회절과 2차 조화파 발생을 이용한 준위상정합 소자의 성능 분석

Analysis of QPM devices by Far-Field Diffraction and Second-Harmonic Generation for Quality Checking

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The development of quasi-phase matching (QPM) devices has gained significant importance in various nonlinear optical frequency conversion processes. QPM devices are successfully realized in ferroelectric crystals such as lithium niobate, lithium tantalate and potassium titanyl phosphate by the process of electric field poling, in which the domain structures are designed to compensate the mismatch among the wave vectors of the interacting light beams. In order to achieve the desired device performance, the fabricated device must reproduce the designed structure with high fidelity throughout the poled region [(1)].

Several methods are available to visualize the resulting domain structure. The most direct way is to observe the surface relief pattern with a microscope after etching the opposite side of the patterned electrode. Müller et al. have described another approach to investigate the poled QPM device, in terms of refractive index step created by applying an electric field [(2)]. With these methods, however, only a small area of the poled pattern can be visualized at a time, and scanning is usually necessary for a complete examination. Furthermore, they do not give quantitative estimates for the final device performance. On the other hand, measurement of the SHG tuning curve (second-harmonic output intensity versus wavelength or temperature) provides a direct measure of the final performance of the fabricated QPM device [(1).] However, it is not an easy task to measure the SHG tuning curve owing to the experimental difficulties such as limited tunability of the source laser and the sample temperature, and their narrow bandwidths for long devices. In this work we measured the far-field diffraction pattern from the poled grating structures, demonstrating that the diffraction pattern is equivalent to the SHG tuning curve. Our method can substitute the more involved SHG method for easy and quick evaluation of the QPM device performance.

Z-cut wafers of congruent lithium niobate were used for periodic poling. We used the standard room-temperature electric field poling technique to make 1 cm-long QPM devices with various periods. After poling, the un-patterned face (－Z) was etched to reveal the surface-relief grating structure according to the fabricated periodic domain reversal. A He-Ne laser beam was expanded and collimated to cover the whole length of the device, and illuminated at normal incidence on the etched surface, which acted as a binary phase grating. One of the first-order diffracted beams was focused on a CCD camera using a lens (f = 1.00 m) to measure the intensity pattern in the Fraunhofer regime. For comparison, we also measured the SHG intensity while tuning the fundamental wavelength around the QPM wavelength determined by the period and the material dispersion. The output second-harmonic intensity was measured as the fundamental wavelength was tuned in the vicinity of the QPM condition.

The measured diffraction pattern and the SHG tuning curve for a perfectly periodic sample are shown in Fig. 1. The two theoretical graphs (solid lines) must be identical, if the diffraction pattern is obtained in the Fraunhofer regime, and the fundamental depletion is small in SHG. Under these conditions the diffracted amplitude pattern is simply the Fourier transform of the phase structure given by surface relief to the spatial frequency domain [3], while the QPM second harmonic amplitude is also the Fourier transform of the nonlinear optical coefficient d(z) (z being the propagation distance) to the wave vector mismatch domain [1]. In our SHG experiment the wave vector mismatch is represented by the fundamental wavelength. For a perfectly periodic structure in a well-defined region, the Fourier-transform result must be a shifted sinc-function in both cases as shown in Fig. 1. The experimental data agree well with the theoretical predictions, proving that the diffraction pattern provides equivalent information as the SHG tuning curve.

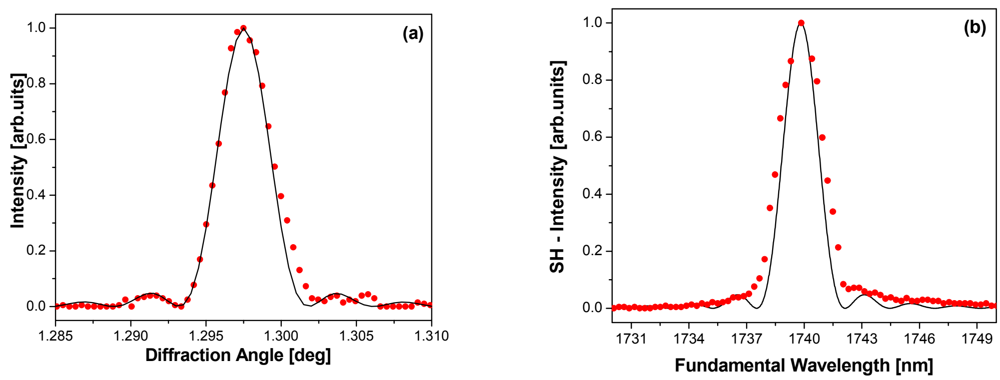

Fig. 1. First-order intensity spectrum for periodically poled lithium niobate of period 24.0 μm. (a) Far-field diffraction pattern, and (b) SHG wavelength tuning curve.

Furthermore, we applied the same analyses to other types of QPM devices such as poorly poled samples, those containing aperiodic domains, and periodic ones with different duty cycles, and compared the two spectra, verifying that the two spectra are equivalent. Our proposed method of diffraction spectrum measurement gives the same quantitative estimation of the final performance of fabricated QPM devices as SHG, with ease and at a much lower cost.

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