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THE TRIPLING OF CO₂ LASER
RADIATION IN DBr, DCl AND Se

ADDENDUM TO
FINAL TECHNICAL REPORT
for period May 1, 1977 - January 31, 1979

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This Section discusses the use of deuterium chloride gas and selenium vapor for the tripling of CO₂ laser radiation in a laser fusion driver system appropriate for power plant operation. Each laser module in such a system would deliver 50 - 100 kilojoules of energy in several nanoseconds or 10 - 30 terawatts of peak power. The aperture of power amplifier modules for such devices are 1 - 2 M² with the specific system design being determined by the choice of material (NaCl) or aerodynamic windows. In both cases, however, the output flux is several gigawatts per square centimeter and each beam diameter will exceed 30 cm.

Laser beams with these large powers and apertures cannot be focussed without causing optical medium breakdown unless unrealistically long focal length mirrors and conversion cells (exceeding tens of kilometers) are used. Thus conversion cell geometries must accommodate the full aperture of the beam in a "straight-through" configuration.

Optical conversion efficiencies will thus differ from those predicted from the short-focal-length limit calculated in Section IV (Eq. 68). Instead, Eq. 48 of Section II.D. must be used, namely,

$$\eta \equiv \frac{I_3}{I_1} = \left(\frac{96\pi^3 \times 10^7}{c} \right)^2 \left(\frac{\chi^{(3)} N I_1}{\lambda_1} L \right)^2 \frac{\sin^2 \frac{\Delta k L}{2}}{\left(\frac{\Delta k L}{2} \right)^2}$$

For perfect index matching, $\bar{\Delta}k \rightarrow 0$, this becomes

$$\eta \approx \left(\frac{\chi^{(3)}_{NI_1}}{\lambda_1} L \right)^2$$

Heated ovens for selenium cell temperatures of 1300°C are well within the state of the art and results in Se monomer densities of 1×10^{17} atoms/cm³ at atmospheric pressure. Using the value of $\chi^{(3)}_{Se}$ determined from this research (1.1×10^{-33} esu/atom) and a fusion laser intensity of 5×10^9 W/cm², we can calculate the conversion efficiency to be

$$\eta = 3.02 \times 10^{-5} L^2$$

Taking saturation into account via the expression

$$\eta' = \frac{\eta}{1+\eta}$$

we obtain the conversion efficiency for selenium shown in Fig. 1A as a function of cell length. Conversion efficiency as a function of cell length is also shown for several gas pressures of DCl ($\chi^{(3)}_{DCl} = 2.0 \times 10^{-36}$ esu/atom). Thus predicted conversion efficiencies for a "straight-through" geometry are very high for both DCl and Se and can be obtained for reasonable conversion cell lengths.

A DCl conversion cell will require large diameter NaCl windows (at least on the input side) and thus will restrict operating pressures to the range 1-5 atmospheres. The volume of DCl gas needed is approximately 10,000 liters at S.T.P. The

Figure 1A - Conversion Efficiency as a Function of Cell Length for a Collimated Beam of Uniform Intensity

price of the gas is not unreasonable (\$2K based on the price of deuterium) provided the gas is reused. Safety requirements for handling large quantities of DCl are severe due to its toxicity. A properly designed system should be manageable, however.

Obviously, it is not simple to construct a heated selenium conversion cell. Medium homogeneity is the major problem area. Se cell construction itself should not be difficult. A 1300°C cell (with no moving parts or vacuum seals) is quite within the range of high temperature technology. A vertical geometry may be necessary to eliminate convection currents. It is likely that no optical windows would be required if the cell is operated at atmospheric pressure. A detailed, technologically sound, large-aperture heated conversion cell design remains to be developed.

It should be noted that an efficiency limitation of 17% - 25% caused by an interference phenomenon between third-harmonic generation, two-photon absorption and Raman processes has recently been discovered by Kildal and Brueck^{1A}. However, for laser beams with a uniform intensity distribution used in a collimated-beam geometry this limitation does not apply^{2A}, and high energy conversions should still be attainable.

1A. H. Kildal and S.R.J. Brueck, Paper No. 5.10, 1979 IEEE/OSA Conference on Laser Engineering and Applications, Washington, D.C., May 30-June 1, 1979.

2A. A. Flusberg, R.T.V. Kung and H. Friedman (to be published).

FINAL REPORT ERRATA

P.29 Eq. 40 - both parentheses should be squared
Eq. 42 - the parenthesis should be squared

P.81 Eq. 69 - η_p on left hand side should be η'_p .
In next paragraph, η_p should be η'_p .

P.83 Eq. 71 - Right hand side should be $\frac{4P_1}{\lambda b}$