Chapter 7

Optics of absorbing defect lattices

7.1 Introduction

The optics of defect lattices presented in the previous two chapters were for non-absorbing systems. That is, all the components of the refractive index tensor describing the refractive index anisotropy in the system were real. We can make these systems absorbing either by introducing absorbing dye molecules into the material or by going to those wavelength regions where the system has optical absorption. Generally, optical absorption for the electric vector along the direction of the director n is more than that for the E vector perpendicular to the direction of n. It is a common knowledge that the primary effect of absorption is to decrease the transmitted intensity. But there are also non-trivial reflection and diffraction effects which manifest when the system is absorbing. These effects are absent when the system is non-absorbing. Optics of absorbing TGBS and the tapered lattice, forms the subject matter of this chapter.

7.2 Bragg reflection

An interesting effect in an absorbing periodic structure is the Bormann effect. This is an anomalous transmission for that wave which otherwise is strongly Bragg reflected in the non-absorbing case. The transmission is generally higher at one edge of the reflection band as compared to the other edge. The mode that is unreflected suffers uniform absorption in the medium. In anomalous transmission, the Bragg reflected wave has a greater transmittance at one edge and less on the other edge than the transmittance for the wave that is not Bragg reflected by the medium. This seemingly paradoxial effect can be understood in terms of the standing waves formed by the Bragg reflected wave within the reflection band. In TGBS for example, the eigen modes in each band are left circularly polarised and right circularly polarised light. Only one of them gets strongly reflected and as a result the net wave inside the reflection band is a linear vibration. This linear electric vector of the standing wave is absorbed greatest in regions where it is along the local director n and least in regions where it is perpendicular to n provided the linear dichroism is positive. In traversing the reflection band from the long wavelength edge to the short wavelength edge, the azimuth of the linear vibration may change. Therefore in general, the absorption for this linear vibration at one end of the reflection band will be different from absorption at the other end. Hence the transmitted intensity varies as we go from one end of the reflection band to its other end. The Bormann effect has been theoretically and experimentally established in

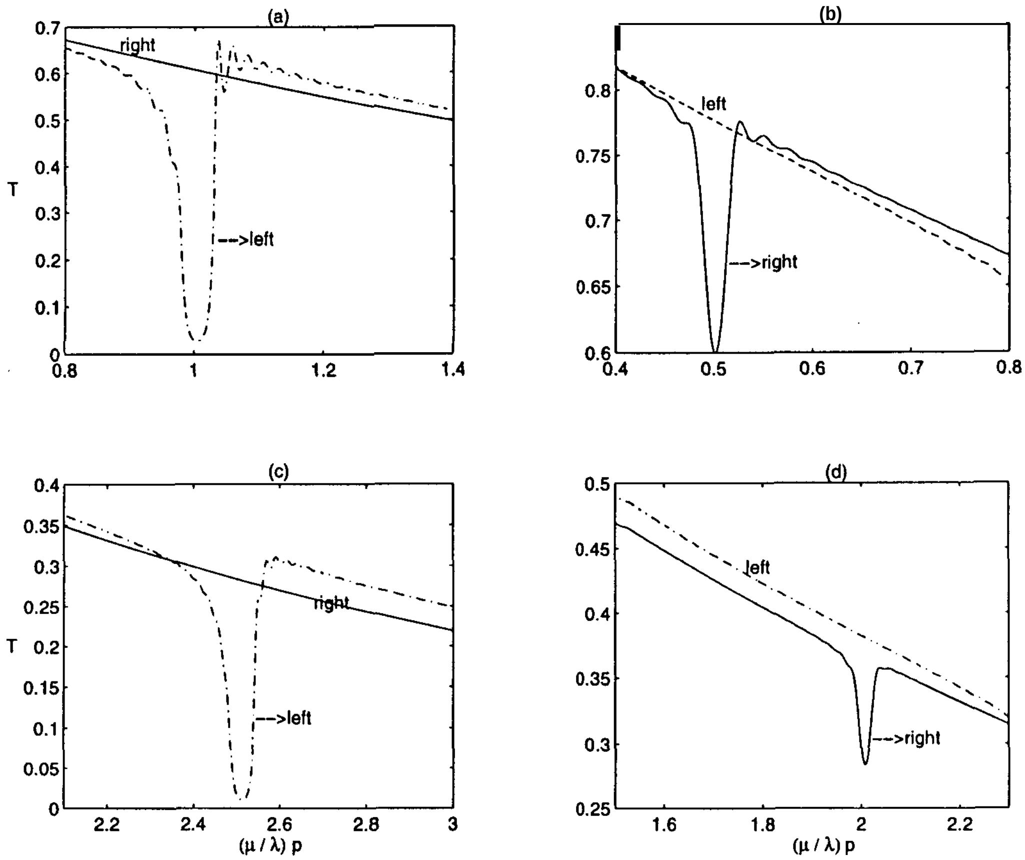

Figure 7.1: *Transmission spectra of TGB_A with $N = 3$ showing the transmittance T as a function of $(\mu p/\lambda)$. In (a) and (b) the anomalous transmission is on the shorter wavelength side of the reflection band. In (c) the anomalous transmission occurs at both the short and long wavelength sides of the reflection band. In (d) the anomalous transmission is absent throughout the band.*

cholesteric liquid crystals [1], [2]. We study here this anomalous transmission in *TGBS* and its indirect manifestation in the reflection spectra of tapered lattices. In addition we also study other effects of absorption on the reflection spectra. The 4 x 4 matrix formulation presented in the previous chapter can be used even in an absorbing system.

7.2.1 Twist grain boundary smectics

(a) Bormann effect

Bormann effect in absorbing $TGBS$ occurs only in the bands associated with the reflection of a circular state. This is shown in Figure 7.1 for a TGB_A with an inter-grain angle of 180°. In every reflection band the circular state which does not suffer reflection is transmitted with an average absorption. However, the reflected circular state is transmitted with a relatively higher intensity over a wavelength range. For the parameters considered in our computations three types of effects are seen in this system. The anomalous transmission or Bormann effect is on the shorter wavelength edge of the reflection band both for a band reflecting left circularly polarised light (as shown in Figure 7.1(a)) and for a band reflecting right circularly polarised light (Figure 7.1(b)). Interestingly, there are some reflection bands in which the anomalous transmission occurs at both the short and long wavelength edges as seen in Figure 7.1(c). Further we also have reflection bands in which the Bormann effect is altogether absent as shown in Figure 7.1(d). On the other hand for other values of intergrain angle, we generally get only one or two of the three types of transmissions. We get similar results in the case of $TGB_{C_\perp}$ also.

(b) Reflection spectra

In absorbing periodic systems, the reflection and transmission spectra are not complementary. Interestingly in absorbing periodic systems, a peak in the reflection band is also a peak in the transmission band around the same wavelength.

Non-uniform absorption

Non-uniform absorption results when the absorbing dye is not spread uni-

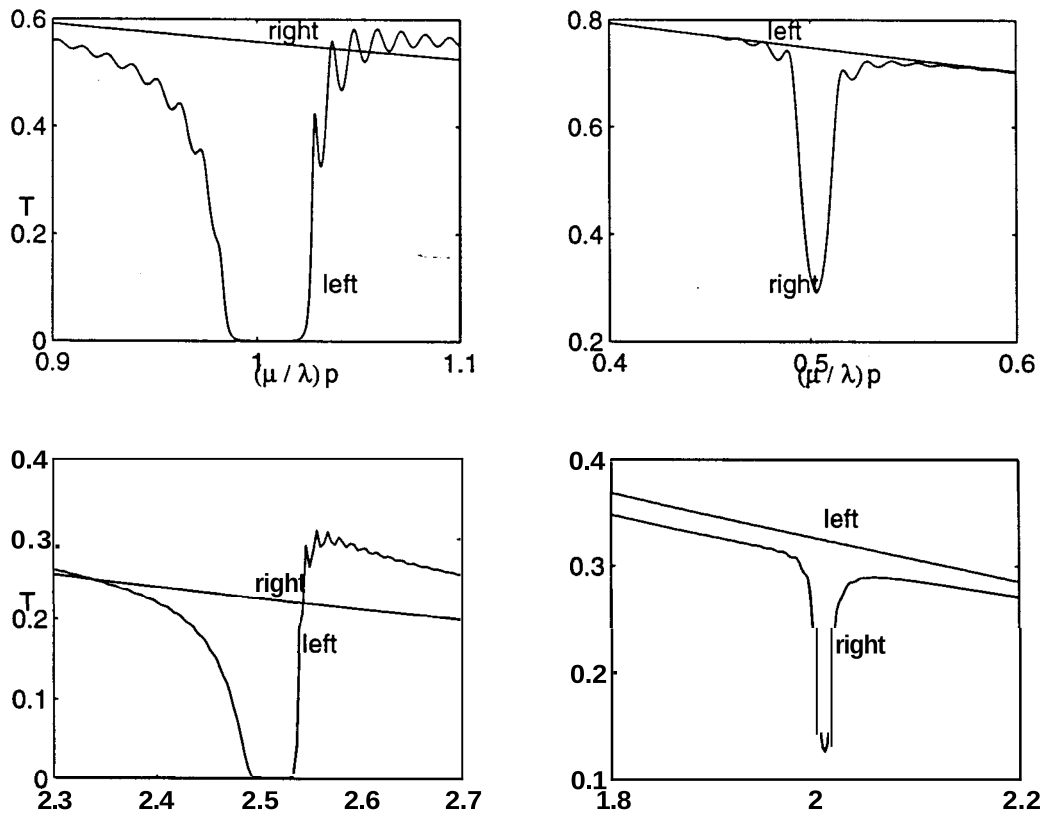

Figure 7.2: *Transmission spectra of TGB_A with $N = 3$ showing the transmittance T as a function of $(\mu p/\lambda)$. The transmittance is with non-uniform absorption for the same set of parameters. The parameters are so chosen that the average absorption is the same as that for the uniformly absorbing case considered earlier.*

formly. The absorbing dye molecules preferentially go into regions of lower molecular order more easily since they are more soluble in a less ordered structure. Thus the grain boundary in TGBS will have more dye molecules than the smectic blocks. This also happens with the soliton lattice created in ferrocholesterics. In this case, the magnetic grains generally move out of the regions of higher magnetic potential energy to regions where the magnetic potential energy is lower. So in realistic cases of defect lattices the absorption is non-uniform throughout the structure. The effect of this non-uniform absorption on a phenomena like Bormann effect in TGB_A is illustrated through Figure 7.2. Here we have assumed that only the grain boundaries absorb. This should be compared with Figure 7.1 where absorption is uniform. We see that the reflection band at $\mu p/\lambda = 0.5$ which exhibited Bormann effect for uniform absorption does not exhibit it in non-uniform absorption case. Also this effect on the large wavelength end for reflection at $\mu p/\lambda = 2.5$ is less pronounced in this present case.

7.2.2 Tapered lattices

Twist tapered lattice

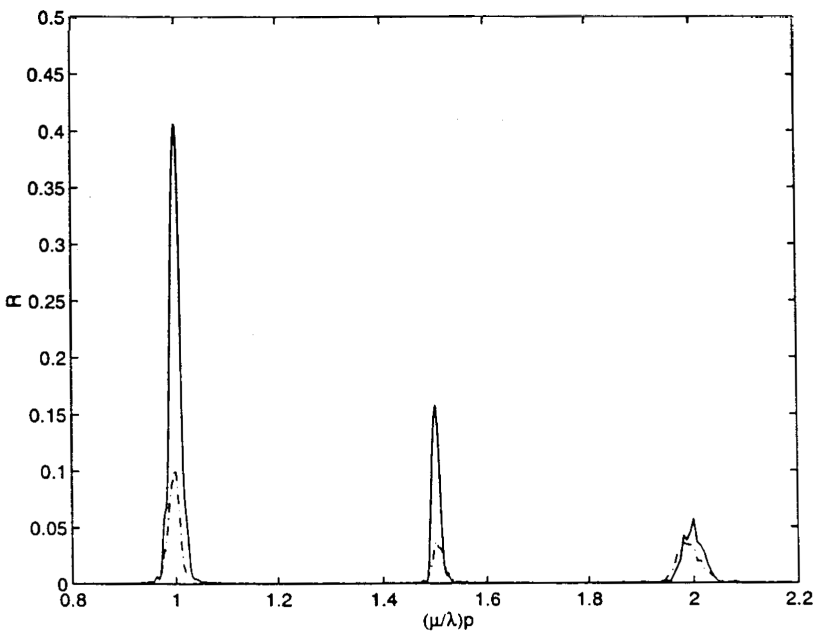

Figure 7.3: *Reflected spectra of absorbing twist tapered lattice (a) $R(k)$ denoted by a continuous line and b) $R(-k)$ denoted by a dashed line. Incident light is left circularly polarised*

We have already stated that the twist tapered lattice reflects both right circular and left circular light in each of its reflection bands. Due to the increased absorption of the standing wave at one edge of the reflection band, the transmittance is asymmetric with a peak at that one edge of the band. In such absorbing systems, the reflection and transmission spectra are not complimentary. **A** peak in the reflection and a peak in the transmission occur at the same wavelength in each band.

Another very interesting optical feature is present in this lattice. It arises due to the inherent asymmetric structure of the tapered lattice. The structure seen by light propagating in the $+\mathbf{k}$ direction is different from that seen by light propagating in the $-\mathbf{k}$ direction. The reflection spectra for right or left circular state for normal incidence along k is different from the one along $-$k. We have already seen this effect in non-absorbing case. This is **all** the more clearly manifest in the absorbing case. Generally, even the widths of the reflection bands are different for the two directions. In Figure **7.3** the effect is shown in the same twist tapered lattice considered previously in the non-absorbing case.

Splay-bend tapered lattice

The splay-bend tapered lattice reflects linearly polarised light polarised long the x direction since for this vibration the structure the structure has a modulation of the index tensor. Here we do not find an asymmetric profile for transmittance or reflection. In this sense this is different from the twist tapered lattice. Since this lattice also is asymmetric, even here $R(\mathrm{k}) \# R(-k)$.

7.3 Optical diffraction

Diffraction for light propagating perpendicular to the direction of lattice modulation has been worked out for absorbing $TGBS$ and tapered lattices. The absorption attenuates considerably the intensity of the diffracted light. Hence only studies on thin samples will be meaningful and in this limit the Raman Nath theory can be used. Incidentally such studies in non-uniformly absorbing $\pi - \pi$ and N – W soliton lattices of cholesterics has lead some interesting results [4].

7.3.1 Twist Grain Boundary Smectics

Uniform absorption

Both TGB_A and $TGB_{C_\perp}$ have similar diffraction patterns with diffraction

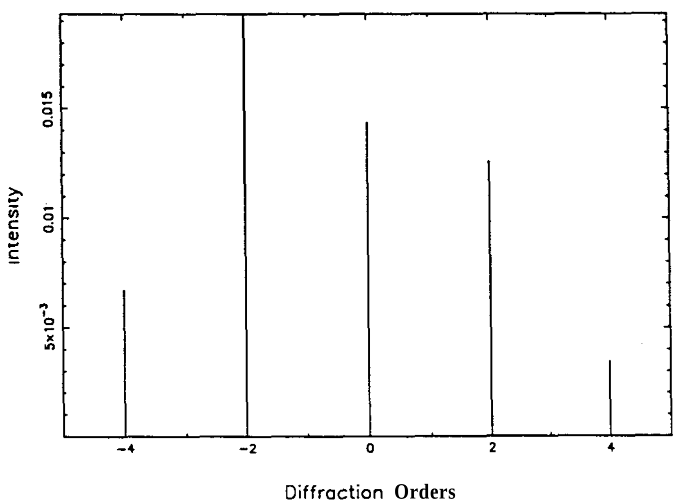

Figure 7.4: *Diffraction pattern for absorbing $TGB_{C_\parallel}$. The angle between the elliptic sections of the index and absorption ellipsoids is 45°. The birefringence $An = 0.1$ and the dichroism $Ak = 0.003$*

peaks at angles Θ given by

$$\Theta = \pm sin^{-1}(2m\lambda/\mu p) \tag{7.1}$$

$$U(\Theta) = \int_{-\infty}^{\infty} exp(-i\frac{2\pi z}{\lambda} sin\Theta)[exp(i\frac{2\pi t}{\lambda}\hat{\mu}(z))]dz \tag{7.2}$$

where

$$\frac{1}{(\hat{\mu}(z))^2} = \frac{(\sin(\psi(z)))^2}{\hat{\mu}_e^2} + \frac{(\cos(\psi(z)))^2}{\hat{\mu}_o^2} \tag{7.3}$$

Here $\hat{\mu}_o$ and $\hat{\mu}_e$ are the local ordinary and the extraordinary complex refractive indices, $\psi(z)$ the orientation of the local director and t is the sample thickness. The diffraction patterns are symmetric. However, surprisingly, in absorbing $TGB_{C_{\parallel}}$ the pattern is asymmetric. This asymmetry is due to the relative tilt between the central elliptic sections, perpendicular to the common two-fold axis of the absorption and the index ellipsoids. The diffraction pattern computed for a relative tilt of $45°$ is shown in Figure 7.4. It is therefore possible to distinguish between TGB_A and $TGB_{C_{\parallel}}$ if they are absorbing. It may be remarked that the diffraction pattern becomes symmetric when the angle between elliptic sections is either equal to $0°$ or $90°$. Thus we find that from a diffraction study of absorbing and non-absorbing $TGBS$ we can distinguish between all the three $TGBS$ viz., TGB_A, $TGB_{C_{\parallel}}$ and $TGB_{C_{\perp}}$.

Non-uniform absorption

The absorbing dye molecules will preferentially exist in grain boundaries. Hence at low concentration of the dye molecules, we can take the smectic blocks both in $TGB_{C_{\parallel}}$ or $TGB_{C_{\perp}}$ to be non-absorbing.

In the case of TGB_A and $TGB_{C_{\parallel}}$ with such a non-uniform absorption even light incident with E vector parallel to the twist axis gives rise to diffraction pattern. Because of the non-uniform absorption there is an amplitude modulation in the transmitted wavefront which results in diffraction. Since in this case

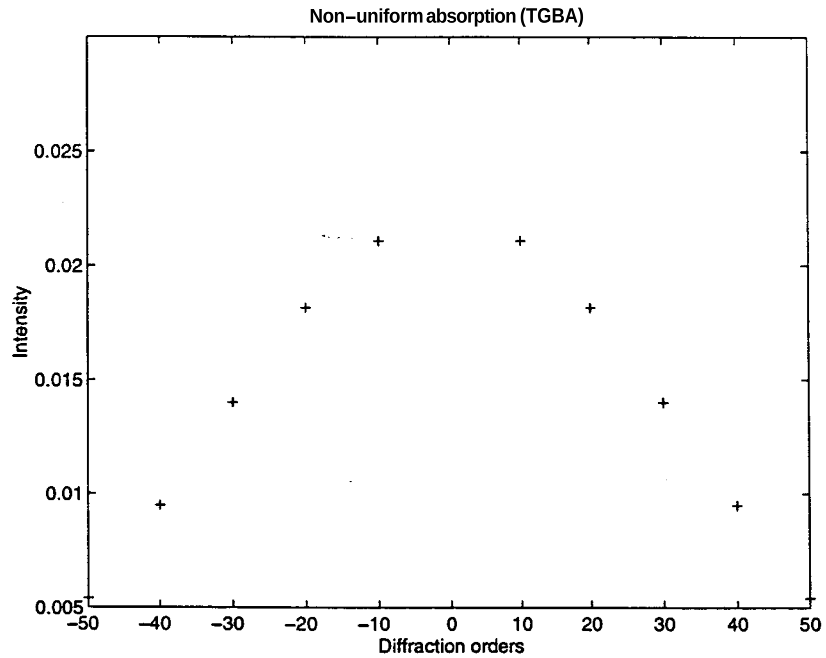

Figure 7.5: *Diffraction pattern of a non-uniformly absorbing TGB_A of thickness 1 micron. The incident light has its E vector parallel to the twist &. An = 0.1.* $\delta k = 0.07$.

the absorbing units are placed closely i.e., at a seperation equal to the smectic block thickness we get many more orders. The light sees a lattice of period nearly equal to distance between the grain boundaries. Hence we can directly arrive at the smectic block thickness in this case. The diffraction pattern for such a non-uniformly absorbing TGB_A is given in Figure 7.5. For the electric vector perpendicular to twist axis, both TGB_A and $TGB_{C_{||}}$ are identical since absorption is confined to grain boundaries where in both are locally uniaxial. That is, the index and absorption ellipsoids are ellipsoids of revolution about n. This results in a symmetric diffraction pattern. This serves as a method to find out whether the absorption is either uniform or non-uniform. Thus

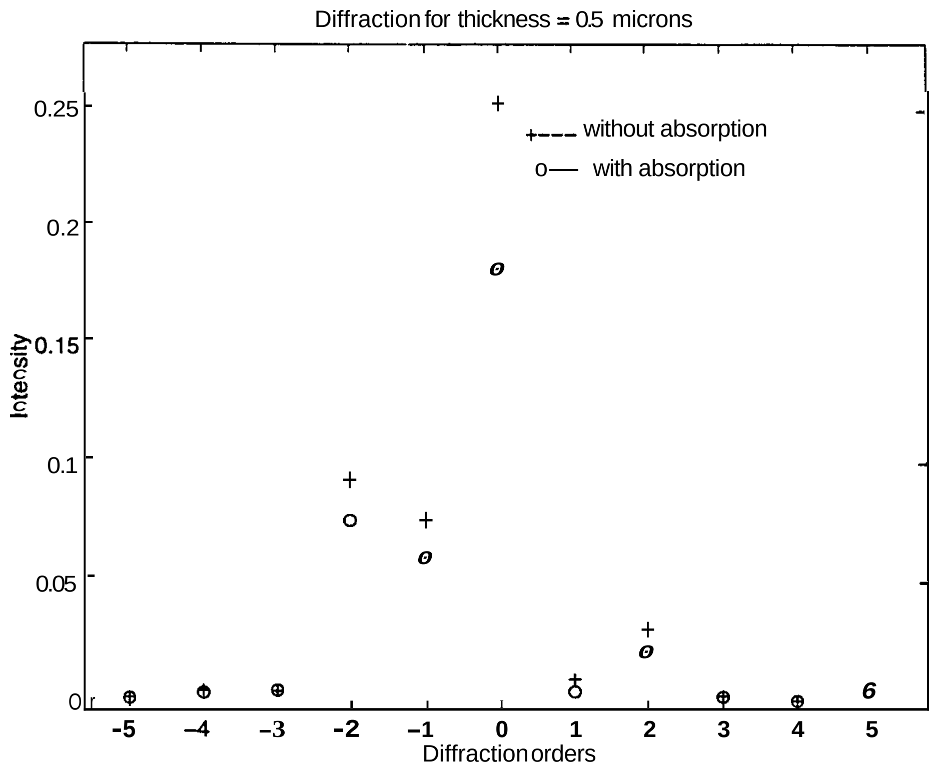

Figure 7.6: *Diffraction pattern from a twist tapered lattice with and without absorption for light incident with the E vector perpendicular to the twist axis.* $An = 0.2$ *and* $Ak = 0.05$.

while uniformly absorbing $TGB_{C_{||}}$ gives rise to an asymmetric diffraction pattern, a $TGB_{C_{||}}$ with absorption, only in grain boundaries leads to a symmetric diffraction pattern.

7.3.2 Tapered lattice

Optical diffraction from twist-tapered lattice and splay-bend tapered lattice does not give rise to qualitatively new features. A typical diffraction pattern for a uniformly absorbing twist tapered lattice with and without absorption are shown in Figure 7.6. As we can see the diffraction pattern essentially asymmetric in both cases but for differences in the intensities.

Non-uniformly absorbing tapered lattices have not been considered since these are dynamic structures moving with a constant velocity. Even at the low velocity considered in our calculations the absorbing magnetic grains cannot redistribute themselves quickly to accommodate the varying director distortions.

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