressing this mold into a resist-coated wafer, separating the mold, and selectively removing the resist with reactive ion etching (RIE) to transfer the nano-pattern to the target material. Main nanoimprint technologies are divided into three types：

(1) Hot embossing nanoimprint : Through heating and pressurizing during the imprint process achieve nano-structure transferred from the mold to the substrate. The key factor is the uniformity control of the temperature and the pressure during imprinting. Besides, thermal expansion would also cause the defect of the structure after pattern transferred [10][11].

(2) UV-nanoimprint lithography : Through UV-curing at room temperature during the imprint process achieves nano-structure transferred from the mold to the substrate. The low temperature process which can improve hot expansion differs from hot embossing nanoimprint. Using low viscosity photoresist is the key to obtain better imprint result [12].

(3) Soft lithography : Concepts of top-down [13] and bottom-up [13] are combined to carry imprinting out on nonplanar substrates with flexible nano-mold. The definition of nano-pattern is given through the top-down process and nano-structure is formed by means of chemical synthesis through the bottom-up process. Because the nano-mold is flexible, the application of fabrication is more widespread. The key point of this fabrication is also the material property of the photoresist utilized [14].

Nowadays, the semiconductor industry will utilize ArF 193nm stepper to fabricate the nano-scale pattern. However, optical lithography is limited by the wavelength of light source and the mask fabrication. Therefore, nanoimprint technologies provide another way to produce a low cost and high throughput method for nano-structure pattern transfer over large areas employing a single lithographic step.

1.4 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 sub-wavelength grating which can efficiently separate two mutually orthogonally polarized lights. Because the proposed sub-wavelength grating is mainly used in display technology and infrared applications, the period of such a grating requires being smaller than the visible spectra, i.e. smaller than 0.4 μm. In addition, wide-area sub-wavelength grating is more and more essential to cater for wide-screen developing. However, the fabrication of the fine line-width of sub-wavelength grating is difficult for semiconductor process. Thus, the other objective in this thesis attempts to fabricate the proposed sub-wavelength grating by nanoimprint technology.

1.5 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**. Finally, the summary of this thesis and future works will be presented in **Chapter 6**.