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Optical second-harmonic generation enhanced by a twist defect in ferroelectric liquid crystals

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Second-harmonic generation (SHG) spectra were numerically calculated in ferroelectric liquid crystals with a twist defect. It is shown that SHG is enhanced when the SHG wavelength is close to the defect mode. The spectral width of the enhanced peak becomes sharper with increasing the sample thickness at the same rate for the width of the defect mode peak. The SHG peak intensity increases with about seventh power of the sample thickness.

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The photonic effect in condensed media has attracted much attention from both scientific and application viewpoints. Chiral liquid crystals (LCs) are interesting, since they spontaneously form helical structures and photonic band gaps are produced in the visible-near-infrared region. Interesting optical properties have been observed when light waves are influenced by the band gap. One well-known phenomenon is a selective reflection for a circulaly polarized wave. In nonlinear optics, phase matching has been achieved by the use of the photonic effect. Shelton and Shen demonstrated the Umklapp process for the third-harmonic generation in cholesteric liquid crystals (CLCs) [1]. Belyakov and Shipov predicted that harmonic generation can be enhanced when the harmonic wave is near the band gap [2,3]. Actually, the enhanced second-harmonic generation (SHG) was observed in ferroelectric LCs (FLCs) [4] and has been studied extensively [5–7].

Recently, photonic defect modes in CLCs received much attention [8–12]. Transfer matrix calculations have been carried out to understand the nature of the defect modes. Yang *et al.* added an isotropic layer in the middle of a CLC and showed that the defect mode emerges inside the photonic band gap [8]. On the other hand, Kopp and Genack introduced a twist defect, which is a phase jump without a spacer, in the middle of a CLC [9]. The twist defect structures were actually produced by a helical stack of overhead transparencies or a dye-doped polymeric CLC [10,11]. In particular, laser emission due to the defect mode was observed with a small lasing threshold in the dye-doped CLC [11]. These results suggest that interesting nonlinear optical phenomena are expected to occur by using defect modes. In this communication, SHG spectra are numerically calculated for the helical structure of FLCs with a twist defect.

Linear and SHG spectra were calculated by the method reported in Ref. [13], where the power depletion of the fundamental wave is assumed to be negligible and the level of approximation is the same as that of 4×4 matrix method. The optical parameters are identical to those in Refs. [13,14]. Namely, the parameters are the same as those in Ref. [7] except for $\tilde{\epsilon}_1=\tilde{\epsilon}_2=2.1$, $\tilde{\epsilon}_3=2.7$. One pitch ($p=0.358\,76\ \mu$m) was sliced into 100 pieces. A single fundamental wave impinges on the FLC cell with an angle of incidence of 1°. The helical axis of FLC was normal to the glass substrates and the helix was right handed. So the right circularly polarized (RCP) waves are selectively reflected but left circularly polarized (LCP) waves are not if no defects are introduced. A twist defect was introduced in the middle of a FLC cell, so that the twist angle was jumped at the defect position by 90°.

According to the previous results for the defect modes in CLCs, the linear reflectance (R) for the defect mode shows anomalous dependence on the total thickness [9]. Namely, the reflectance spectra for RCP and LCP show a dip and a peak in the middle of the selective reflection band, respectively. At a crossover length L_{co}, $R=0.5$ for both RCP and LCP incident waves. Below L_{co}, R approaches 0 for both polarized waves. Beyond L_{co}, R approaches 1 for both polarized waves. For the twist defect in FLCs, reflection spectra for a half pitch band show similar thickness dependence. For

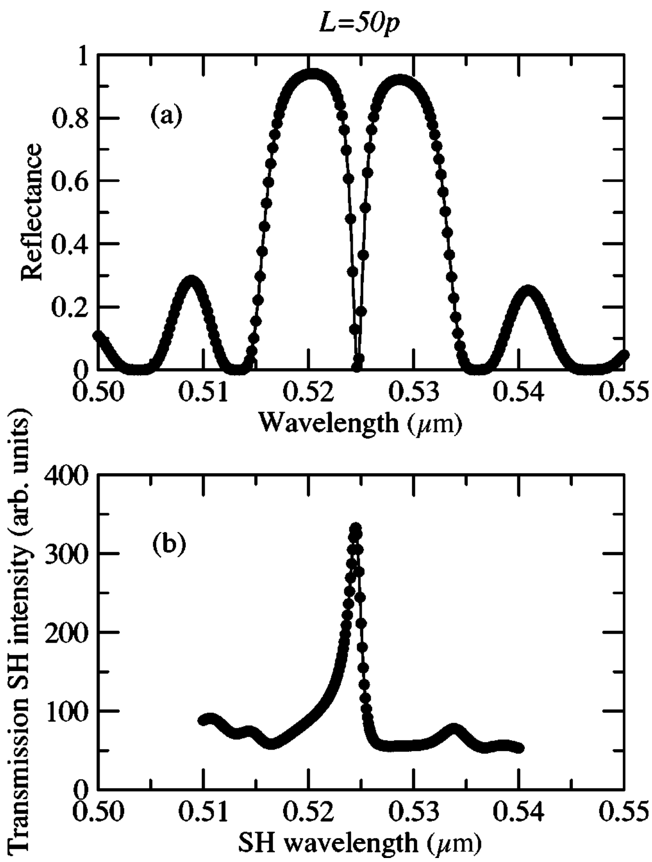

FIG. 1. (a) Linear reflectance and (b) transmission SH spectra for RCP incident wave. $L=50p$.

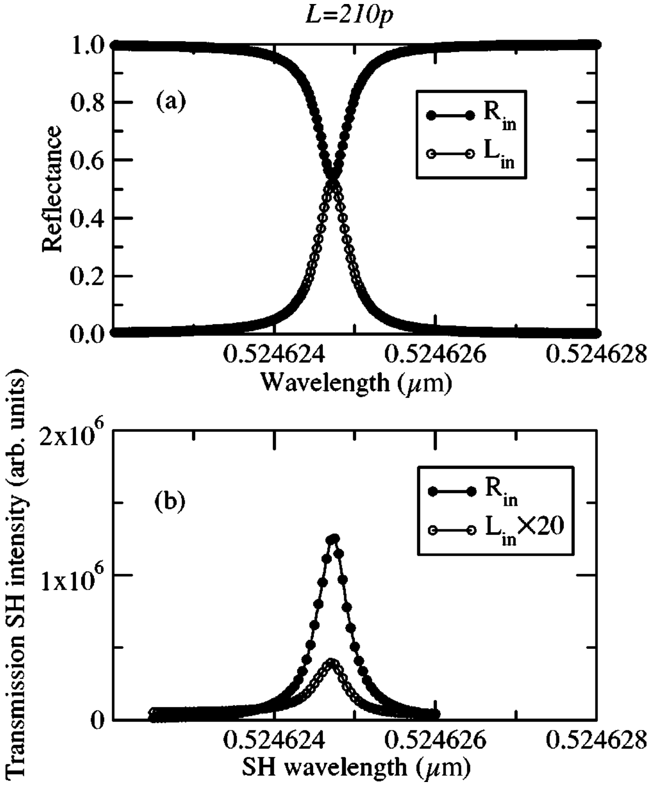

FIG. 2. (a) Linear reflectance and (b) transmission SH spectra for RCP and LCP waves. $L=210p$. The scale of the ordinate is the same as that in Fig. 1(b).

the present calculation, L_{co} was about 210p in total thickness. Because of the limitation of the numerical method, we restricted the calculation up to L_{co}.

For the total thickness (L) of 50p, the linear reflectance and transmission SH spectra were calculated under the incidence of RCP fundamental wave. Figure 1(a) shows the selective reflection for the half pitch band. Because of the relatively thin thickness, the maximum reflectance is less than 1

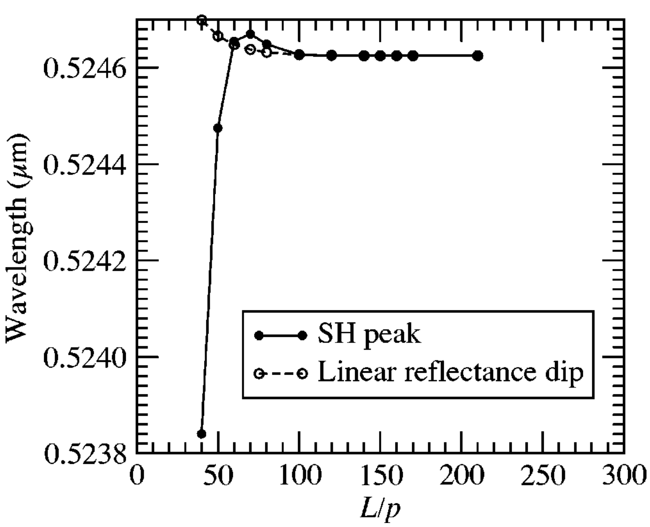

FIG. 3. Thickness dependence of the position of the linear reflectance dip and the transmission SH peak for RCP wave.

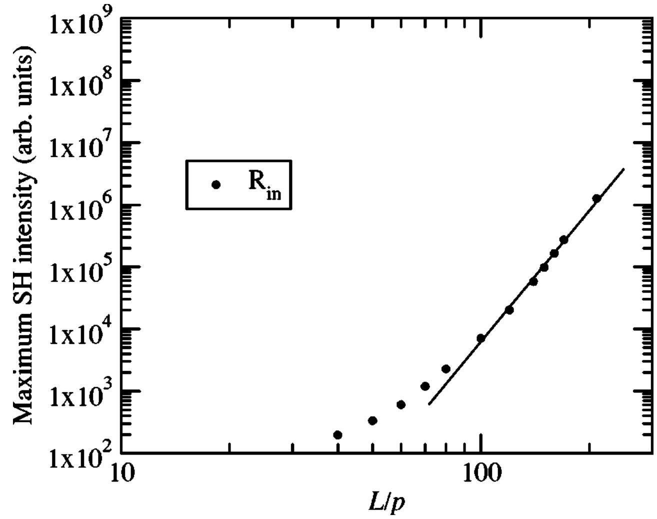

FIG. 4. Thickness dependence of the transmission SH peak intensity. The line indicates the L^7 dependence.

even inside the band gap. Inside the band gap, a deep dip due to the defect mode is cleary seen. Since the thickness is well below L_{co}, R is close to 0 at the dip. This behavior is the same as that for CLCs [9]. Figure 1 (b) shows the SH spectrum for the RCP incident wave. The result indicates that SHG is enhanced near the position of the defect mode. It is known that a special phase matching occurs by the incidence of counter propagating fundamental waves along the helical axis of FLC cells near the edge of the photonic gap. In this case, the higher-energy edge is effective and the special phase matching occurs at the first minimum of the oscillation in the reflectance spectrum [7]. For the present case, however, the special phase matching is not obvious in Fig. 1(b). This is because of the use of a single incident wave in the present geometry.

Figure 2 shows the linear reflectance and transmission SHG spectra for $L=210p$ (L_{co}) upon the incidence of RCP and LCP waves. The spectra only in the vicinity of the defect mode are shown in an expanded scale. SHG is enhanced near the defect mode. The enhancement occurs for the incidence of not only an RCP wave but also an LCP wave at the same wavelength. RCP wave generates stronger SH wave. The line widths for the SHG are found to be almost the same as those for the linear reflectance and show the similar thickness dependence to the CLC case [9].

The positions of the defect mode for the linear reflection and transmission SH peak are shown in Fig. 3. In the region of 100–210p, the thickness dependence is small and SH peaks are located at the defect mode for the linear spectra.

Thickness dependence of the transmission SH peak intensities is shown in Fig. 4. The result indicates that the SH intensity shows about the L^7 dependence in the region of 100–210p. Although the numerical results were obtained in the restricted lengths, the thickness dependent property in this region is distinct from the conventional phase matching (L^2) and the special phase matching (L^4) [7].

This result demonstrates that the defect modes in LCs provide interesting nonlinear optical properties.

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