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Range-gated LADAR coherent imaging using parametric up-conversion of IR and NIR light for imaging with a visible-range fast-shuttered intensified digital CCD camera.

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ABSTRACT

Research is presented on infrared (IR) and near infrared (NIR) sensitive sensor technologies for use in a high speed shuttered/intensified digital video camera system for range-gated imaging at "eye-safe" wavelengths in the region of 1.5 microns. The study is based upon nonlinear crystals used for second harmonic generation (SHG) in optical parametric oscillators (OPOs) for conversion of NIR and IR laser light to visible range light for detection with generic S-20 photocathodes. The intensifiers are "stripline" geometry 18-mm diameter microchannel plate intensifiers (MCPIIs), designed by Los Alamos National Laboratory and manufactured by Philips Photonics. The MCPIIs are designed for fast optical shuttering with exposures in the 100-200 ps range, and are coupled to a fast readout CCD camera. Conversion efficiency and resolution for the wavelength conversion process are reported. Experimental set-ups for the wavelength shifting and the optical configurations for producing and transporting laser reflectance images are discussed.

Key words: range-gated imaging, eye-safe wavelengths, nonlinear crystal, MCPII, CCD camera.

1. INTRODUCTION

The original application of gated or shuttered microchannel plate image-intensified (MCPII) video cameras, (which were designed by the Laboratory's Test and Physics division groups), was for imaging of transient plasmas associated with nuclear device diagnostics for the nation's Underground Nuclear Test (UGT) program conducted by Los Alamos National Laboratory (LANL) at the Nevada Test Site (NTS) for the AEC, ERDA, and DOE (refs 1,2). This technology (fast shuttered MCPII), coupled to fast scan video cameras was deployed to take single transient exposures from one camera or multiple exposures from using several cameras strategically time phased to capture physics events of interest. The current use of the cameras is intended to address military LADAR applications to locate/identify targets at varying distances by employing range gating principles wherein the cameras are shuttered to coincide with the arrival time of reflected laser beams, thereby giving range information from time-of-flight considerations. Our previous research and development efforts (ref 3) have demonstrated range-gated imaging using our fast shuttered camera for military mine detection in murky water. That research showed substantial image enhancement obtained by recording only those unscattered

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photons from a Nd:Yag laser (doubled to give 532nm for good transmission in water) which travel on a ballistic path back to the MCPII arriving at the MCPII during the exposure period for the gated intensifiers which was precisely timed to the laser illumination pulse.

The fast-shuttered MCPII combined with LANL's high frame-rate digital CCD camera, (model GY-11) (refs 4,5,6), used with nonlinear crystals for second harmonic generation (SHG) for the up-conversion of coherent "eye safe" IR images (refs 7,8), can provide unique possibilities for optically imaging remote targets in adverse environments with covert laser illumination.

2. TECHNICAL OBJECTIVES

The primary research goal is an experimental demonstration of range-gated LADAR coherent imaging using parametric up-conversion of IR and NIR light imaged with a fast shuttered intensified digital video camera. The concept is illustrated in figure 1. A pulsed laser operating at eye safe wavelength (Lambda 1), of 1.56 microns with pulse width in the range of 1 to 10ns illuminates the scene. The reflected beam from the scene is collected by a lens and mixed with the light from second laser (Lambda 2) of 532nm, and imaged unto a nonlinear crystal that has proper parameters to convert a fraction of the Lambda 1 signal into a third wavelength, Lambda 3, of 807nm. A simpler case which uses the wavelength conversion technique, but without the second laser will also produce visible wavelength light by second harmonic generation (SHG) resulting in frequency doubling of the 1560nm light to produce 772nm light. Both converted wavelengths are suitable for imaging with S-20 photocathodes.

Our laboratory setup is illustrated in Figure 2, where a remotely located target is illuminated using a synchronized approximately 20pS FWHM laser pulse of 1.54 micron light. Those photons coherently scattered back from the target on a ballistic trajectory will be imaged onto a

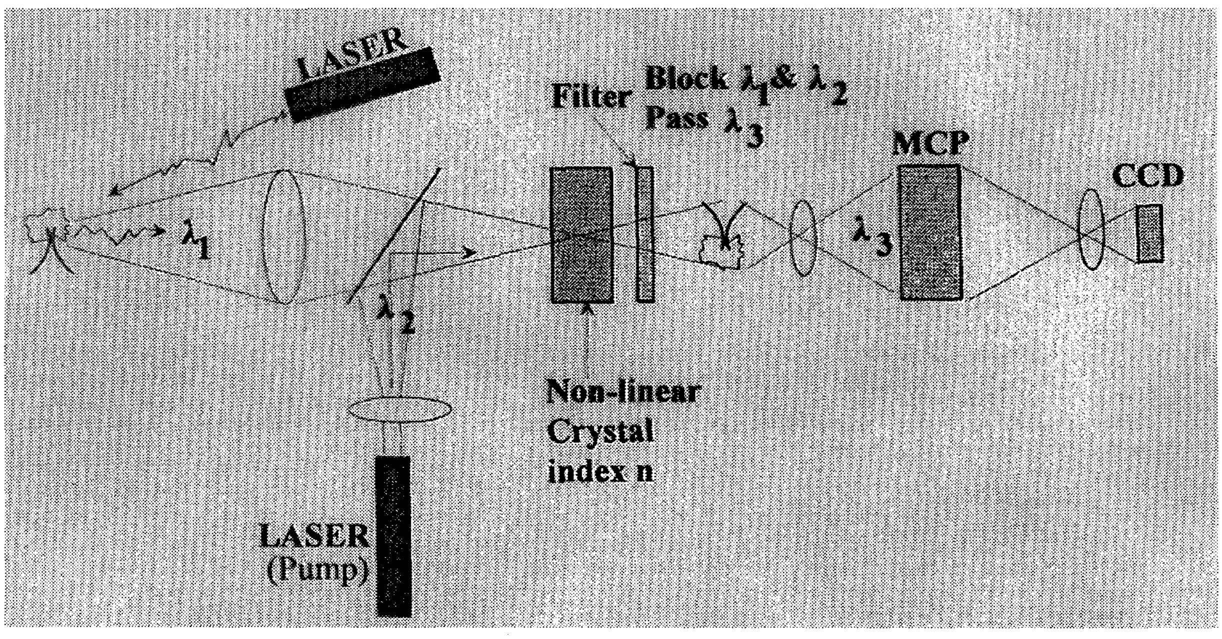

Figure 1. Concept of Optical Parametric Oscillator/Amplifier (OPO/OPA) configurations for wavelength conversion/gain using nonlinear crystal technology for imaging IR/NIR images with visible range sensors. The Pump laser is required for wavelength conversion with gain, but not if wavelength conversion only is desired.

crystal suitable for second harmonic generation (SHG), converted to 772nm, and recorded by a shuttered intensified digital CCD camera. The laser pulse arrival time will be walked in time through the shutter-opening duration with picosecond accuracy by varying a passive electronic delay. This walk through technique will demonstrate the imaging technique by recording and digitizing *images returned before, including, and after the target.* These images will provide quantitative measures of the sensitivity, temporal resolution, and spatial resolution of range-gated up-converted coherent LIDAR imaging.

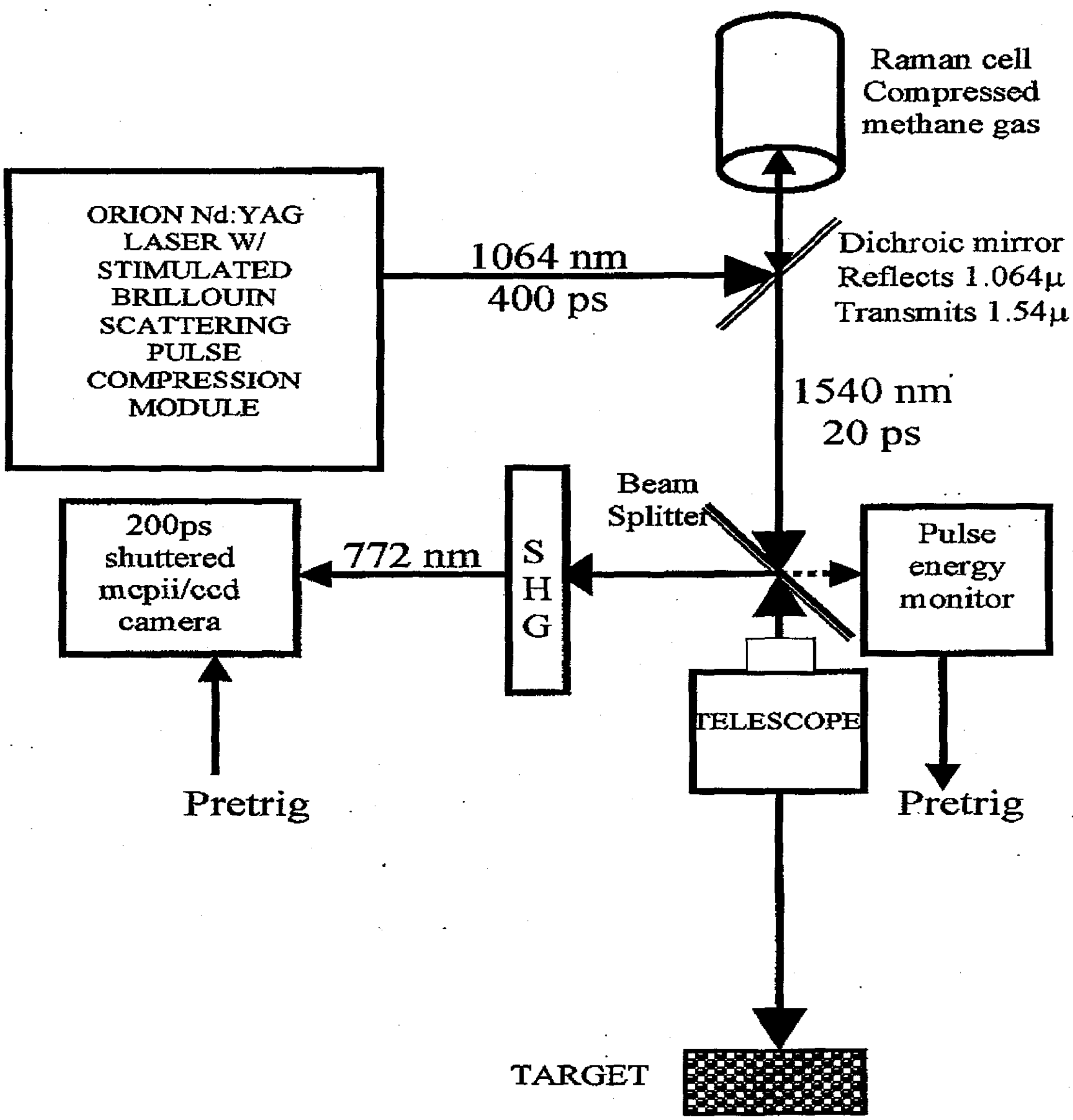

Figure 2. Laboratory setup for wavelength conversion without gain by second harmonic generation (SHG) in a nonlinear crystal. The telescope transports the "probe" laser beam and receives the reflected beam from the target. Timing is provided via a pre trigger which is supplied by a photo diode that senses the return beam.

3. OPO/OPA DISCUSSION

Second harmonic generation, parametric up-conversion and parametric down-conversion provides sources of ***coherent*** radiation from the UV to the IR. These effects occur in asymmetric materials for which the ***nonlinear*** polarization vector, $\mathbf{P}_i$ can be written as

$$\mathbf{P}_i = \sum_{jk} d_{ijk} E_j E_k$$

where d_{ijk} is the nonlinear coefficient, and E_j, E_k are the optical field amplitudes. In addition to this symmetry requirement, energy and momentum must be conserved in this process.

For second harmonic generation, the phase (index) matching equations are:

$$\omega_2 = 2\omega_1$$

$$\hat{k}_2 = 2\hat{k}_1$$

where ω is the angular frequency and **k** is the momentum of the wave. An example of this is doubling the 1064 nm output from Nd:YAG to 532 nm using a crystal with a large non-linear coefficient. If this crystal has large enough non-linear coefficient and is pumped at high enough powers, the same amount of energy can be coupled out at the harmonic as at the fundamental.

For parametric up-conversion or down-conversion the phase matching equations are:

$$\omega_{pump} = \omega_{signal} + \omega_{idler}$$

$$\hat{k}_{pump} = \hat{k}_{signal} + \hat{k}_{idler}$$

In parametric conversion, two signals are mixed to obtain the sum and difference frequencies as in a third harmonic generator (THG) that mixes 1064 and 532 to produce 355. Or a single frequency (pump) is converted to two frequencies (signal and idler). Typically the optical parametric oscillator (OPO) is a singly resonant cavity at the idler frequency and the signal frequency is the output of the oscillator. Changing the index of refraction of the non-linear crystal varies the output wavelength. The index is changed by applied electric fields, change in the angle of incidence of the pump radiation, and/or by changing the temperature of the non-linear crystal.

4. KTP EXPERIMENTS

These initial experiments were performed at Los Alamos National Laboratory. Our ORION laser set-up, illustrated in figure 3, is for the generation of bright fast laser pulse at the eye-safe wavelength of 1.54 microns (2mj, 20ps, 3mm dia.=1.4 GW/cm^2). This has been accomplished by arranging the ORION laser system as shown in figure 3, which leaves intact the generation of UV light pulses using fourth harmonic generation (FHG) to make 400ps 266nm light as well as the option for Raman compression to a 20 ps pulse of 299nm light. As shown in fig 2, about 60 % of the 1064 nm beam is split off for the Raman compression to 1.54 microns, thus leaving sufficient 1064 intensity for the generation of the second and fourth harmonics.

Peak power and energy/pulse measurements were performed on the 1.54 micron light and on the 772nm light. Also, initial resolution data were taken using a transmission bar pattern which was exposed (see figure 3) to the 1.54 micron light and the pattern image was subsequently up-converted by SHG in a KTP crystal to 772nm and recorded with an ungated CCD camera.

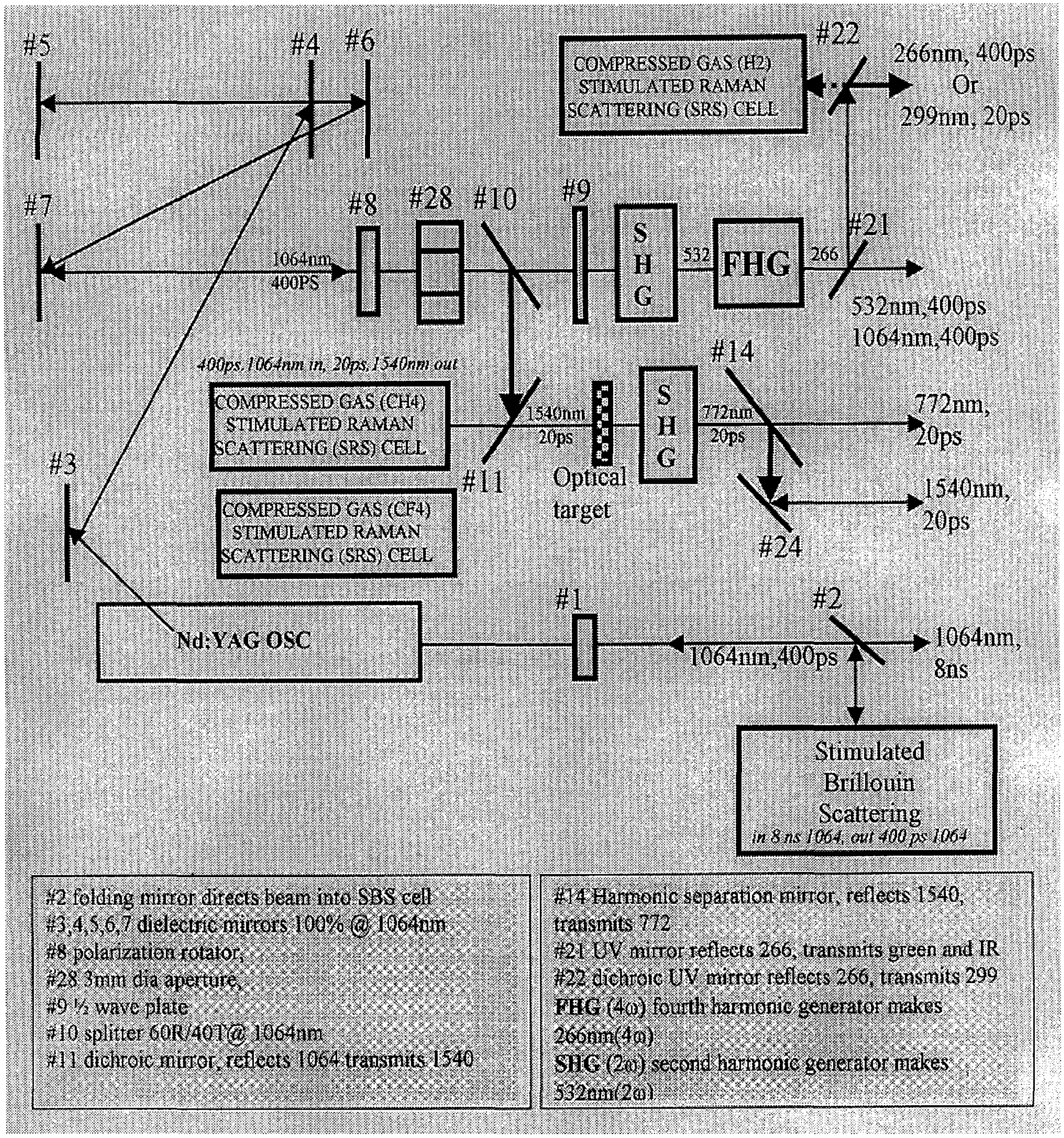

Figure 3. Setup for SHG for shifting 1.5 micron light to 772nm light in KTP crystal.

The resolution obtained from adjacent black and transparent bars of 0.75mm (1.33 lp/mm) is shown in figure 4. The images are from 1.54 micron light transmitted through the pattern and onto the KTP crystal for conversion to 772nm. The two wavelengths are then separated with a dichroic mirror before recording with a CCD camera.

Figure 4. Wavelength converted images depicting horizontal (left hand image) and vertical (right hand image) resolution of approximately 1.33 lp/mm for 1.54 micron image incident on the KTP crystal.

5. LBO EXPERIMENTS

These experiments were continued at Sandia National Laboratories with the setup shown in figure 5. A better crystal was researched and LBO was selected for its wider acceptance angles and better imaging qualities. For complete separation of the incident and converted wavelengths, a Pellin Broca prism was included.

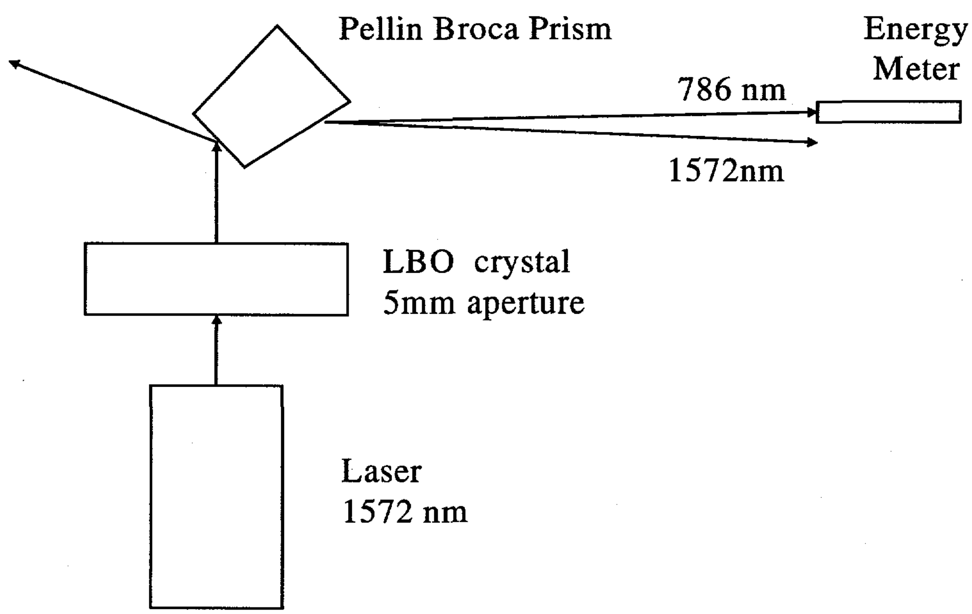

Figure 5. The setup for characterizing LBO crystal resolution and SHG efficiency.

To verify that the measurements observed for wavelength conversion were reasonably close to predictable or expected values, we used a computer based code, (ref 9) for predicting the efficiency as functions of input wavelength, flux magnitude, crystal temperature, etc..

The calculated data are in figure 6, and the measured data are in figure 7. The data are in fair agreement. As seen in the calculated plot, the weaker input flux results in a weaker converted flux, being exponentially dependent roughly related by the square root of the input flux.

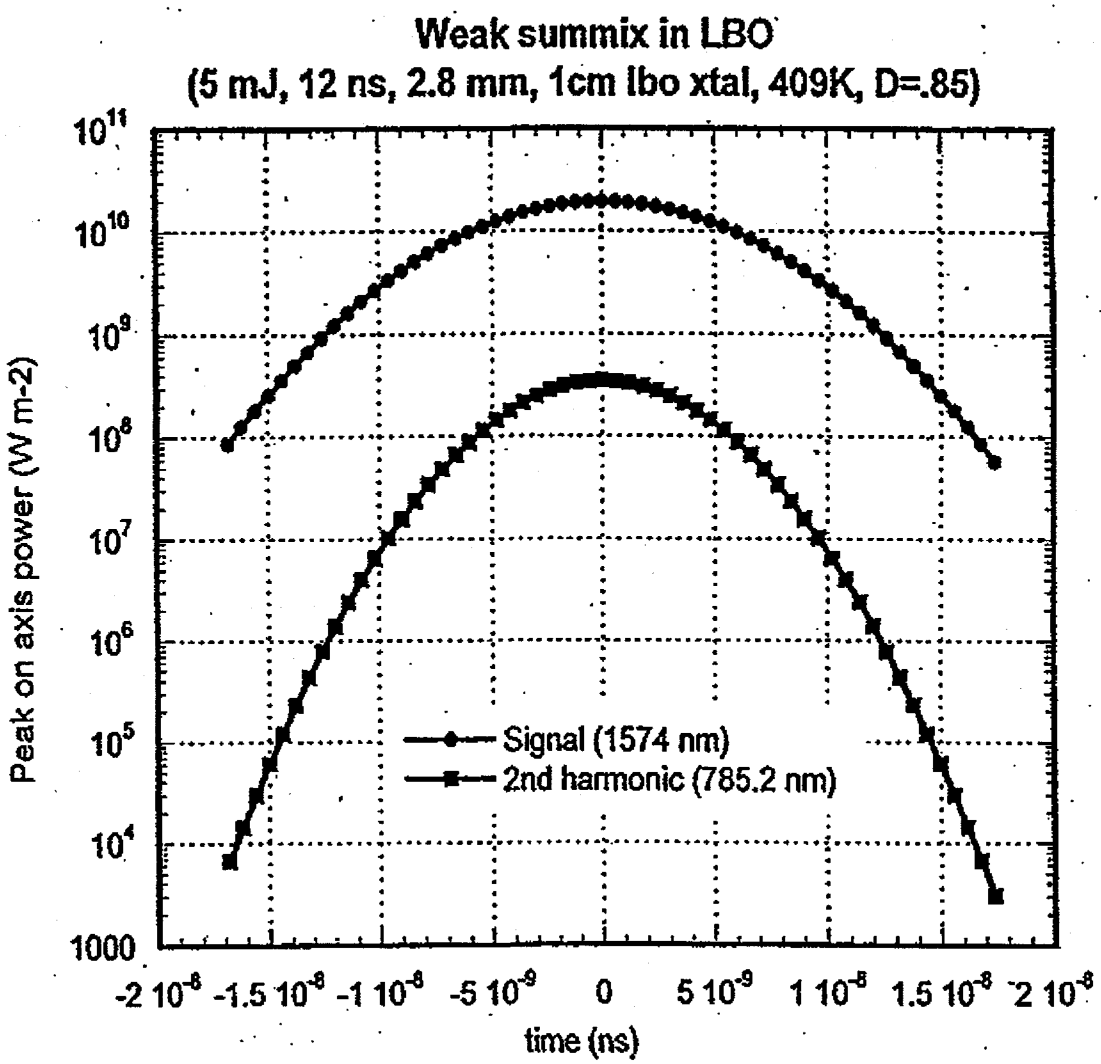

Figure 6. Calculated LBO efficiency for SHG in LBO as a function of input flux.

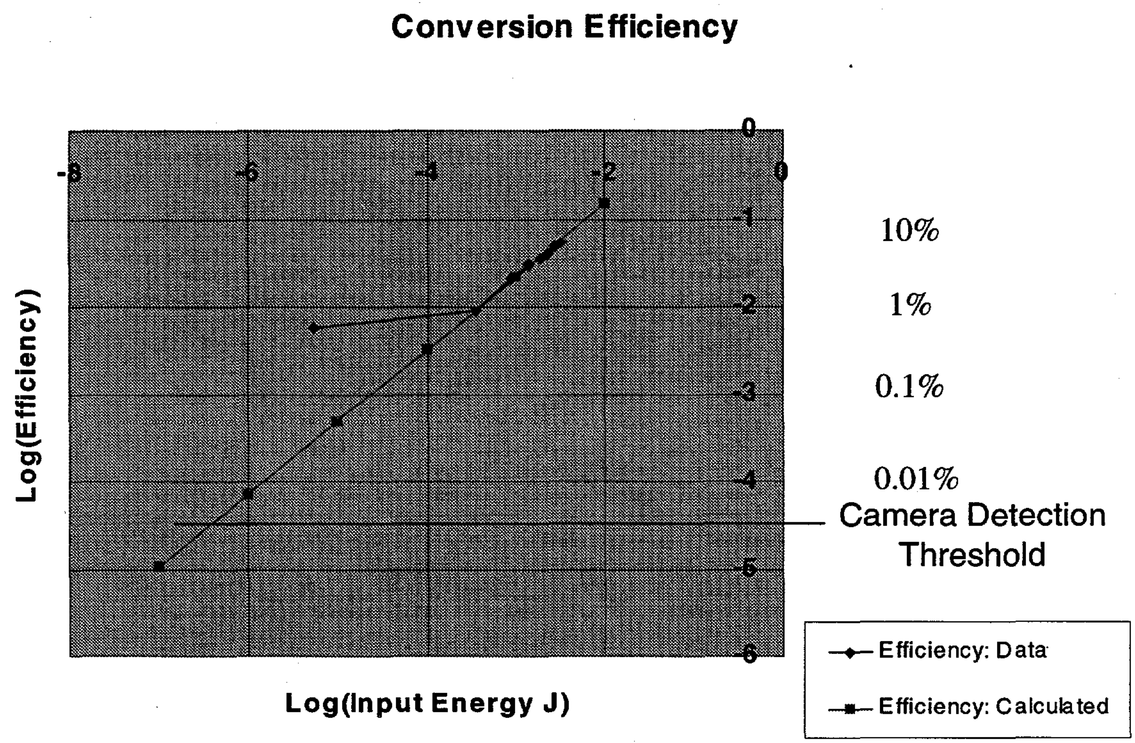

Figure 7. Measured efficiency for SHG in LBO crystal. Data were obtained from setup shown in figure 5. The CCD camera threshold sensitivity was established first and the conversion efficiencies were measured next with a radiometer located in the focal plane of the camera.

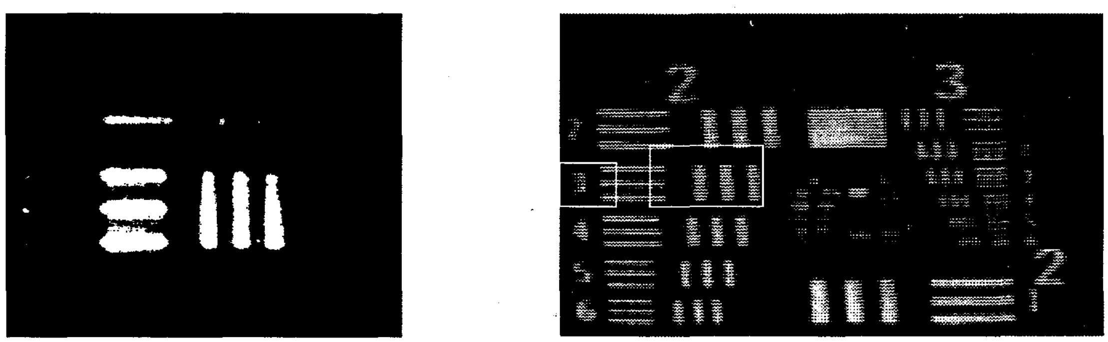

Image through LBO crystal

Approximate areas imaged on resolution pattern

Figure 8. Resolution obtained from SHG in the LBO crystal is shown in the left hand image. The region shown "boxed" in right hand image is the portion of the Air Force resolution pattern imaged through the crystal aperture. This group is approximately 5 lp/mm.

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