Characterization of Partially Deuterated KDP Crystals Using Two-Wavelength Phase-Matching Angles

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Large-aperture partially deuterated KDP crystals enable high-energy broadband parametric amplifiers pumped by frequency-converted, high-energy nanosecond Nd:glass lasers, opening the way for the generation of optical pulses with energy of hundreds of joules and bandwidth supporting sub-20-fs pulses.[1–5] The optimal noncollinear angle between signal and pump beams for broadband gain depends on the deuteration level. This optimization is practically difficult because of uncertainties in the deuteration level of grown DKDP crystals, as well as in the models used to calculate the wavelength-dependent and deuteration-dependent optical indices that are required for phase-matching calculations.

We present the concept and application of a novel two-wavelength phase-matching technique that precisely determines the deuteration level of a DKDP crystal consistent with known index models. The determined deuteration level and model are the much-needed combination required for performance modeling and experimental optimization of an optical parametric amplifier (OPA). By experimentally determining the deuteration level of a crystal consistent with a specific index model, the described technique allows for more-accurate performance simulations as well as better identification of optimal phase-matching conditions for experimental implementation.

Determining a deuteration level consistent with a specific index model relies on the measurements of phase-matching angles at two different wavelengths [Fig. 1(a)]. Combined monochromatic sources at λ_1 and λ_2 are used as the OPA seed to facilitate the measurement of the gain as a function of phase-matching angle and allow one to directly determine the crystal's deuteration

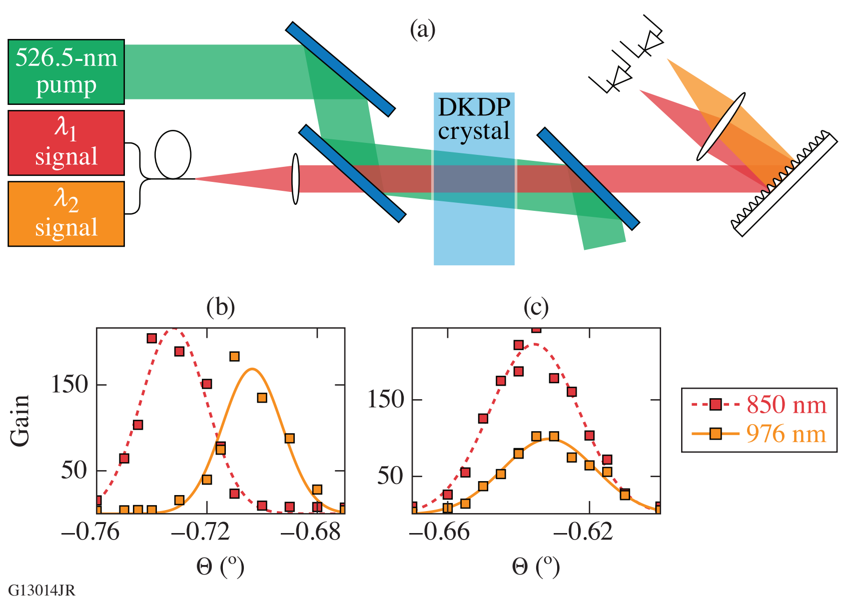

Figure 1
(a) Layout of the experimental setup. [(b),(c)] Measured gain versus rotation-stage angle for one crystal at α = 0.49° and α = 0.61°, respectively. The data at each wavelength (squares) are fitted by a Gaussian function (solid and dashed curves).

level. Indeed, simulations and analysis of the phase-matching conditions for a noncollinear OPA show that there is a one-to-one relation between the difference θ_1–θ_2 in phase-matching angles and the deuteration level x for a given noncollinear angle and index model. Examples of measured small-signal gain curves at two wavelengths as a function of the crystal angle relative to normal incidence are shown in Fig. 1(b). For each wavelength, the optimal angle for phase matching is determined by fitting the data with a Gaussian function. The deuteration level consistent with the measured angle difference and a specific index model is then determined, as well as a confidence interval obtained from the fitting routines. The ordinary and extraordinary indices of DKDP are determined as a function of wavelength and deuteration level using interpolation or extrapolation of indices calculated from Sellmeier equations. These equations originate either from the Kirby model for non-deuterated KDP and 96% DKDP,[6] the combination of the Kirby model for 96% DKDP with the Zernike model for KDP (used for studies of broadband phase-matching in DKDP by Webb *et al.*[7] and then applied to broadband parametric amplification by Lozhkarev *et al.*[8]), or the Fujioka model for DKDP at various deuteration levels.[9]

Four DKDP crystals with a nominal deuteration level ranging from 70% to 98% have been characterized. For each crystal, a noncollinear angle was calculated using the nominal deuteration level and Fujioka index model to phase-match the two cw wavelengths at the same crystal angle. The actual difference in phase-matching angle θ_1–θ_2 measured during a first campaign was used to determine the deuteration level that is consistent with the data for each index model [see, for example, Fig. 1(b)]. For some crystals, an updated noncollinear angle was calculated from the determined deuteration level for θ_1–$\theta_2 = 0$ and used for a second measurement campaign [see, for example, Fig. 1(c)]. Figure 2 presents the difference between the determined deuteration levels x_{Fujioka}, x_{Kirby}, and $x_{\text{Lozhkarev}}$ and the deuteration level x_{vendor} determined by the crystal's vendor from pycnometer measurements performed on the solution during crystal growth. The length of each marker in the vertical direction indicates the 95% confidence interval on the deuteration level determined during each campaign, which is 1.4% on average. The results show excellent consistency between campaigns. Whereas different models yield different deuteration levels from the same measured data, the calculated gain properties for a specific model and the corresponding deuteration level are in excellent agreement between models. This experimental technique has supported the development of broadband gain models and the determination of optimal phase-matching conditions for high-energy amplification on the MTW-OPAL Laser System, an optical parametric amplifier line (OPAL) pumped by the Multi-Terawatt (MTW) laser at the Laboratory for Laser Energetics.[5]

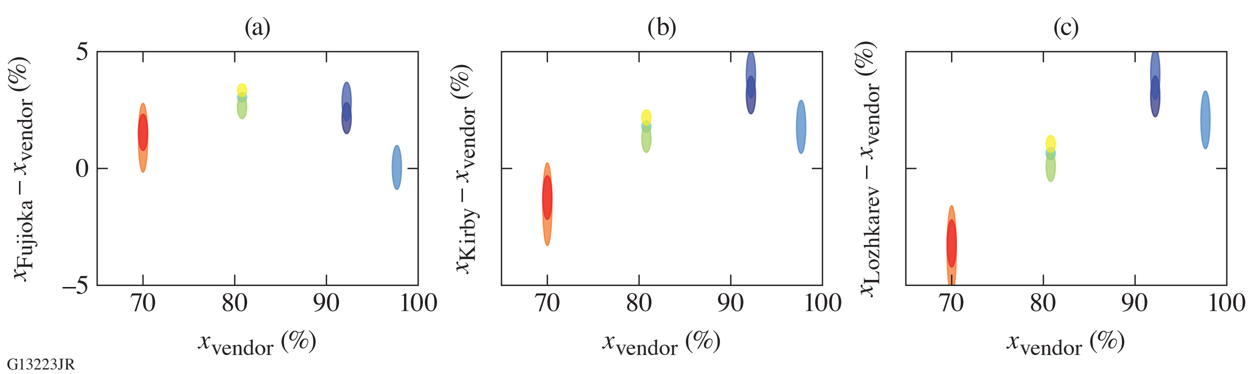

Figure 2
Determined deuteration level for the four crystals over eight campaigns using the index model from (a) Fujioka, (b) Kirby, and (c) Lozhkarev.

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