2.2 Background on Nonlinear Bragg Gratings Before discussing the complexities of nonlinear Bragg gratings, this section reviews some basic concepts of Bragg gratings and nonlinearity.	2.2 Một số vấn đề cơ bản về Cách tử Bragg phi tuyến Trước khi đề cập đến các cách tử Bragg phi tuyến, trong phần này chúng tôi sẽ nhắc lại một số khái niệm cơ bản về cách tử Bragg và các quá trình phi tuyến.

2.2.1 Linear Bragg Gratings	2.2.1 Cách tử Bragg tuyến tính
Bragg gratings have attracted much attention in the linear regime for many years. In its simplest form a Bragg grating consists of a periodic modulation of the refractive index, as illustrated in Figure 2.1. By properly designing the periodic layered medium, …………………….	Trong nhiều năm qua, Cách tử Bragg trong chế độ tuyến tính đã thu hút rất nhiều sự chú ý của cộng đồng khoa học. Dạng đơn giản nhất của cách tử Bragg là một bộ phận điều khiển chiết suất biến đổi tuần hoàn (Hình 2.1). Thông qua việc thiết kế môi trường phân tầng thích hợp,
Figure 2.1: Schematic of a linear Bragg grating with periodicity A: nQi and nQ2 are the linear refractive indices of two adjacent layers.	Hình 2.1: Sơ đồ cách tử Bragg tuyến tính chu kỳ Λ: nQi và nQ2 là chiết suất tuyến tính của hai lớp lân cận nhau.
it can achieve extremely high reflectance for a selected spectral region, hence acting as a reflector for an incident monochromatic plane wave in this spectral region. In the case of a periodic medium made of layers of two materials with different linear refractive indices, constructive interference in reflection occurs when the resonance condition, called the Bragg condition, is satisfied:	Chúng ta có thể thu được hệ số phản xạ rất lớn ở một vùng phổ nhất định, lúc này thiết bị sẽ đóng vai trò là bộ phản xạ đối với sóng phẳng đơn sắc trong vùng phổ này. Trong trường hợp môi trường tuần hoàn cấu thành từ hai lớp vật liệu có chiết suất tuyến tính khác nhau, các sóng sẽ tăng cường lẫn nhau trong quá trình phản xạ (giao thoa tăng cường) trong điều kiện thích hợp, gọi là điều kiện Bragg có dạng như sau:
Aq = 2nA. (2.1)	Aq = 2nA. (2.1)
Here A is the period of the grating, n is the average refractive index, and Ao is the wavelength of the light impinging on the periodic structure. At a wavelength far from this Bragg condition, the light that is reflected upon the successive periods of the structure is out of phase. As a result, the light that propagates through the structure is essentially unimpeded, allowing the incident wave to transmit through without much reflection. However, if the frequency of the incident wave is within the so-called stopband range, the wave becomes evanescent. This phenomenon is referred to as Bragg resonance. The bandwidth of the stopband of a periodic medium is given by [15]:	[redacted]

AA gap = 2—Ao, (2.2)

where Au is the index difference between the adjacent alternating materials. It can be seen that the bandwidth of the device can be tuned by adjusting the refractive indices of the adjacent layers.

The wavelength-selective nature of Bragg gratings allows for linear, wavelength-domain optical signal processing applications in optical communications [14], including wavelength filtering and dispersion compensation. Various types of fiber Bragg gratings (FBGs) have also been commercially applied in optical fiber sensor systems [9, 14].

2.2.2 Nonlinearities in Optical Materials

The field of nonlinear optics explores and exploits the modification of the optical properties of a material system in the presence of light [16]. The invention of the laser in 1960 enabled examinations of the behavior of light in optical materials at higher intensities, making the study of nonlinear optics possible. To the existing advantages of linear optics, nonlinear optics can add further improvements and efficiency to switching and routing by manipulating light with other light that controls the properties of the medium. Thus, ultrafast nonlinear devices can contribute to alleviating the electronic bottleneck by implementing critical signal processing operations without the need to convert into the electronic domain.

[redacted]

The concept of the Kerr nonlinearity was briefly introduced in the last chapter (see Section 1.2.1). The intensity-dependent refractive index of a nonlinear material is defined in Eq. (1.1). An optical wave traveling in a Kerr nonlinear medium undergoes self-phase modulation (SPM). The phase shift experienced by a pulse of intensity I(z,t) traveling over a distance Az due to SPM is given by: A0SPM = 7Azn2I(z,t). The dependence of the phase shift on frequency leads to chirping (i.e., the distribution of the pulse’s instantaneous frequencies vary temporally). The intensity dependence of the refractive index in Eq. (1.1) can also lead to another nonlinear phenomenon, known as cross-phase modulation (XPM). Unlike SPM where a pulse induces a phase shift by its own intensity, XPM occurs when two or more signals interact with each other. Thus, the total phase shift for a specific signal wave depends on both the intensity of the signal wave and the intensity of other simultaneously transmitted signal waves. The phase shift for the jth signal wave over a distance Az with M signal waves in a medium due to both SPM and XPM is A0NL = A0(j)sPM + A0(j)XPM = 7Az {^n2Ij + 2 SM=j u2I^j [2].

Group velocity dispersion (GVD) must be considered in any analysis of nonlinear interactions since it determines the path length over which nonlinearly-interacting pulses influence one another. It is also significant in ultrashort pulse propagation systems because optical pulses have relatively large spectral bandwidth. Different spectral components of a pulse travel at different group velocities,

[redacted]

[redacted]

[redacted]

causing the pulse to change its temporal width as it propagates. For short optical pulses the dispersive and nonlinear effects act together on the pulse and lead to new features. In particular, a pulse can maintain its temporal shape and travels indefinitely through a nonlinear medium when the SPM and GVD effects compensate each other completely. This is known as a soliton which will be discussed later in this chapter.

2.2.3 Nonlinearity with Periodicity

The previous two sections introduced the fundamental concepts and potential applications of Bragg gratings and nonlinearity. In this section we ask: “what if nonlinearity and periodicity are combined?”

Figure 1.5 illustrates a simple nonlinear periodic structure which consists of alternating layers of linear and nonlinear materials. Adding nonlinearity to the considerations of the stopband in a Bragg structure, the Bragg frequency in Eq. (2.1) and the bandwidth of the stopband in Eq. (2.2) can be rewritten by replacing the refractive indices with intensity-dependent ones:

……………….

The above equations suggest that both the size (width and depth) of the stopband Augap and the position of the center frequency uQ may potentially change with incident intensity. Therefore, the transmission of light through a nonlinear periodic stack is both wavelength- and intensity- dependent, as illustrated in Figure 2.2. The Kerr coefficient is assumed to be positive in this case. According to Eq. (2.3), and demonstrated

[redacted]

with the three curves in Figure 2.2, the Bragg resonance frequency uQ shifts to lower frequencies with increasing intensity; while the width of the stopband widens with increasing intensity.	[redacted]
The above description of the dynamic movement of the stopband with intensity shows nonlinear Bragg structures as excellent candidates for all-optical signal processing devices such as switches. Figure 2.2 also illustrates the switching capability of such structures. The frequency component at ui is transmitted at low intensities, but is reflected strongly at higher intensities; while the frequency component at u2 is strongly reflected at low intensities, but is scarcely reflected at high intensities. Because of the combined effect from nonlinearity and periodicity, light waves at frequencies ui and u2 become detuned from the Bragg condition at high intensities, changing their transmission characteristics. This property can be used to realize an optical switch.	[redacted]
Figure 2.2: Intensity-dependent response of a nonlinear Bragg structure. It shows that the Bragg frequency w0 shifts to lower frequencies ^0 and u'0 with increasing intensity. In addition, the size of the bandgap Augap increases with increasing intensity.	[redacted]
In addition to switching, nonlinear Bragg structures have been either theoretically predicted or experimentally demonstrated to provide limiting, pulse compression, and logic operations. In the next section, a review of the research work investigating the behavior of Bragg structures with a 3rd-order nonlinearity is	[redacted]

presented.	