Section 1
LASER SYSTEMS REPORT

1.A Laser Wavelength Conversion Program at LLE

Volume 2 of the LLE Review discussed the desirability of using shorter wavelength lasers for laser fusion. In that report it was shown that it was possible to convert 1.054 μm radiation to its second harmonic at .527 μm with high efficiency and, even more important, it was shown that it is possible to predict with great accuracy the performance of such a doubling system. We may now report that we have successfully extended this program to the third harmonic at .35 μm with experimental observation of greater than 60% overall conversion efficiency from 1.054 μm to .35 μm. This implies that an optimized system with no reflection losses would have an overall efficiency of up to 80 percent.

It is important to note that for lossless non-linear crystals the theory of non-linear conversion predicts that it is possible to convert 1.054 μm laser radiation at constant power to its third harmonic at .35 μm with almost 100% efficiency. The most important parameter in the third harmonic generation is the mixing ratio of 2ω (green) to 1ω (red) intensity. From a quantum mechanical point of view, photons must interact one for one; therefore, an ideal tripling system will mix one photon of green light with one of red to produce one photon in the "blue" at 3500 Å. This implies that the intensity of the green should be twice that of the red upon entering the second (mixing) crystal. Figure 1 illustrates the sensitivity of the overall tripling efficiency as a function of the mixing ratio for a particular choice of a KDP Type II crystal. These and the other theoretical predictions were calculated using the LLE code MIXER. A successful tripling program, therefore, requires that one find a doubling arrangement which converts red to green with 67% efficiency over a wide intensity range.

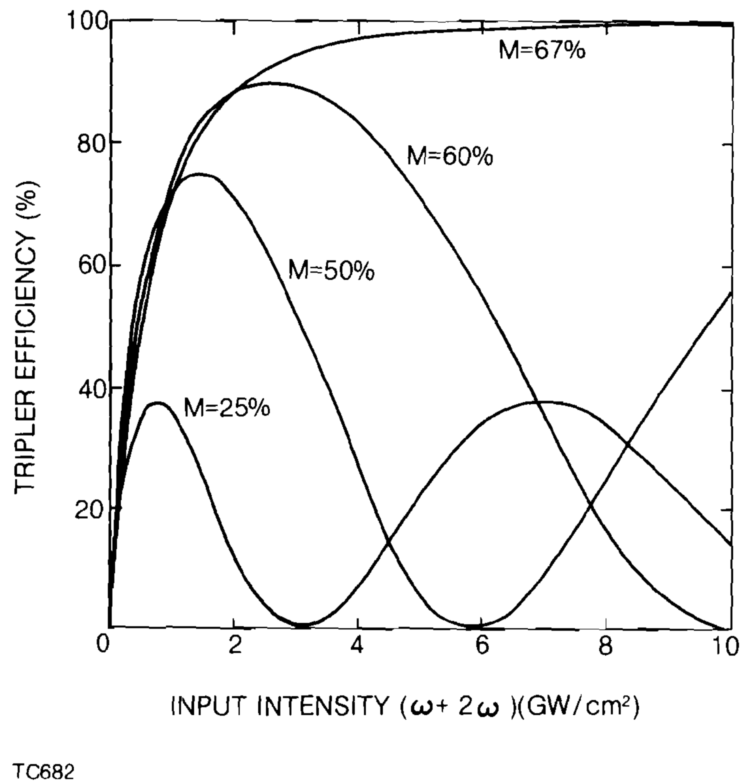

Figure 1 *Tripling efficiency of a 9 mm thick phase-matched KDP Type II crystal as a function of total input intensity, for various percentages ("mixes") M of second harmonic in the input. A small absorption of 0.04 cm^{-1} is included for the fundamental.*

Three different methods of accomplishing this result are illustrated in Figure 2. The C scheme, labeled Polarization-Bypass Scheme for Type I crystals, is the simplest to understand. Type I crystals only double the ordinary wave; therefore, if the doubling crystal is oriented for best phase matching but the polarization is adjusted so only 67% of the red light is in the ordinary beam, the conversion efficiency can be at most 67%. The doubling crystal is chosen to be sufficiently thick that most of the ordinary red light is converted to green. The other 33% of the red light, polarized in the extraordinary direction, passes through the crystal undisturbed and the desired 2:1 ratio of green energy to red is achieved at the tripler input.

The B scheme, labeled the Polarization-Mismatch Scheme, uses two Type II crystals. Again the input extraordinary beam contains 33% of the red energy. A Type II doubling crystal combines photons in the ordinary and extraordinary beams one for one; if the doubler thickness is chosen appropriately, all the energy in the extraordinary wave will combine with half of the energy in the ordinary wave to give green light, with a conversion efficiency of 67%. The other 33% of the initial red energy emerges from the doubler as unconverted ordinary light. Again the desired tripler input mix is obtained.

The A scheme, labeled Angle Detuning, requires a doubler which would normally achieve an excessive efficiency (i.e. more than 67%). This is detuned (typically by a few hundred microradians) to provide a doubling efficiency close to 67% over a broad intensity range. Either a Type I or a Type II crystal may be used as the doubler. Unfortunately this

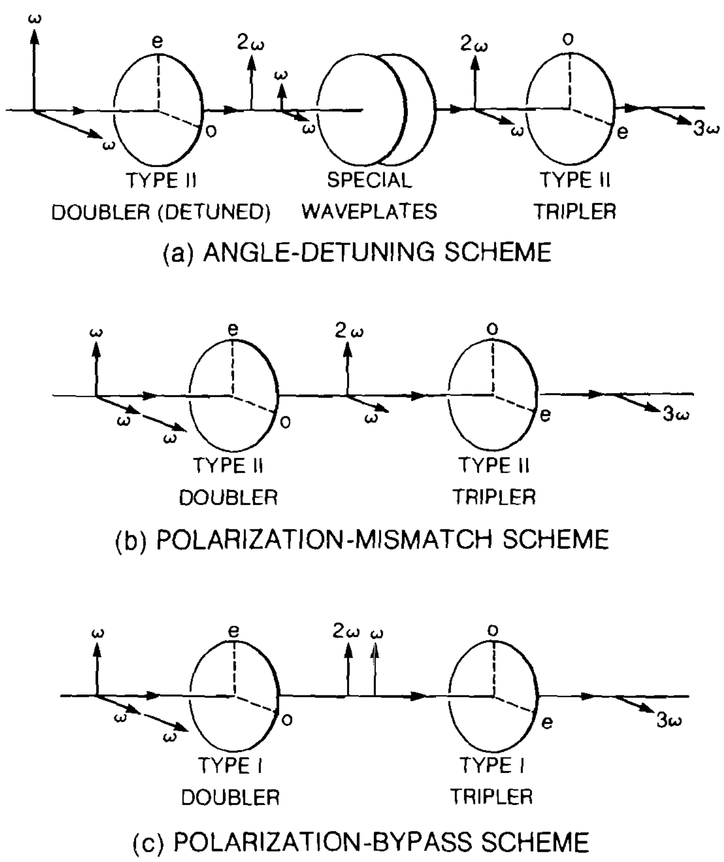

Figure 2 *Idealized doubler performance for three tripling schemes. In each case two out of three ordinary photons at ω are converted in the doubler to one extraordinary photon at 2ω. The unconverted photons at ω emerge, respectively, (a) elliptically polarized at 45° to the o- and e-axes, (b) plane polarized parallel to the o-axis, and (c) plane polarized parallel to the e-axis.*

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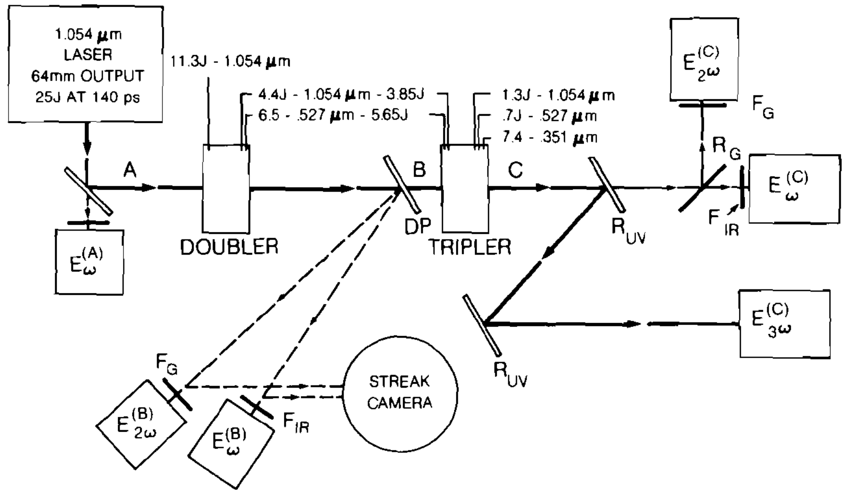

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Figure 3 *Schematic layout of tripling experiments. Energies measured by calorimeters refer to locations A, B, and C. Quoted energies are energies just inside crystal surfaces and reflect ± 2% measurement accuracy. UV output is filtered by high reflectance, dielectric mirrors (R_{UV}) only; R_G is a high-reflectance green mirror; F_{IR} and F_G are IR and green-pass filters; DP is a diagnostic (wedged) glass plate.*

scheme is very sensitive to errors in alignment, particularly for Type I doublers, since it does not operate on the phase-matching peak. For Type II doublers two extra waveplates are required between the crystals.

The C scheme is also sensitive to angular mismatch because it uses Type I crystals. We have therefore concentrated our experimental program on the second, Polarization Mismatch, scheme which is insensitive to angular mismatch as it operates on the phase-matching peaks of two Type II crystals. We have also tried the angle-detuning scheme and proved that it works. The measurements were made with a portion of the GDL laser system terminated at the 64 mm amplifiers. Both conversion crystals were 60 mm in diameter. The experimental arrangement is shown in Figure 3. Each of the measurements was confirmed by a redundant measurement of both the converted and unconverted light. On every shot time dependent streak measurements were taken of the red and green beams, and on some shots simultaneous streaks were obtained of all three wavelengths.

The experimental results for harmonic conversion over a wide range of intensities are shown in Figure 4. This data has been corrected for Fresnel reflection losses from the uncoated surfaces. The excellent correlation between the observations and the calculations is clear evidence for the applicability of the theory. The calculations represent an integration over both the spatial and temporal intensity profiles of the laser beams as determined from near field and streak camera measurements.

Close agreement between theory and experiment has also been obtained using crystals of different thicknesses, confirming the theoretical scaling law that the intensity at which peak tripling efficiency is attained is inversely proportional to the square root of the crystal thickness. It is therefore possible to design tripling systems to work in different regions from that shown in Figure 4.

These experiments clearly demonstrate that it is possible to convert 1.054 μm radiation to .35 μm with the high efficiencies predicted by the theory.

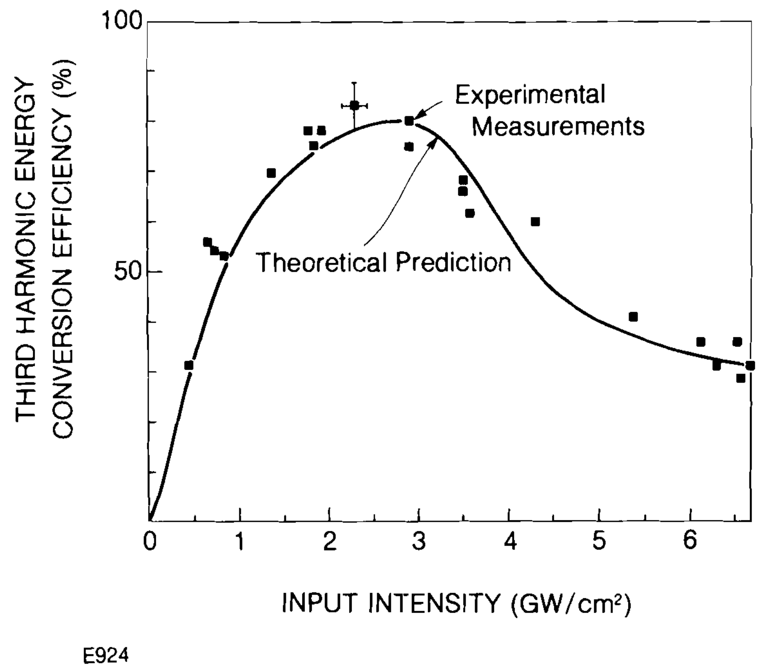

Figure 4 *Third harmonic generation efficiency for 12 mm, Type II KDP. Theoretical prediction used experimental temporal and spatial pulse shapes.*

1.B Tests of Double Pass Geometry Using Active Mirrors

The use of multiple optical passes through the same active laser medium has been demonstrated in a number of different laser systems.[1] Calculations using the LLE RAINBOW propagation code suggested that multi-passing might be advantageous for a system employing "active mirror"[2] laser amplifiers.

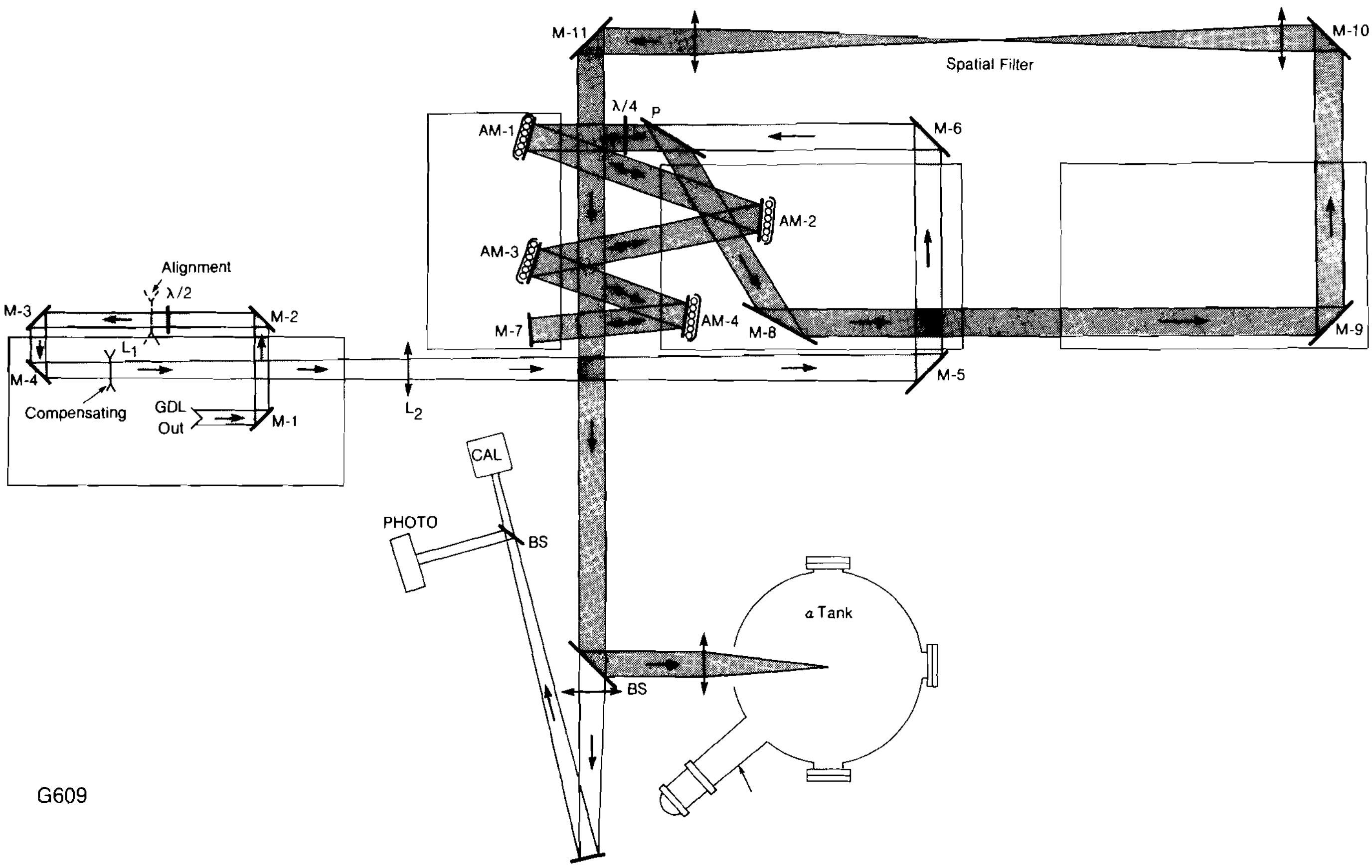

Figure 5 Optical configuration for long pulses (700 psec) of double pass active mirror tests.

Tests have been carried out on the GDL laser system to investigate the performance of a multipass active mirror system. The optical arrangement for the test is shown in Figure 5. The linearly "P" polarized beam coming from the 90 mm amplifiers of the one beam GDL laser is expanded from 90 mm to 150 mm in diameter and transmitted through the dielectric polarizer P. The beam is then converted to circular polarization in the λ/4 quartz waveplate. It is then amplified in passing through active mirror elements AM-1 through AM-4, reflected at mirror M-7, and then amplified a second time in the active mirror elements. Since there are an odd number of reflections, the handedness of the circular polarization is reversed, thus providing an "S" polarized beam after passing through the quarter waveplate. This allows the polarizer P to reflect the beam into the output path containing M-8 through M-11. The output of the laser beam was used in the biophysics x-ray diffraction studies described in Section 3 of this publication.

The primary advantage of the double pass method is in improving the extraction efficiency of each amplifier disc.

Extraction efficiency is important for longer pulses so these tests were carried out with 700 picosecond pulses. At long pulse widths the energy limitation of the system was determined by material damage to the dielectric coatings on the active mirror units and on the 1/4 wave plate. For these tests the front face of AM-1 was uncoated while the other units used standard LLE anti-reflection coatings.

The system was fired for a total of 111 high power laser shots over a period of four weeks. The performance of the system is shown in Figure 6. The observed output energy versus input energy for the double pass system is shown in the upper curve. The continuous line is the prediction of the propagation code RAINBOW. The lower curve shows the performance of the same four 15 cm active mirror units operating in a single pass configuration. The excellent correlation between the measured and calculated values indicates that the system performs in a predictable fashion. The maximum output energy is the same for the single and double pass arrangement since it is determined by energy loading on the output amplifier surfaces. The obvious advantage of the double pass configuration is demonstrated by the reduced driver energy needed for a given output.

It was not possible to determine detailed beam quality in this series of measurements due to surface damage initially present in some of the optics used in these experiments. The output data, however, were all measured beyond a 5 meter spatial filter with a 2 mm pinhole.

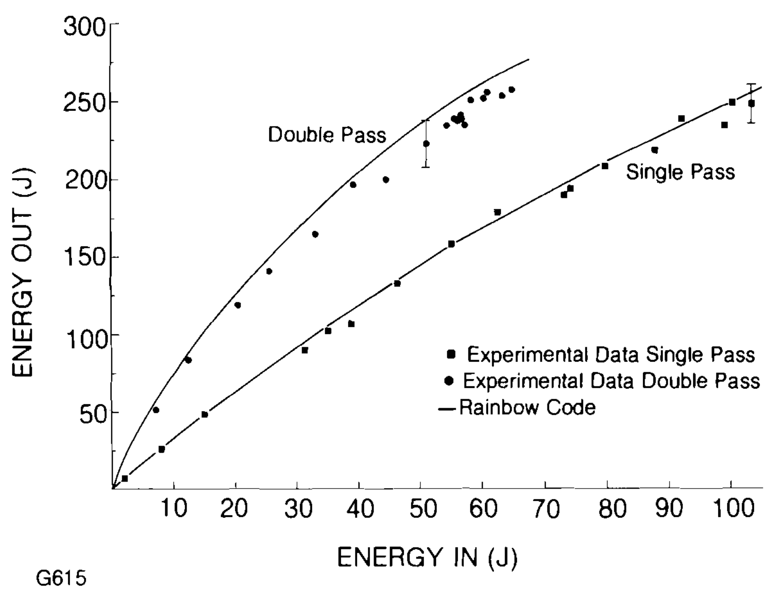

Figure 6 Comparison of experimental observations with RAINBOW code predictions for single and double pass operation of four 15 cm active mirror units.