Section 2
PROGRESS IN LASER FUSION

2.A Laser Wavelength Conversion Program at LLE

The majority of laser fusion experimentation to date has been undertaken with Nd:glass lasers ($\lambda = 1.054\ \mu m$) or CO_2 lasers ($\lambda = 10.6\ \mu m$). There has been increasing interest, however, in shorter wavelength drivers, since they appear to offer significant advantages. Absorption of high intensity laser radiation is accompanied by production of energetic (suprathermal) electrons which may preheat the DT fuel. Since the preheat raises the fuel adiabat, the high fuel density necessary for ignition is more difficult to achieve. The net result is larger target and driver energy requirements for high gain targets. Considerable theoretical and experimental work has shown[1] that the effective suprathermal temperature, T_H, scales as $(I\ \lambda^2)^n$ with $n = 0.4 \pm 0.1$. Since the suprathermal electron range in the target wall scales as $T_H{}^2$, substantial fuel preheat reduction can be made by reducing λ by a factor of 2-3. The alternative of reducing the laser intensity I leads to target designs more susceptible to Rayleigh-Taylor instabilities. Reducing λ (or I) will also increase the laser light absorption fraction.

Because of the considerable potential of shorter wavelength drivers, a wavelength conversion program has been initiated at LLE to study the feasibility of converting the Nd:glass laser output ($\lambda = 1.054\ \mu m$) by frequency doubling and tripling ($\lambda = 0.53\ \mu m$, $0.35\ \mu m$) with KDP (potassium diphosphate) crystals[2]. Conversion to even shorter wavelengths would lead to problems with absorption in the focusing elements (for target irradiation) and has not been pursued. At the present time, conversion from $\lambda = 1.054\ \mu m$ is far more practical than direct use of shorter wavelength lasers. The program to date has involved experimental conversion studies on the GDL laser system with laser intensities appropriate for high power target irradiation. Accompanying this, a substantial theoretical effort has yielded a computer code (MIXER) with the capability of making detailed simulations of the wavelength conversion process. The progress to date has been very encouraging: doubling efficiencies greater than 80% and preliminary high tripling efficiencies have been obtained in remarkable agreement with MIXER simulations. At LLE the most likely application to future laser fusion studies will be with frequency tripled light ($\lambda = 0.35\ \mu m$). Compared to experiments with unconverted light, the loss of laser energy in conversion is expected to be far more than compensated by improved absorption and target performance with the shorter wavelength light.

Frequency tripling is carried out as a two step process with KDP crystals. First, part of the initial beam at frequency ω is doubled to 2ω. The remaining amount at ω is mixed with the 2ω component to yield 3ω in the second step. The initial LLE conversion experiments were frequency doubling experiments with the goal of optimizing the output for the tripling step to follow. The doubling results will be discussed here, while the tripling work (still underway at the end of this quarter) will be described in more detail at a later date. A particularly important fact for the frequency doubling strategy is that the optimum intensity ratio of 2ω to ω for input to tripling is 2 to 1; that is, equal photon numbers of ω and 2ω light. Therefore, the desired conversion efficiency from ω to 2ω is 67% if a tripling step is to follow.

There are a number of factors which contribute to the conversion efficiency of a crystal:

a. Crystal cut
b. Crystal length and area
c. Crystal alignment (tilt angle)
d. Beam spatial and temporal profile
e. Crystal temperature
f. Coating and materials damage limitations

Factors a-e have been studied with the aid of the computer code MIXER as a very important guide for these experiments. This has made possible a rapid optimization of these factors.

The choice of crystal cut is very important. There are two options here, referred to as type I and type II conversion. See Figure 8. (In type I doubling, the components of the incident E vector are both along the ordinary axes of the crystal, and maintain their relative phase while propagating through the crystal. In type II doubling, a component of the incident E vector lies along the extraordinary axis of the crystal; the components therefore do not stay in phase while propagating through the crystal.) We have concentrated on type II doubling for several reasons. The alignment and pointing requirements for a type I doubling crystal are a factor of two more stringent than for a type II crystal of the same dimensions. Additionally, a type I crystal must be a factor of 1.35 thicker than a type II crystal to yield the same conversion efficiency at the same intensity. The type I crystal is therefore a factor of 2.7 more sensitive to pointing error or beam divergence. Also, it is possible to cut a larger diameter type II than type I crystal from the same raw crystal. This would become especially significant for multi-beam fusion applications of frequency conversion.

The initial frequency conversion experiments with the GDL laser system have been limited to a 60 mm diameter beam, since the KDP crystals on hand had a 64 mm aperture. The tests were carried out at the output of the last 64 mm rod amplifier of GDL. The energy available at this point in the system was 22J in 140 psec (FWHM).

Figure 9 gives measured energy conversion efficiencies to the second harmonic (2ω) as a function of incident