Relative signs of the nonlinear coefficients of potassium titanyl phosphate

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We measure the nonlinear optical d coefficients of potassium titanyl phosphate relative to d_{11} of quartz and use these to calculate the effective coefficient d_{eff} for type-I phase matching. We compare the calculations with a variety of measurements and determine that the signs of the different d coefficients are all the same. © 1997 Optical Society of America

1. Introduction

The d coefficients of potassium titanyl phosphate (KTP) have been measured by many authors,[1–6] but only Boulanger *et al.*[1] have made a thorough investigation of their relative signs. From the size of d_{eff} as a function of the phase-matching direction, they concluded that the different d coefficients should have the same sign. Unfortunately, the absolute values of their d coefficients were not in agreement with those published by other authors.[2–6]

In a recent paper van der Mooren *et al.*[7] reported on the type-I phase-matching angles and conversion efficiency in KTP for second-harmonic generation (SHG) at a fundamental wavelength of 773–834 nm. Using a simplified model to calculate the d coefficients, they found that, within the error bars, their measurements were in agreement with the coefficients as published by Vanherzeele and Bierlein.[2] However, the agreement appears to be due to the fact that van der Mooren *et al.*[7] used a different d coefficient for the quartz reference with respect to Vanherzeele and Bierlein.[2] Also, the model they used was too simplified to explain the measured data in a correct way.

To clarify this confusing situation, we decided to revaluate the nonlinear optical response of KTP. Using the Maker fringe technique and the model as described by Boulanger *et al.*,[1] we determined the absolute values and the relative signs of the relevant d coefficients. We demonstrate clearly that the relative signs are all the same. Although we also find the same d_{eff} as Boulanger *et al.*,[1] our values for the d coefficients are substantially larger and in much better agreement with those of Vanherzeele and Bierlein.[2]

2. Relative Signs of d_{15}, d_{24} and d_{33}

For KTP d_{eff} can be described with the field tensor $F^{(2)}$ in the following way[1]:

$$d_{\mathrm{eff}} = F_{15}d_{15} + F_{24}d_{24} + F_{31}d_{31} + F_{32}d_{32} + F_{33}d_{33}. \quad (1)$$

In Fig. 1 the field factors for type-I phase-matching SHG at a fundamental wavelength of 834 nm are plotted as a function of the phase-matching orientation. From Fig. 1 and Eq. (1) it is clear that the influence of d_{31} and d_{32} on d_{eff} is small in comparison with d_{15} and d_{24} and the use of Kleinmann's rule is allowed, as was supposed by Boulanger *et al.*[1]

It is also clear that the field factors F_{15}, F_{24}, and F_{33} have the same shape as a function of the phase-matching orientation. Therefore it is not possible to subtract the values of the d coefficients from a single experiment for type-I phase matching as a function of the phase-matching direction, as was done by Boulanger *et al.*,[1] and these measurements should be used only as a check for the values that are determined in a different way.

First we determined the relative signs of d_{15} and d_{24}. We used the Maker fringe technique to measure the d coefficients of KTP relative to d_{11} of quartz (0.30 pm/V at 1064 nm). We performed these measurements at a fundamental wavelength of 1064 nm, and we found that $|d_{15}| = 1.78$ pm/V, $|d_{24}| = 3.37$ pm/V, and $|d_{33}| = 17.4$ pm/V. These values agree well with those obtained by Vanherzeele and Bierlein[2] (see Table 1).

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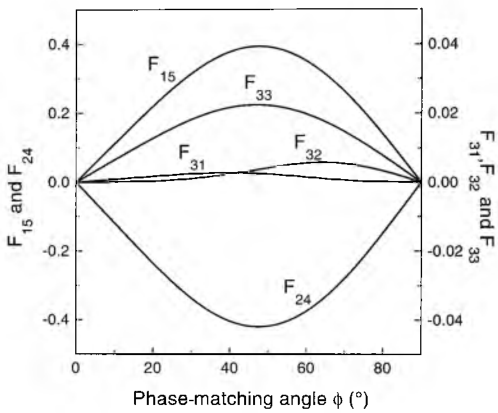

Fig. 1. Field factors for type-I SHG at a fundamental wavelength of 834 nm as a function of phase-matching angle ϕ.

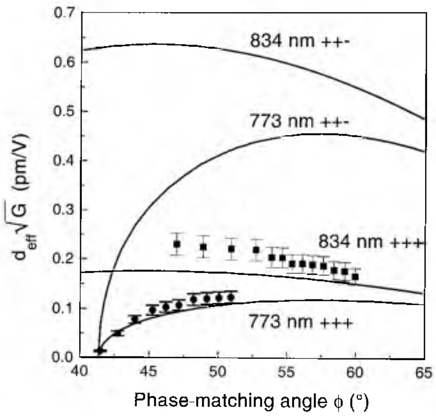

Fig. 2. Calculated (curves) and measured[7] (circles and squares) $d_{\mathrm{eff}}\sqrt{G}$ (G is the walkoff correction) as a function of phase-matching angle ϕ. Calculations are made for the same sign $(+++)$ and for different signs $(++-)$ of d_{33} with respect to d_{15} and d_{24}.

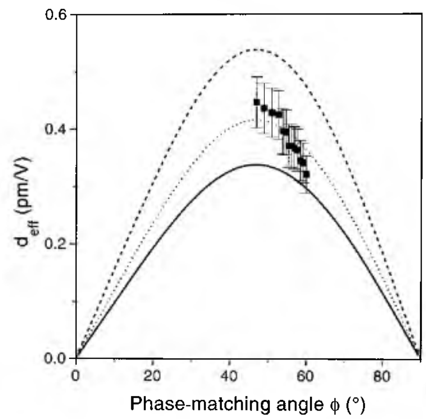

Fig. 3. d_{eff} for type-I SHG as a function of phase-matching angle ϕ calculated from the d coefficients given by different authors (Kato,[3,4] dashed curve; Vanherzeele and Bierlein,[2] dotted curve; Boulanger[1] and the current study, solid curve).

From this d_{eff} can be calculated for type-II phase matching for the propagation directions $\phi = 25°$ and $\theta = 90°$ once the relative signs are known. Assuming that d_{15} and d_{24} have the same sign gives a value of 3.09 pm/V, whereas different signs give 2.45 pm/V. Given the values in the literature[2–6] of approximately 3.2 pm/V, we can conclude that d_{15} and d_{24} must have the same sign.

For the calculations of d_{eff} for type-I phase matching we made use of Miller's rule to correct for the wavelength dependence. We calculated phase-matching curves and walkoff angles based on the refractive indices as given by Vanherzeele *et al.*[8]

Figure 2 shows the measurements from van der Mooren *et al.*,[7] which were corrected for the d_{11} they used for quartz, and the calculated curves for different signs of d_{33} with respect to d_{15} and d_{24}. From this it is obvious that the three important d coefficients should all have the same sign.

In Fig. 3 we plotted d_{eff} from the coefficients as given by other authors[1–4] (Table 1). Note that the d coefficients of Vanherzeele and Bierlein[2] give a better agreement between the calculation and the measurements than those we found with the Maker fringe technique. This might be due to the fact that the measurements of Vanherzeele and Bierlein[2] were performed at a fundamental wavelength of 880 nm, which is near the fundamental wavelength of the type-I phase-matching experiments. In that case the correction resulting from Miller's rule are smaller than for our measurements, for which the fundamental wavelength was 1064 nm.

Furthermore, we observed that the numbers given by Boulanger *et al.*[1] give the same d_{eff} although their values for different coefficients are approximately 1.3 times smaller. Therefore we conclude that it is hard to subtract the absolute values of the different d coefficients from a type-I phase-matching experiment.

Table 1. *d* Coefficients at a Fundamental Wavelength of 1064 nm

Coefficient (pm/V)	This Study	Boulanger *et al.*[1]	Vanherzeele and Bierlein[2]	Kato[3,4]
d_{15}	1.78	1.4	1.91	1.9
d_{24}	3.37	2.65	3.64	3.4
d_{33}	17.4	10.7	16.9	8.1

3. Conclusion

We have determined the values and relative signs of the various d coefficients of KTP as well as d_{eff} using the Maker fringe technique. We have shown that the relative signs are all the same, as was reported by Boulanger *et al.*,[1] but that the absolute values are in much better agreement with those of Vanherzeele and Bierlein.[2] In conclusion, we can say that type-I phase matching for KTP in a small wavelength region is a useful technique to determine the relative signs of the d coefficients once the magnitudes are known.

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