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Light diffraction on periodically poled domain structures in lithium niobate crystal in an sunusoidal voltage

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Periodical domain structures (PDS) in lithium niobate are attractive for electro-optic (EO) applications like Bragg deflectors, optical switches and wide-band optical amplitude modulators with the small values of control voltage [1-3]. We report on the experimental investigations of Bragg diffraction in the presence of an external sinusoidal electric field, which has been implemented for extraordinary light waves with the wavelength λ = 655 nm on PDS produced by electric field poling in a $LiNbO_3$: 5 % MgO crystal in Labfer Ltd, Russia. To account for obtained results in the frame of known model of Bragg diffraction [4] the dielectric permittivity perturbations caused by electrically-induced in PDS phase grating [1-3] as well as by alternating 180-degree domain walls [5,6] are considered.

The examined PDS with the Y-walls and the spatial period Λ = 8.79 μm was fabricated in the single crystal sample having sizes 40×2×1 mm^3 along the X, Y, and Z axis, respectively. The lateral dimensions of domain walls agree with associated sizes of the crystal. A sinusoidal voltage with the frequency f = 1 kHz and amplitudes U_m from 0 to 136 V was applied to the sample along Z axis by the use of the pressed metallic electrodes. The focused to the central part of sample by cylindrical lens Z-polarized light beam with λ = 655 nm and power of 25 mW was propagated in XY plane at Bragg angle θ_B to the Y axis and experienced transformation to the diffracted beam on an interaction length d = 2 mm. The time dependences of diffracted beam were recorded by using the photodiode and digital oscilloscope Tektronix TDS 2012C.

It was established that experimental time evolution of diffraction efficiency can be represented as the following Fourier decomposition:

$$\eta(t,U_m) = \eta^{(0)}(U_m) + \eta^{(1)}(U_m)\sin\left[\frac{2\pi}{T}(t+t_0)\right] + \eta^{(2)}(U_m)\cos\left[\frac{4\pi}{T}(t+t_0)\right], \qquad (1)$$

where $T = 1/f$ and the parameter t_0 is determined by initial phase of applied voltage. The amplitudes of Fourier harmonics, which were found from the fitting the dependence (1) to the experimental data for $\eta_{ex}(t)$ at different amplitudes U_m are shown by points in Figure 1.

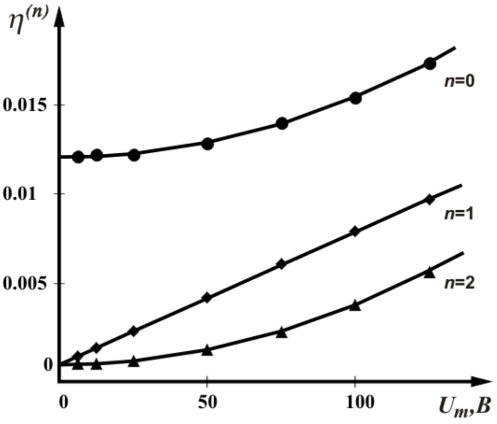

Figure 1. Amplitudes of Fourier harmonics $\eta^{(n)}$ in decomposition of time evolution for efficiency of Bragg diffraction on PDS vs amplitude of applied sinusoidal voltage. The curves are least-square fit to the Eqs. (4)–(6).

The description of observed Bragg diffraction with weak efficiency the approximate expression derived from [3, 4] can be used:

$$\eta_e \approx \left(\frac{\pi d}{\lambda\cos\theta_B}\right)^2 \left|\Delta\dot{n}_e\right|^2 . \qquad (2)$$

The amplitude of the 1-st spatial harmonic for perturbation of extraordinary refractive index n_e with tacking into account the sinusoidal in time EO contribution of PDS as well as the stationary one from electric and elastic fields of domain walls [5, 6] we derive as

$$\Delta\dot{n}_e(t) = -\frac{1}{2}n_e^3\left[r_{33}\dot{F}_{eo}^{(1)}\frac{U_m}{h}\sin\left(\frac{2\pi}{T}t\right) - \left(R_{33}+p_{31}\frac{d_{31}^S}{C_{11}^P}\right)P_S^2\dot{F}_{dw}^{(1)}\right], \qquad (3)$$

where h is the crystal thickness, $\dot{F}_{eo}^{(1)}$ and $\dot{F}_{dw}^{(1)}$ is the amplitudes of the first spatial harmonic generated by the external electric field (*eo*) and domain walls (*dw*), r_{33} is the linear EO coefficient, R_{33} is the EO constant of the quadratic effect, p_{31} is the elasto-optic constant, d_{31}^S is the electrostriction coefficient of the mechanically clamped crystal, C_{11}^P is the modulus of elasticity for the constant electric polarization, and P_S is the modulus of the spontaneous polarization. Use of Eqs. (2) and (3) yields

$$\eta_e^{(0)}(U_m) = \left(\frac{\pi d n_e^3}{2\lambda\cos\theta_B}\right)^2\left[\left(R_{33}+p_{31}\frac{d_{31}^S}{C_{11}^P}\right)^2 P_S^4\left(F_{dw}^{(1)}\right)^2 + \frac{\left(r_{33}F_{eo}^{(1)}\right)^2}{2h^2}U_m^2\right], \qquad (4)$$

$$\eta_e^{(1)}(U_m) = -2\left(\frac{\pi d n_e^3}{2\lambda\cos\theta_B}\right)^2 r_{33}\left(R_{33}+p_{31}\frac{d_{31}^S}{C_{11}^P}\right)P_S^2\,\frac{F_{eo}^{(1)}F_{dw}^{(1)}}{h}\cos\Delta\varphi\, U_m, \qquad (5)$$

$$\eta_e^{(2)}(U_m) = -\left(\frac{\pi d n_e^3}{2\lambda\cos\theta_B}\right)^2\frac{\left(r_{33}F_{eo}^{(1)}\right)^2}{2h^2}U_m^2, \qquad (6)$$

where $\dot{F}_{eo}^{(1)} = F_{eo}^{(1)}\exp(i\varphi_{eo})$, $\dot{F}_{dw}^{(1)} = F_{dw}^{(1)}\exp(i\varphi_{dw})$, and $\Delta\varphi = \varphi_{eo} - \varphi_{dw}$.

The results of our fit procedure based on Eqs. (4)–(6) and on the uses of the material parameters of lithium niobate (see, for example, [3, 5, 6]), namely, r_{33}=30.8 pm/V, R_{33}=0.091 m^4/C^2, p_{31}=0.17, d_{31}^S=0.216$\cdot$10^9 m^{2}N/C^2, C_{11}^P=2.03$\cdot$10^{11} N/m^2, P_S=0,75 C/m^2, and n_e=2.187, as well as the values F_{eo} = 0.538, F_{dw}=42.9$\cdot$10^{-6} and $\Delta\varphi$ = 65°, are shown in Fig. 1 by the solid lines.

The distinction between F_{eo} = 0.538 and 2/π = 0.637 inherent for ideal PDS [7] can be due to the availability of air gaps between the pressed electrodes and the LiNbO$_3$: 5 % MgO sample.

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