...e Grüneisen parameter calculated from the single ...tal and the polycrystal TOEC with that calculated ... bulk data. Using values for the linear expansion ...ient, $\alpha=7.02\times10^{-6}$ °C^{-1}, and specific heat, ...0.065 cal g^{-1} °C^{-1} obtained from handbooks and ...density $\rho=8.578$ g/cm^3, and isothermal bulk mod... $K^T=1.687\times10^{12}$ dyn/cm^2 obtained in the present ... in the relation

$$\gamma_B=3\alpha K^T/C_v\rho \qquad (4)$$

...es the value for the bulk Grüneisen parameter of ...1.52. Using the methods of Ref. 4 for obtaining ... Grüneisen parameter from the elastic constants by ...aging the contribution of 39 pure-mode phonons ...at parameter results in values of $\gamma_{SC}=1.511\pm0.026$ ... $\gamma_{PC}=1.546\pm0.092$ for the single crystal and the ...crystal, respectively. A useful calculational equa... for the polycrystal Grüneisen parameter which can ...obtained from the equations of Brugger[4] by imposing ...ropy conditions is

$$\ldots=(K^Tm_1'-\Delta K)/6C_{11}^S+(K^Tm_2'-\Delta K)/3C_{44}^S, \qquad (5)$$

...re m_1' and m_2' are the measured hydrostatic pres... slopes for the polycrystal and $\Delta K=K^S-K^T$ is the ...ference between the adiabatic and isothermal bulk ...duli.

...A second check on the values of the TOEC deter...ed here is to compare the measured polycrystal ...stants with values calculated from the single-...stal constants. Recently, equations permitting this comparison were derived[30] using strain-energy density considerations with the approximation that a uniform state of strain acting on the surface of a homogeneous, quasi-isotropic, polycrystalline body produces a uniform strain throughout the body. This development, analogous to that of Voigt relating the second-order elastic constants,[31] leads to the following relations between the TOEC:

$$\nu_1=\tfrac{1}{3}\tfrac{1}{5}(C_{111}+18C_{112}+16C_{123}-30C_{144}-12C_{166}+16C_{456})$$

$$\nu_2=\tfrac{1}{3}\tfrac{1}{5}(C_{111}+4C_{112}-5C_{123}+19C_{144}+2C_{166}-12C_{456})$$

$$\nu_3=\tfrac{1}{3}\tfrac{1}{5}(C_{111}-3C_{112}+2C_{123}-9C_{144}+9C_{166}+9C_{456}). \qquad (6)$$

Using the values of C_{ijk} for columbium given in Table III in these equations results in $\nu_1=-4.59\pm0.38$, $\nu_2=-3.80\pm0.15$, and $\nu_3=+0.78\pm0.09$, all in units of 10^{12} dyn/cm^2. These values are seen to be in very good agreement with the values measured for the polycrystal sample B shown in Table V which provides an indirect check on both sets of TOEC.

ACKNOWLEDGMENTS

We are grateful for the excellent work in sample preparation done by Robert G. Herron who polished the samples and Paul C. Romo who performed the x-ray orientations.

[30] R. Chang, Appl. Phys. Letters **11**, 305 (1967).
[31] W. Voigt, *Lehrbuch der Kristallphysik* (B. G. Tuebner, Leipzig, 1928), p. 962.

JOURNAL OF APPLIED PHYSICS VOLUME 39, NUMBER 7 JUNE 1968

Lithium Niobate: Effects of Composition on the Refractive Indices and Optical Second-Harmonic Generation*

J. E. MIDWINTER†
Royal Radar Establishment, Malvern, Worc's, England

(Received 22 January 1968)

Crystals of lithium niobate have been grown with varying amounts of Li_2O, Nb_2O_5, and MgO present in the melt. The refractive indices have been measured and the birefringence so obtained correlated with the phase-matching temperature for second-harmonic generation (SHG) and with the composition. The use of optical methods is decribed for the study of compositional uniformity and a method of correcting the effects of uniform composition gradients on SHG described.

I. INTRODUCTION

An extensive literature already exists on lithium ...bate with reference to its use in nonlinear optics for ...ixing or modulating optical beams. It was first pro...ed in this connection by Boyd *et al.*,[1] who described its nonlinear properties and refractive-index data suitable for calculating the details of phase matching. Miller *et al.*[2] extended this data by pointing out the favorable property of thermally tunable refractive indices present in lithium niobate and showed how this could be used to obtain noncritical phase matching. Hobden and Warner[3] have given extensive details of the wavelength and thermal variation of the refractive

* Based in part on a dissertation submitted to the University of London in partial fulfullment of the requirements for the degree of Doctor of Philosophy.
† Present address: Perkin–Elmer Corp., Norwalk, Conn. 06810.
[1] G. D. Boyd, R. C. Miller, K. Nassau, W. L. Bond, and A. ...age, Appl. Phys. Letters **5**, 234 (1964).
[2] R. C. Miller, G. D. Boyd, and A. Savage, Appl. Phys. Letters **6**, 77 (1965).
[3] M. V. Hobden and J. Warner, Phys. Letters **22**, 243 (1966).