The estimated error is significantly smaller than previous measurements. The enhancement factor \( (2n - 1)/n \) due to \( n \) randomly phased longitudinal modes is experimentally checked.

3) A general analytical expression is developed for the case of a lowest order Gaussian beam of finite size \( w_0 \) in a nonlinear crystal of length \( L \), at or near index matching. The amount of SHG depends upon the ratio of \( L \) to a "Rayleigh length" \( L_R = \pi w_0^2/\alpha \). The dependence of SHG upon crystal orientation is explained by the Gaussian plane wave spectrum associated with the finite crystal size. Between the middle two regions, there is an optimum degree of focusing, for maximum SHG, occurring when \( 2L = L_R \). The amount of SHG at optimum focusing varies as \( L \). (For very short crystals or for crystals in which \( a \) is very small, the four regions exist, and the optimum condition is modified.)

These analytical results are verified in detail using a wide range of degrees of focusing in ADP crystals of three different lengths. The absolute value of \( d_{31} \) in ADP when measured with a focused beam also agrees very closely with the value measured with a collimated beam, thus further verifying the analysis.

4) Quadrupolar SHG, dc electric-field-induced SHG (ESHG), and the classical Kerr effect have been measured in the centrosymmetric crystal calcite using a focused CW 6328 A laser beam. The observed quadrupolar effect in calcite, compared to \( d_{31} \) in ADP, has a magnitude \( 0.85 \times 10^{-8} \pm 14 \) percent, or somewhat smaller than the value of a similar bulk (not identical) quantity measured with pulsed ruby lasers by Tarrhane et al. The observed coefficient for ESHG, relative to ADP, was \( 2.1 \times 10^{-8} \pm 24 \) percent. The measured effective Kerr coefficient (not corrected for the combined effects of photothermial and stress effects proportional to the square of the electric field) was \( 2.1 \times 10^{-4} \) esu \pm 16 percent. The center of the quadratic variation of ESHG with dc electric field was observed to be displaced from zero dc field, as previously observed by Tarrhane et al. One previously observed displacement of this displacement as due to inhomogeneous dc electric fields is ruled out by these experiments. Alternative explanations remaining are surface harmonic generation (previously proposed) and the effects of a quadrupolar correction to the Poynting theorem.

5A-3 Measurement of Optical Second-Harmonic Generation in Centrosymmetric and Noncentrosymmetric Crystals Using Focused Gaussian Laser Beams

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The optical second-harmonic generation (SHG) caused by a focused, lowest order Gaussian laser beam in index-matched crystals of ADP and calcite has been analyzed in detail, and measured experimentally with CW 6328 A laser beams, leading to the following results:

1) For a collimated laser beam, the dependence of SHG upon crystal orientation near index matching differs from the simple (sin \( 2\phi \)/\( 2\phi \)) dependence in small but significant details. These small differences are fully explained by the Gaussian plane wave spectrum associated with the finite Gaussian transverse variation of the laser beam.

2) Using a focused laser beam, the nonlinearity in ADP is found to be \( d_{31} \) (ADP, 6328 A) \( = 1.30 \times 10^{-9} \) cm V \( \pm 12 \) percent.

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References


5A-4 Theoretical and Experimental Studies of Optical Second-Harmonic Generation in Birefringent Crystals


A theory has been developed to describe second-harmonic generation (SHG) from a laser beam for the various modes of a resonator. The scalar diffraction integral is solved for the propagation of an extraordinary harmonic wave close to index matching. The approximations involved are identical to those used in deriving the modes of a resonator. The theory developed is completely general and can be applied for crystals of any length. Kleinman et al. have treated two special cases where 1 \( \gg a \) and 1 \( \ll z_0 \) was the confocal parameter of the beam. Our theory can be used for these regions but the experimental and theoretical results to be presented apply to the region where 1 \( \sim a \), which is most important for practical devices.

A detailed solution of the diffraction integral in a birefringent medium shows that the effect of anisotropy can be described completely by moving the source by \( x \tan \alpha \) (where \( \alpha \) is the distance traveled in the medium and \( \alpha \) is the angle between the Poynting vector and the wave normal). This result is applied to the propagation of waves radiating from the second harmonic polarization generated by a Gaussian beam. The expression for the SH polarization is obtained by squaring the Poynting vector for the field in the Gaussian beam. The diffraction integral for the harmonic wave has to be integrated over the \( x \) and \( y \) directions which are normal to the propagation direction \( z \), and also along the \( z \) direction to include SHG along the entire length of the crystal. The first two integrations can be performed exactly but the final integral has to be carried out numerically. The effects of absorption and scatter at both the fundamental and harmonic frequencies are included.

Two types of calculation are made, one of the form of the harmonic beam at the exit face of the crystal which we define as the near-field pattern, and the other of the form of the beam at large distances defined as the far-field pattern. Both the intensity and phase distributions are computed for these two cases. A number of computations have been made of both the near-field and far-field patterns of harmonic from a TM01 beam with \( 2a = 31.4 \text{ mm} \) for ADP crystals thicknesses between 3 and 40 mm. An approximation for the near field has been found which avoids numerical integration but gives results in good agreement with the exact theory. Far-field patterns have been computed for different positions of the crystal in the Gaussian beam and the SHG efficiency obtained. Calculations have also been performed to obtain the efficiency for various crystal thicknesses.

The field patterns of second harmonic generation generated by TEM modes have also been investigated. No exact solutions have been carried out for this mode since an approximate solution has been found adequate to describe the different patterns. In this description the harmonic wave can be expressed as two orthogonal modes, TEM modes, and the difference between them is determined by the position of the crystal in the beam. As a result of this phase difference the far-field pattern consists of three maxima when the