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CAVE: The Design of a Precision Metrology Instrument for Studying Performance of KDP Crystals

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Abstract

A device has been developed to measure the frequency conversion performance of large aperture potassium dihydrogen phosphate (KDP) crystals. Third harmonic generation using KDP is critical to the function of the National Ignition Facility (NIF) laser. The crystals in the converter can be angularly or thermally tuned but are subject to larger aperture inhomogeneities that are functions of growth, manufacturing and mounting. The CAVE (Crystal Alignment Verification Equipment) instrument scans the crystals in a thermally and mechanically controlled environment to determine the local peak tuning angles. The CAVE can then estimate the optimum tuning angle and conversion efficiency over the entire aperture. Coupled with other metrology techniques, the CAVE will help determine which crystal life-cycle components most affect harmonic conversion.

Keywords: frequency conversion, harmonic generation, nonlinear optics, KDP, optical testing

1. Introduction

In order to meet current NIF specifications, third harmonic conversion efficiencies of 85% of the input pulse peak irradiance are required. The NIF converter design sends an input irradiance of 3.3 GW/cm^2 through a pair of 410 mm square crystals, a type I 11mm KDP second harmonic generator (SHG) and a type II 9.2 mm KD*P third harmonic generator (THG)[1]. The ideal conversion efficiency for this system including crystal absorption is 90.8%[2]. This sets a total conversion error budget of 5.8% of which angular sensitivity is the largest contributor (Table 1). Figure 1 shows the μ radian level tuning that must be maintained. The solid curve represents the detuning of the SHG to find the optimal mixture of 1ω and 2ω light for maximum 3ω conversion through the THG (40 μ radian error band for 85% conversion) The dotted line shows the detuning of the THG given the optimum mixture from the SHG (120 μ radian error band for 85% conversion). Evidence from current experiments at Lawrence Livermore National Laboratory indicate that these curves, known as rocking curves, can shift for different spatial locations on a crystal. Significant spatial non-uniformity in frequency conversion has been observed with the 37cm aperture Beamlet experiment.[3] A device is needed to measure these conversion variations directly by measuring multiple rocking curves over an entire crystal.

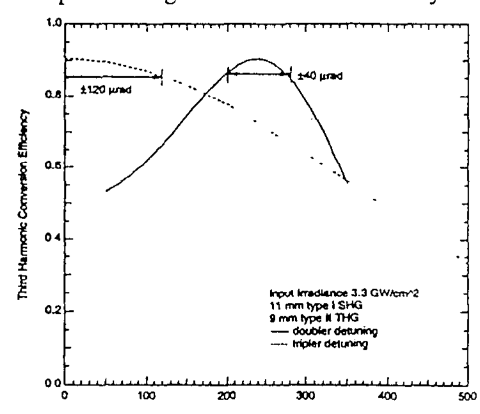

Figure 1. Rocking curve data for NIF doubling (SHG) and mixing (THG) crystals

Table 1. NIF frequency converter error budget.[1]

Source of Efficiency Reduction	Magnitude
Loss Terms	2.8 %
Dynamic Range Terms	1 %
Angular Sensitivity Terms	5 %
Total RSS Accumulation	**5.8%**

The COMS device, developed for the NOVA laser system, can measure a conversion rocking curve for two points on a KDP crystal with a low irradiance laser. This, however, has been shown to be insufficient to extrapolate to entire crystal apertures at NIF power settings. The CAVE device has been designed and is being constructed to fill the role of measuring harmonic conversion over entire crystal

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apertures. It will help expand the knowledge of frequency conversion to realize the NIF 85% efficiency goal. The final version of CAVE will be used for alignment and conversion verification of the NIF Final Optics Assemblies before they are attached to the laser system[4].

2. The CAVE Design

The CAVE device is designed to measure crystals up to the 41cm square NIF size. A cell is made to hold both a doubling and tripling crystal or a single crystal for a given aperture size (Figure 2a). In order to minimize distortion of the crystal from mounting, both mounting surfaces are diamond flycut to 1 micron flat. The cell flanges give an even preload of 2 N/cm to hold the crystal edges against the mounting surface. Crystals are held in a vertical position to eliminate gravity sag as they are scanned. Three actuators kinematically attach to the cell to tip, tilt and focus the crystal and are capable of tuning the angles to less than 0.5 μ radians. The crystal autocollimator (Figure 3a) measures the angle of the diamond turned surface relative to the reference flat. This autocollimator can remove the stage errors as the crystal cell moves in the x direction.

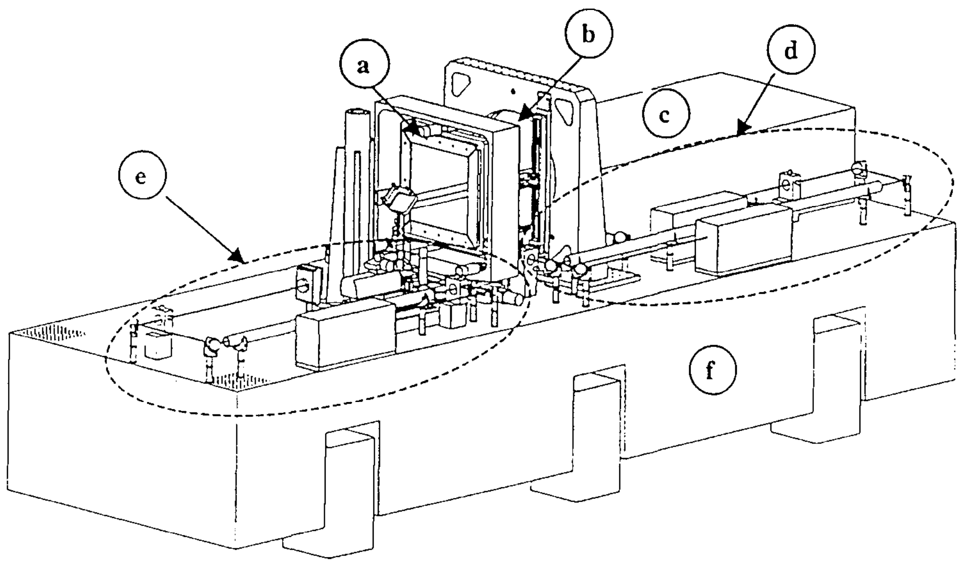

Figure 2 The CAVE device layout, including, a) crystal cell, b) reference flat, c) Nd YLF probe laser d) input beamtrain, e) output beamtrain, and f) optics table

All angle measurements are referenced to a 610 mm optical flat that is mounted in line with the crystals (Figure 2b). This reference flat is ¼ wave and has angular variations calibrated to 1.2 μ radians. The flat serves as the null and the angles of the laser and the crystal mount are measured relative to its normal.

The Nd·YLF probe laser (Figure 2c) can achieve an irradiance of 4 GW/cm^2 at the crystal. The laser has a pulse length of 50 picoseconds, a pulse diameter of 5mm at the test surface, and a maximum repetition rate of 10 Hz. With this short pulse length, the crystal can be probed with many high irradiance pulses without significant thermal changes (±0.1°C). The input beamtrain (Figure 2d) relay images the laser beam to the crystal surface. A portion of the beam can be split off to reference crystals and a reference power meter. This reference power measurement can be used to normalize the output power if there are variations in the pulse shape, energy or beam profile. In order to scan the crystal in the y-axis, periscopes translate the beamtrain on the input and output sides of the crystal. Two optical trombones maintain the relay path length for each y movement. An autocollimator monitors

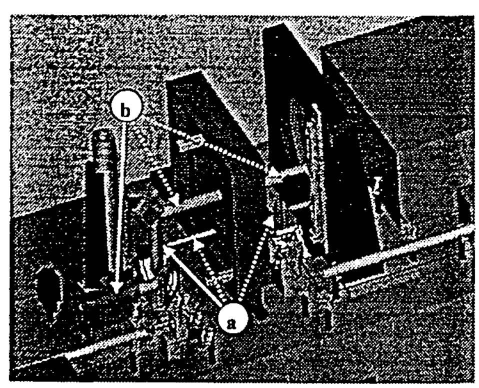

Figure 3. The CAVE measurement core with; a) the crystal autocollimator and measurement path, and b) the laser autocollimator and measurement path. Dotted lines point to highlighted paths

the alignment of the output beamtrain (Figure 2e) and measures the angle of a laser pulse relative to the reference flat. Figure 3b shows the path of the laser autocollimator for measuring both the reference flat and the beam. A tip/tilt mirror on the input side controls the pointing of the laser. On the output side another tip/tilt mirror aligns the autocollimator with the reference flat. Further down the output beamtrain the output power meter measures the pulse conversion. Additional crystal diagnostics have been added to the output side to image the beam at the crystal surface to observe local variations in conversion efficiency.

Several environmental controls need to be maintained for the CAVE device to operate effectively. The optics table (Figure 2f) is on air isolators to attenuate vibrations above 2 Hz. The table is housed in a Class 100 clean room enclosure that maintains temperature of 20 ± 0.1°C.

The operating modes of the CAVE device are energy meter calibration, crystal scanning and rocking curve measurement. An absolute energy meter is inserted at several places on the beamtrain to calibrate the input, output and reference meters to take out system losses. Once crystals are loaded in the cell, the main stage moves to the first horizontal scanning position and the cell is angularly aligned. For vertical scanning the beam is moved with the periscopes and aligned for the new position. When a position is set, the cell is tipped or tilted to the desired angle, a pulse is released and all data is recorded. This is repeated for all of the points on the rocking curve. The final output of each experiment is an array of horizontal location, vertical location and probing angle with the corresponding normalized conversion power output.

3. The CAVE Error Budget

The final machine must measure rocking curves at multiple locations on a KDP crystal with a high level of repeatability. The error bars for a single shot (single point on a rocking curve) have been designed to be less than 10 μ radians in angle and 1% of total energy. Many of the large angular errors inherent in machine motion and are taken out with the metrology control, most notably with the autocollimators which monitor the angles of the crystal and the laser relative to the reference flat. Table 2 shows the angular errors and the root mean square total and Table 3 shows the power measurement errors.

Table 2 Angle Measurement Error Budget for the CAVE device.

Component	Net Errors (μ radians)
Reference Flat	3.2
Crystal Mount	1.7
Input Beamtrain	1.9
Output Beamtrain	1.0
Laser Autocollimator	6.5
Crystal Autocollimator	2.5
Total RSS Error	**8.2**

Table 3 Power Measurement Error Budget for the CAVE device.

Component	Net Errors * (% Power)
Input Beam Power Meter	0.5
Conversion/Output Power Meter	0.5
Reference Power Meter	0.5
Total RSS Error	**0.9**

*Errors are the same for 1ω, 2ω and 3ω

4. Summary

The first CAVE prototype is currently being constructed and tested at Lawrence Livermore National Laboratory The device scans KDP crystals and measures conversion efficiency vs rocking angle for any spatial location. The CAVE is designed for accuracy of 10 μ radians in phase matching angle measurement and 1% in conversion power measurement The machine errors will be tested and analyzed, leading to a final design that will be used for qualification of the NIF frequency converters The immediate use for the CAVE prototype will be to help advance crystal development to reach the NIF conversion goals

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