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LANDILLY STON

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PROGRESS REPORT

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PRINCIPAL INVESTIGATOR:

Donald A. Whitney

CO-PRINCIPAL INVESTIGATOR: Kyong H. Kim

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#### Summary

This semiannual progress report covers work performed during the period from April 13, 1988 to October 13, 1988 under NASA grant number NAG-1-877 entitled "Development of mid-infrared solid state lasers for spaceborne lidar". We have designed a flashlamppumped  $Cr^{3+}$ :GSAG laser of pulsed laser energy greater than 200 mJ and of pulse width of 1 ms FWHM to simulate a high power laser diode in pumping mid-infrared laser crystals such as  ${\rm Tm}^{3+},\ {\rm Er}^{3+}$ and/or Ho3+-ion doped YAG, YLF or other host materials. This Cr3+:GSAG laser will be used to determine optimum conditions for laser diode pumped mid-infrared lasers, maximum energy extraction limit with longitudinal pumping, thermal damage limit, and other problems related to high power laser diode pumping. We have completed a modification of an existing flashlamp-pumped and liquid-nitrogen-cooled rare earth laser system for 60 J electrical input energy and 500  $\mu$ s pulse width, and have carried out preliminary experiments with a Ho<sup>3+</sup>:Er<sup>3+</sup>:Tm<sup>3+</sup>:YAG crystal to test the system performance. This flashlamp-pumped rare earth laser system will be used to determine optimum  $Tm^{3+}$ -ion concentration in Ho<sup>3+</sup>:Cr<sup>3+</sup>:Tm<sup>3+</sup>:YAG crystal in the remaining research period.

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# I. Flashlamp Pumped Cr:GSAG Laser for Rare Earth Laser Pumping

#### 1. Introduction

During this report period we have designed a flashlamp pumped Cr:GSAG laser to simulate a high power laser diode in pumping rare earth ion (such as  $Tm^{3+}$ ,  $Er^{3+}$  and  $Ho^{3+}$ ) doped crystals and to study various problems involved with high power laser diode pumping. The diode-pumped solid state laser system has been known as a very promising technology for the spaceborne lidar (light detection and ranging) and windshear lidar applications because of its long system lifetime, reliability, high efficiency, low thermal loading, compactness and low-voltage operation. However, the current technology on the laser diode is not mature especially in high power or high energy applications and its price per unit output power is very high. The reported highest cw laser output from a single array diode is 38 W [Ref.1]. The highest quasi-cw laser output from a one-dimensional bar is 134 W for a pulse width of 150  $\mu s$  and repetition rate of 40 Hz and that from a twodimensional stacked bar is 800 W (corresponding power density of 2  $kW/cm^2$ ) for the same pulse width and repetition. The flashlamp pumped Cr:GSAG laser can be built with a relatively low cost and can deliver high laser output energies of 200 mJ - 1 J. The corresponding average laser pulse powers are 100 W - 2 kW for 0.2 -2 ms pulses. In addition, since the wavelength of most currently well-developed laser diodes is located near 800 nm, the Cr:GSAG laser wavelength matches well to the diode wavelength and can be precisely tuned to the absorption peak of the rare earth ions. Since the absorption lines of the  ${\tt Tm^{3+}}$  and  ${\tt Er^{3+}-ions}$  match well with the diode laser wavelength and efficient energy transfer from the  $Tm^{3+}$  and  $Er^{3+}$  ions to  $Ho^{3+}$  ions has been already utilized in low

power laser operation with laser diode pumping as listed in Table 1 [Refs.2-7], high power laser operation of rare earth crystals, such as Ho<sup>3+</sup>:Tm<sup>3+</sup>:YAG, Ho<sup>3+</sup>:Er<sup>3+</sup>:Tm<sup>3+</sup>:YAG, Er:YAG and Er:YLF, at various wavelengths of 2.1  $\mu\text{m}$ , 2.3  $\mu\text{m}$  and 2.9  $\mu\text{m}$  may be expected with high power laser diode pumping. The flashlamp pumped Cr:GSAG laser will be used not only to simulate high power laser diode pumps but also to determine an optimum combination of the host and rare earth ions, threshold, slope efficiency, operating temperature and output coupler's reflectance for the efficient rare earth lasers. Furthermore, William E. Krupke predicted that the solid state lasers pumped longitudinally with laser diodes are limited to a maximum deliverable output of 10 W [Ref.8]. The Cr:GSAG laser will be useful in determination of the upper limit of the rare earth laser output with a longitudinal pumping at a wavelength which corresponds to diode laser wavelength and absorption peak of the rare earth ions.

In the following sections we will describe the characteristics of the flashlamp pumped Cr:GSAG laser and its system design.

### 2. Flashlamp Pumped Cr:GSAG Laser

Fig.1 shows the absorption and fluorescence spectra of the Cr:GSAG crystal. The fluorescence spectrum covers well the laser diode wavelength range which is around 780 nm to 850 nm. Previously other research groups [Refs.9,10] have demonstrated tunable laser operation of the crystal in the wavelength range from 765 nm to 800 nm and obtained the maximum laser output of 200 mJ at 780 nm with a pulse width of 150  $\mu$ s. It is our primary objective to develop a long-pulsed high energy Cr:GSAG laser of adjustable pulsed laser energy of 200 mJ to 1 J and pulse width of 0.2 ms to 1 ms at the wavelength of 790 nm.

Typical pulse forming network (PFN) with a single RLC circuit

is shown in Fig.2. According to the Refs.11-13, the design parameters can be calculated using the following relations:

$$C = [2 E_{o} \alpha^{4} T^{2} K_{o}^{-4}]^{1/3}$$

$$K_{o} = 1.28 l_{f}/D (p/x)^{1/5}$$

$$L = T^{2} / C$$

$$V_{o} = [2 E_{o} / C]^{1/2}$$

$$E_{x} = K_{e} T^{1/2}$$

$$\tau_{life} = [E_{o} / E_{x}]^{-8.5}$$

$$I = (V / K_{o})^{2}$$

$$A = \pi (D / 2)^{2}$$

$$T_{B} = [\{9450 \times (D/100)^{0.03} (I/A)^{0.01}\}^{6} + \{93 \times (D/100)^{0.27} (I/A)^{0.34}\}^{6}]^{1/6}$$

$$\lambda_{p} = 2.898 \times 10^{6} / T_{B}$$

$$Z_{o} = [L / C]^{1/2}$$

$$R_{t} = \rho l_{f} / A$$

$$I_{p} = V / (Z_{o} + R_{t})$$

where C is the capacitance of the charging capacitor in Farad,  $E_o$ is electrical energy stored in capacitor in Joule,  $\alpha$  is damping factor (=0.8 for critical damping), T is circuit time constant (=  $T_o/3$ ),  $T_o$  is current pulse width measured at 1/3 of peak in second,  $K_o$  is impedance parameter of flashlamp in  $\Omega(amp)^{0.5}$ ,  $l_f$  is arc length of the flashlamp in cm, D is flashlamp bore diameter in cm, p is gas fill pressure in flashlamp in Torr, x is a constant (= 450 for Xe-gas, and 805 for Kr-gas), L is inductance in Henry,  $V_o$ is initial capacitor voltage in volt,  $E_x$  is explosion energy in Joule,  $K_e$  is explosion energy constant of the given flashlamp,  $\tau_{life}$ is flashlamp lifetime in shot number, V and I are instantaneous flashlamp discharge voltage and current in volt and ampere, respectively, A is flashlamp bore cross section in cm<sup>2</sup>.  $T_B$  is blackbody temperature in  ${}^{\circ}$ K,  $\lambda_{\rm p}$  is the wavelength at the peak of the blackbody spectrum in nm, Z<sub>o</sub> is the impedance of the LC circuit in ohm, R<sub>t</sub> is flashlamp resistance,  $\rho$  is flashlamp resistivity in  $\Omega$ ·cm (0.02 for pulse width between 100 µs and 1 ms pulses), and I<sub>p</sub> is the peak current on the discharge circuit. The result of the calculated parameters for ILC model 4F3 flashlamp [D = 0.4 cm, 1<sub>f</sub> = 7.62 cm, K<sub>o</sub> = 25  $\Omega$ (amp)<sup>0.5</sup>, K<sub>e</sub> = 7.5 x 10<sup>4</sup> Watts(sec)<sup>0.5</sup>, Max I<sub>p</sub> = 500 A ] is shown on Table 2. As long as the pulse width is kept long, the lifetime of the flashlamp can be extended even at high input energies.

In order to have long square-wave pulses, pulse forming network with multiple LC series sections has been designed. Design parameters for the multisection PFN circuit can be calculated according to Ref.14 using the same relations and parameters as above unless otherwise specified below:

 $V = 2 [K_0^2 E_0 / T_0]^{1/3}$   $C = [E_0 T^2 / K_0^4 ]^{1/3} / 2$   $L = [T^4 K_0^4 / E_0 ]^{1/3} / 2$   $C_0 = C/n$   $L_0 = L/n$   $\tau_{rise} \approx [L_0 C_0]^{1/2}$   $Z_0 = [L / C ]^{1/2}$   $I = V / 2Z_0$   $I_p = V / (Z_0 + R_t)$ 

where n is the number of the LC sections, C is capacitance of total charging capacitors, L is total inductance,  $C_o$  and  $L_o$  are each sectional capacitance and inductance, respectively, and  $\tau_{\rm rise}$  is risetime of the square wave pulse. Typical pulse forming network with 3 LC sections is shown in Fig.3 and the calculated parameters for the PFN circuit with the same ILC model 4L3

flashlamp are listed on Table 3. The computer programs used in a HP9845B computer for the above calculations are found in the Appendix. The 3 LC section PFN designed for 300 J input energy and 1 ms pulse width with  $C_o = 150 \ \mu\text{F}$  and  $L = 185 \ \mu\text{H}$  is being assembled for a preliminary setup in present time, and will be scaled up to higher energy and longer pulse width later.

The experimental arrangement to be used for the rare earth laser system with the flashlamp pumped Cr:GSAG laser pumping is shown in Fig.4. The Cr:GSAG laser will be tuned with an internal prism to the absorption line of rare earth ions near typical diode laser wavelength which is around 790 nm, and then will be focused by a lens to the rare earth ion doped crystal through the highly reflective mirror for the rare earth laser. Narrow line pumping of the rare earth lasers with the Cr:GSAG laser will be useful to study the energy transfer processes and their effect on laser performance, and will enable simulation of high power diode laser pumping. Q-switching experiment will be also performed to study the efficiency of energy transfer mechanisms for short pulse DIAL and Doppler Lidar operation.

## **II.** Flashlamp-Pumped Rare Earth Laser System

#### 1. Introduction

Recently, codoping Cr<sup>3+</sup>-ions in rare earth ion doped crystals has been demonstrated by many research groups as an effective way to improve efficiency of flashlamp pumped laser systems. Diodepumped rare earth lasers are promising candidates for the spaceborne lidar system in the mid-infrared spectral region. However, we see from the situation of the current technology that the flashlamp pumped laser systems have still several practical advantages over the diode-pumped lasers, although the latter have an order of magnitude higher efficiency and more easily obtain room temperature operation. The major advantages are that the flashlamp systems are well developed and easily accessible. Especially in high laser energy (or power) applications the technology for the flashlamp pumped laser system is well developed compared to that for the diode lasers and capable to deliver a high laser energy (or power) at a relatively low cost. Thus, understanding of the mechanisms of the energy transfer processes between the chromium ions and rare earth ions such as Tm<sup>3+</sup>, Ho<sup>3+</sup> and Er<sup>3+</sup> is very important to determine optimum doping concentrations and a proper host material, and to increase the laser efficiency. During this report period we have prepared for the flashlamp pumped and liquid nitrogen cooled rare earth laser system, which is shown in Fig.5, to study the laser characteristics of three Ho<sup>3+</sup>:Cr<sup>3+</sup>:Tm<sup>3+</sup>:YAG crystals provided by Coherent Laser Technology Company and to determined the optimum Tm<sup>3+</sup> concentration in the Ho<sup>3+</sup>:Cr<sup>3+</sup>:Tm<sup>3+</sup>:YAG crystals.

## 2. Flashlamp Pumped Rare Earth Laser Experiment

Fig.5 shows the typical energy transfer processes among Ho<sup>3+</sup>, Cr<sup>3+</sup> and Tm<sup>3+</sup> ions the YAG crystal. The broad <sup>4</sup>T<sub>1</sub> and <sup>4</sup>T<sub>2</sub> states of the Cr<sup>3+</sup>-ions provide an efficient absorption of the flashlamp light and energy transfer takes place from the <sup>4</sup>T<sub>1</sub> state of the Cr<sup>3+</sup>-ion to the <sup>3</sup>H<sub>4</sub> state of the Tm<sup>3+</sup>-ion and from the <sup>4</sup>T<sub>1</sub> state to the <sup>3</sup>H<sub>4</sub> through a cascade transition to the <sup>4</sup>T<sub>2</sub> state. Then, when the Tm<sup>3+</sup> ions in the <sup>3</sup>H<sub>4</sub> state make transitions to the <sup>3</sup>F<sub>4</sub> state, the transition energy is used to excite another Tm<sup>3+</sup>-ion from the ground state to the <sup>3</sup>F<sub>4</sub> state. This , so called cross-relaxation phenomenon, will provide two excited Tm<sup>3+</sup> ions for one single pump photon by increasing the quantum efficiency to 2. Then the excited Tm<sup>3+</sup> ions transfer to the <sup>5</sup>I<sub>7</sub> state of the Ho<sup>3+</sup> ions and the 2.1 µm laser transition takes place between the <sup>5</sup>I<sub>7</sub> and <sup>5</sup>I<sub>8</sub> states of the Ho<sup>3+</sup> ions. Since the crystals provided by Coherent Laser Technology Company have different Tm<sup>3+</sup>-ion concentrations with fixed Cr<sup>3+</sup> and

 $Tm^{3+}$ -ion concentrations, the normal mode and Q-switched laser study on those crystals at various operating temperatures as well as the spectroscopic study will provide information on the energy transfer processes among those three ions and enable us to determine optimum  $Tm^{3+}$ -ion concentration in the Ho<sup>3+</sup>:Cr<sup>3+</sup>:Tm<sup>3+</sup>:YAG crystal for the best flashlamp pumped and Q-switched 2.1  $\mu$ m laser performance.

In order to test the system performance we have taken normal mode laser operation of a Ho<sup>3+</sup>:Er<sup>3+</sup>:Tm<sup>3+</sup>:YAG crystal under flashlamp pumping at various operating temperatures and with various output mirror reflectivities. The crystal had a doping concentration of 0.02 Ho<sup>3+</sup>, 0.40  $Er^{3+}$  and 0.06  $Tm^{3+}$ , and its dimension was 5 mm in diameter and 90 mm in length. A single LC section pulse forming network of C = 146.5  $\mu F$  and L = 184  $\mu H$  was used to generate discharge pulses with current pulse width of 500  $\mu s$  (=  $T_{\rm o})$  at the capacitor charging voltage of 909 volts (=  $V_{\rm o})$  at which the corresponding electrical input energy was 60 J (=  $E_o$ ). The normal mode laser output energy as a function of the electrical input energy were measured at various operating temperatures with a 95% and 98% reflective output mirrors, respectively, as shown in Figs.7 and 8. As the operating temperature was decreased, the slope efficiency was increased and the threshold energy was decreased. The various electrical input energies were obtained by changing the charging voltage. Fig.9 shows the normal mode laser output of the same crystal obtained with various output mirror reflectivities as a function of the electrical input energy at the operating temperature of 170 °K. The normal mode laser output measurement was taken without the Q-switch crystal and polarizer in the experimental setup shown in Fig.5, and the resonator length was 91 cm.

Finally, the normal mode laser output was measured with a 2.17 mm thick ZnSe plate placed at the Brewster angle (=  $67.8^{\circ}$ ) in the normal mode laser resonator to measure the optical loss caused

by the ZnSe polarizer. Figs.10 and 11 show the difference of the normal mode laser output between without and with ZnSe plate in the resonator. Optical loss in the ZnSe plate could be estimated by observing the variation of the slope efficiency with mirror reflectivity. The slope efficiency  $\sigma_s$  is assumed to vary with the output mirror reflectivity  $R_m$  according to Ref.16 as

$$\sigma_{\rm s} = \sigma_{\rm sm} \ln (R_{\rm m}) / \ln (R_{\rm m} R_{\rm L})$$

where  $R_L$  is a fictitious mirror reflectivity representing the losses in the system and  $\sigma_{sm}$  is the maximum slope efficiency obtainable from the material.  $R_L$  is related to the losses L in the system as  $R_L = 1 - L$ . The above equation can be rewritten as

$$1/\sigma_{\rm s} = (-\ln R_{\rm L}/\sigma_{\rm sm}) (-1/\ln R_{\rm m}) + (1/\sigma_{\rm sm}).$$

The inverse slope efficiency is plotted as a function of  $-1/\ln R_m$ in Fig.12 using the data shown in Figs.10 and 11. From the slopes and y-intercepts of the two lines, each corresponding to results obtained with and without ZnSe plate in the resonator, respectively, we obtain  $R_L = \exp(-20.868/64.681) = 0.72425$  for the case of the ZnSe plate placed in the resonator and  $R_L = \exp(-$ 16.953/78.465) = 0.80569. Thus, the loss coefficient of the ZnSe plate is calculated as  $\alpha = L_{with} - L_{without} = (1 - R_L with) - (1 - R_L without) = 0.081$  (or 0.081/0.217 cm = .375 cm<sup>-1</sup>). This means that the ZnSe plate causes only 8% loss of the laser efficiency.

Table 2. Calculated Parameters for Single-LC-Section Pulse Forming

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Network.

FLASHLAMP PULSE FORMING NETWORK

PULSE ENERGY	PULSE WIDTH	CAPACI.	INDUCT.	VOLT	EXPLO. ENERGY	LIFE	BLKBDY TEMP.	PEAK WAVELEN.
J	uSEC	F	Н	۷	J	(10^6)	К	nm 
100	100	6.15E-05	1.81E-05	1802.8	433.0	25.7E-02	8906	325.4
	200	9.77E-05	4.55E-05	1430.9	612.4	48.9E-01	8865	326.9
	300	1.28E-04	7.81E-05	1250.0	750.0	27.4E+00	8841	327.8
	400	1.55E-04	1.15E-04	1135.7	866.0	93.1E+00	8824	328.4
	500	1.80E-04	1.54E-04	1054.3	968.2	24.0E+01	8811	328.9
	600	2.03E-04	1.97E-04	992.1	1060.7	52.2E+01	8800	329.3
	700	2.25E-04	2.42E-04	942.4	1145.6	10.0E+02	8791	329.7
	800	2.465-04	2.89E-04	901.4	1224.7	17.7E+02	8783	330.0
	900	2.66E-04	3.38E-04	866.7	1299.0	29.2E+02	8776	330.2
	1000	2.86E-04	3.89E-04	836.8	1369.3	45.7E+02	8770	330.4
200	 100	7.75E-05	1.43E-05	2271.4	433.0	71.0E-05	8947	323.9
200	200	1.23E-04	3.61E-05	1802.8	612.4	13.5E-03	8906	325.4
	300	1.61E-04	6.20E-05	1574.9	750.0	75.7E-03	8882	326.3
	400	1.95E-04	9.10E-05	1430.9	866.0	25.7E-02	8865	326.9
	500	2.27E-04	1.23E-04	1328.3	968.2	66.4E-02	8851	327.4
	600	2.56E-04	1.56E-04	1250.0	1060.7	14.4E-01	8841	327.8
	700	2.84E-04	1.92E-04	1187.4	1145.6	27.7E-01	8832	328.1
	800	3.10E-04	2.29E-04	1135.7	1224.7	48.9E-01	8824	328.4
	900	3.35E-04	2.68E-04	1092.0	1299.0	80.7E-01	8817	328.7
	1000	3.60E-04	3.09E-04	1054.3	1369.3	12.6E+00	8811	328.9
300	100	8.88E-05	1.25E-05	2600.1	433.0	22.6E-06	8971	323.0
	200	1.41E-04	3.15E-05	2063.7	612.4	43.1E-05	8930	324.5
	300	1.85E-04	5.428-05	1802.8	750.0	24.1E-04	8906	325.4
	400	2.24E-04	7.95E-05	1638.0	866.0	81.9E-04	8889	326.0
	500	2.60E-04	1.07E-04	1520.6	968.2	21.2E-03	8875	326.5
	600	2.93E-04	1.36E-04	1430.9	1060.7	45.9E-03	8865	326.9
	700	3.25E-04	1.68E-04	1359.2	1145.6	88.4E-03	8855	327.3
	800	3.55E-04	2.00E-04	1300.1	1224.7	15.6E-02	8848	327.5
	900	3.84E-04	2.34E-04	1250.0	1299.0	25.7E-02	8841	327.8
	1000	4.12E-04	2.70E-04	1206.9	1369.3	40.2E-02	8834 	328.0
400	100	9.77E-05	1.14E-05	2861.8	433.0	19.6E-07	8988	322.4
	200	1.556-04	2.87E-05	2271.4	612.4	37.3E-06	8947	323.9
	300	2.03E-04	4.92E-05	1984.3	750.0	20.9E-05	8923	324.8
	400	2.46E-04	7.22E-05	1802.8	866.0	71.0E-05	8906	325.4
	500	2.86E-04	9.73E-05	1673.6	968.2	18.3E-04	8892	325.9
	600	3.23E-04	1.24E-04	1574.9	1060.7	39.8E-04	8882	326.3 007 7
	700	3.57E-04	1.52E-04	1496.0	1145.6	76.6E-04	8872 0075	320.0 336.0
	800	3.91E-04	1.82E-04	1430.9	1224.7	13.5E-03	8860	320.7 337 3
	900	4.23E-04	2.13E-04	1375.8	1299.0	22.3E-03	8838	32(.2 337 4
	1000	4.53E-04	2.45E-04 	1328.3	1369.3	34.9E-03	8801 	327 <b>.4</b> 
500	100	1.05E-04	1.06E-05	3082.8	433.0	29.4E-08	9002	321.9
	200	1.67E-04	2.66E-05	2446.8	612.4	56.0E-07	8960	323.4
	300	2.19E-04	4.57E-05	2137.5	750.0	31.4E-06	8936	324.3
	400	2.65E-04	6.70E-05	1942.0	866.0	10.7E-05	8919	324.9
	500	3.08E-04	9.03E-05	1802.8	968.2	27.5E-05	8906	325.4
	600	3.47E-04	1.15E-04	1696.5	1060.7	59.7E-05	8895	325.8
	700	3.85E-04	1.41E-04	1611.5	1145.6	11.5E-04	8886	326.1
	800	4.21E-04	1.69E-04	1541.4	1224.7	20.3E-04	8878	326.4
	900 900	4.55E-04	1.98E-04	1482.0	1299.0	33.5E-04	8871	326.7
	1000	4.88F-04	2.27E-04	1430.9	1369.3	52.4E-04	8865	326.9

## III. Conclusion

We have calculated pulse forming network parameters for long square-wave typed flashlamp pulse generation and have prepared for construction of a flashlamp-pumped  $Cr^{3+}$ :GSAG laser of pulsed laser grater than 200 mJ and of pulse width of 1 ms FWHM. This Cr:GSAG laser will be used to pump 2 - 3  $\mu\text{m}$  lasers using mid-infrared laser crystals such as  $Tm^{3+}$ ,  $Er^{3+}$  and/or  $Ho^{3+}$ -ion doped YAG, YLF or other host materials. We have also completed a modification of an existing flashlamp-pumped and liquid-nitrogen-cooled rare earth laser system for 60 J electrical input energy and 500  $\mu \text{s}$  pulse width to determine optimum  $Tm^{3+}$ -ion concentration in Ho<sup>3+</sup>:Cr<sup>3+</sup>:Tm<sup>3+</sup>:YAG crystal, and have carried out preliminary experiments with a Ho<sup>3+</sup>:Er<sup>3+</sup>:Tm<sup>3+</sup>:YAG crystal to test the system performance. The slope efficiency of the Ho<sup>3+</sup>:Er<sup>3+</sup>:Tm<sup>3+</sup>:YAG laser increased as the operating temperature decreased and the highest slope efficiency obtained with a 60% reflective mirror was 0.88%. The optical loss coefficient of a 2.17 mm thick ZnSe plate placed at the Brewster angle in the laser resonator as a polarizer was measured to be 0.0814.

Material	lon Con- <u>centraion</u>	Laser λ	Diode <u>Power</u>	Laser Output	Threshold	Slope <sup>*</sup> Efficiency	Reference
Tm,Ho:YLF	1.5 % Tm 0 2 % Ho	2.31μm(Tm) 2.08um(Ho)	21mW @791_nm	5.5 mW	10.5 mW 3.1 mW	42 % 26 %	ref.2
Tm,Ho:YAG	5.7 % Tm 0.36% Ho	2.1 µm	100 mW	2.7 mW	3.8 mW absorbed	17 %	ref. 3
Cr,Tm,Ho:YAG	2.5×10 <sup>20</sup> cm <sup>-3</sup> Cr 8 × 10 <sup>20</sup> cm <sup>-3</sup> Tm 5 × 1019 cm-3 Ho	2.1 µm		1.2 mW	4.4 mW absorbed	19%	ref. 4
Er,Tm,Ho:YLF (at T=77 <sup>o</sup> K)	1 at wt % Ho 50 % Er	2.06 µm @ 784 nm	200 mW	20 mW	5 mW	20 % (Conversion efficiency)	ref. 5
Er,Tm,Ho:YAG (at T=77 <sup>0</sup> K)	60 % Er 3 % Tm 2 % Up	2.1 µm	100 mW @ 785.5 nm	5.6 mW	40 mW	19 %	ref. 6
Er:YLF	2 % HO 8 % Er	2.8 µm	200 mW		147 mW	0.7 %	ref. 7

\* with respect to absorbed pump power.

Table1. Laser Diode Pumped Rare Earth Laser Work Done By Others In 2 - 3 µm Range

Table 3. Calculated Parameters for Multi-LC-Section Pulse Forming

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Network. ORIGINAL PAGE IS MULTISECTION PULSE FORMING NETWORKS OF POOR QUALITY

J         USEC         F         Interval         State         State <thstate< th="">         State         State&lt;</thstate<>	TEMP. K
	8732
$ \begin{array}{c} 160 & 1.69E-04 & 2.37E-04 & 1089 & 5.62E-05 & 7.96E-04 & 100 & 376 \\ 600 & 2.21E-04 & 4.07E-04 & 961 & 7.37E-05 & 1.39E-04 & 100 & 376 \\ 900 & 2.68E-04 & 5.97E-04 & 864 & 8.93E-05 & 1.99E-04 & 103 & 319 \\ 1000 & 3.11E-04 & 8.04E-04 & 202 & 1.04E-04 & 2.68E-04 & 167 & 284 \\ 1200 & 3.51E-04 & 1.03E-03 & 775 & 1.17E-04 & 3.42E-04 & 200 & 258 \\ 1400 & 3.89E-04 & 1.26E-03 & 775 & 1.17E-04 & 3.42E-04 & 200 & 200 \\ 1600 & 4.25E-04 & 1.51E-03 & 636 & 1.42E-04 & 5.02E-04 & 263 & 200 \\ 1600 & 4.25E-04 & 1.7EE-03 & 637 & 1.53E-04 & 5.87E-04 & 300 & 200 \\ 2000 & 4.92E-04 & 2.03E-03 & 637 & 1.64E-04 & 6.76E-04 & 333 & 196 \\ \hline \\ 2000 & 4.92E-04 & 2.03E-03 & 637 & 1.64E-04 & 6.76E-04 & 333 & 196 \\ \hline \\ 2000 & 2.00 & 1.34E-04 & 7.47E-05 & 1728 & 4.46E-05 & 2.49E-05 & 67 & 637 \\ 630 & 2.79E-04 & 3.23E-04 & 1972 & 7.09E-05 & 6.27E-05 & 67 & 637 \\ 640 & 2.13E-04 & 6.38E-04 & 1011 & 1.31E-04 & 2.13E-04 & 167 & 406 \\ 1008 & 3.92E-04 & 6.38E-04 & 1011 & 1.31E-04 & 2.13E-04 & 167 & 406 \\ 1008 & 3.92E-04 & 6.38E-04 & 1011 & 1.31E-04 & 2.71E-04 & 200 & 370 \\ 1400 & 4.90E-04 & 1.00E-03 & 903 & 1.63E-04 & 3.33E-04 & 263 & 342 \\ 1400 & 4.90E-04 & 1.00E-03 & 903 & 1.63E-04 & 3.38E-04 & 267 & 319 \\ 1600 & 5.36E-04 & 1.19E-03 & 864 & 1.79E-04 & 3.98E-04 & 267 & 319 \\ 1600 & 5.36E-04 & 1.19E-03 & 802 & 2.07E-04 & 5.36E-04 & 133 & 284 \\ 2000 & 6.22E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.48E-05 & 67 & 772 \\ 600 & 3.19E-04 & 2.82E-04 & 1372 & 1.06E-04 & 9.41E-05 & 106 & 637 \\ 600 & 3.19E-04 & 2.82E-04 & 1372 & 1.06E-04 & 9.41E-05 & 106 & 637 \\ 800 & 3.08E-04 & 4.1E-03 & 989 & 2.04E-04 & 4.68E-04 & 167 & 497 \\ 1200 & 5.06E-04 & 7.11E-03 & 989 & 2.04E-04 & 3.48E-04 & 267 & 393 \\ 1800 & 6.03E-04 & 1.44E-03 & 989 & 2.04E-04 & 3.48E-04 & 267 & 393 \\ 1800 & 6.13E-04 & 1.04E-03 & 989 & 2.04E-04 & 3.48E-04 & 267 & 393 \\ 1800 & 6.13E-04 & 1.22E-03 & 1137 & 1.42E-04 & 3.38E-04 & 267 & 393 \\ 1800 & 6.13E-04 & 1.49E-04 & 1728 & 8.93E-05 & 1.98E-05 & 67 & 772 \\ 1000 & 4.93E-04 & 5.93E-05 & 2177 & 5.62E-05 & 1.98E-05 & 67 & 782 \\ 1000 & 5.57E-04 & 3.76E-0$	8692
$\begin{array}{c} 1.000 & 1.21E = 04 & 4.07E = 04 & 951 & 7.37E = 05 & 1.38E = 04 & 1.38 & 319 \\ 300 & 2.68E = 04 & 5.97E = 04 & 864 & 8.98E = 05 & 1.99E = 04 & 133 & 319 \\ 1000 & 3.51E = 04 & 1.03E = 03 & 755 & 1.17E = 04 & 3.42E = 04 & 208 & 258 \\ 1200 & 3.51E = 04 & 1.02E = 03 & 715 & 1.17E = 04 & 3.42E = 04 & 208 & 238 \\ 1400 & 4.25E = 04 & 1.5E = 03 & 636 & 1.42E = 04 & 5.02E = 04 & 267 & 222 \\ 1600 & 4.25E = 04 & 1.5E = 03 & 636 & 1.42E = 04 & 5.02E = 04 & 267 & 228 \\ 1600 & 4.25E = 04 & 1.7E = 03 & 659 & 1.53E = 04 & 5.87E = 04 & 300 & 208 \\ 2000 & 4.93E = 04 & 2.03E = 03 & 659 & 1.53E = 04 & 5.87E = 04 & 300 & 208 \\ 2000 & 4.93E = 04 & 2.03E = 03 & 637 & 1.64E = 04 & 6.76E = 04 & 333 & 196 \\ 2000 & 4.93E = 04 & 2.03E = 03 & 637 & 1.64E = 04 & 6.76E = 04 & 300 & 208 \\ 400 & 2.13E = 04 & 1.38E = 04 & 1372 & 7.09E = 05 & 6.27E = 05 & 67 & 637 \\ 400 & 2.13E = 04 & 1.38E = 04 & 1372 & 7.09E = 05 & 6.27E = 05 & 67 & 637 \\ 400 & 2.79E = 04 & 1.32E = 04 & 1011 & 1.31E = 04 & 2.13E = 04 & 100 & 523 \\ 800 & 3.92E = 04 & 6.38E = 04 & 1011 & 1.31E = 04 & 2.13E = 04 & 100 & 523 \\ 1000 & 4.90E = 04 & 1.00E = 03 & 903 & 1.63E = 04 & 3.38E = 04 & 233 & 342 \\ 1400 & 4.90E = 04 & 1.00E = 03 & 903 & 1.63E = 04 & 3.98E = 04 & 267 & 319 \\ 1600 & 5.79E = 04 & 1.40E = 03 & 831 & 1.92E = 04 & 4.66E = 04 & 300 & 300 \\ 2000 & 6.22E = 04 & 1.61E = 03 & 802 & 2.07E = 04 & 5.36E = 04 & 333 & 284 \\ 2000 & 6.22E = 04 & 1.61E = 03 & 802 & 2.07E = 04 & 5.36E = 04 & 333 & 284 \\ 2000 & 6.38E = 04 & 1.44E = 04 & 1224 & 1.29E = 04 & 1.38E = 04 & 167 & 497 \\ 1200 & 5.06E = 04 & 1.72E & 1.06E = 04 & 2.37E = 04 & 2.62E = 04 & 333 & 218 \\ 1200 & 5.06E = 04 & 1.71E = 04 & 1226 & 1.38E = 04 & 167 & 497 \\ 1200 & 5.06E = 04 & 1.72E & 9951 & 2.21E = 04 & 4.66E = 04 & 333 & 351 \\ 1200 & 7.12E = 04 & 1.22E = 03 & 918 & 2.37E = 04 & 4.66E = 04 & 333 & 351 \\ 1200 & 7.12E = 04 & 1.44E = 04 & 1246 & 1.29E = 04 & 1.38E = 04 & 267 & 399 \\ 1800 & 6.38E = 04 & 5.93E = 05 & 2177 & 5.62E = 05 & 1.98E = 05 & 67 & 832 \\ 1600 & 6.13E = 04 & 5.93E = 05 & 2177 & 5.62E = 05 & $	8669
300         2.68E-04         5.97E-04         864         8.92E-05         1.97E-04         167         204           1000         3.11E-04         8.04E-04         802         1.04E-04         3.42E-04         200         258           1200         3.51E-04         1.26E-03         755         1.17E-04         3.42E-04         200         258           1600         4.25E-04         1.51E-03         637         1.42E-04         5.02E-04         267         222           1600         4.25E-04         1.76E-03         657         1.53E-04         5.07E-04         300         2003           2000         1.34E-04         7.47E-05         1728         4.46E-05         2.49E-05         33         882           2000         2001         1.34E-04         3.23E-04         1198         9.29E-05         1.08E-04         100         5.23           600         3.79E-04         3.23E-04         1091         1.31E-04         2.13E-04         200         7.09         1.53E-04         163         4.54           1000         3.37E-04         3.23E-04         1091         1.31E-04         2.13E-04         2.03         372           1000         4.42E-04         951 <td>8652</td>	8652
1000         3.11E-04         8.04E-04         302         1.04E-04         2.68         2.78           1200         3.51E-04         1.03E-03         755         1.17E-04         3.42E-04         2.33         238           1400         3.89E-04         1.26E-03         717         1.30E-04         4.20E-04         2.67         222           1600         4.25E-04         1.51E-03         666         1.42E-04         5.02E-04         300         208           2000         4.93E-04         2.03E-03         637         1.64E-04         6.76E-04         333         196           2000         2.03E-04         1.88E-04         1372         7.09E-05         6.27E-05         637         667         637           4000         2.13E-04         1.88E-04         1089         9.2E-05         1.08E-04         100         523           6000         3.92E-04         6.38E-04         1011         1.31E-04         2.13E-04         100         523           10000         3.92E-04         1.08E-03         903         1.63E-04         3.93E-04         233         342           1600         5.36E-04         1.19E-03         804         1.79E-04         3.93E-04         23	8639
$\begin{array}{c} 1.000 & 3.51E-04 & 1.03E-03 & 755 & 1.17E-04 & 3.42E-04 & 2.33 & 2.38 \\ 1400 & 3.89E-04 & 1.26E-03 & 675 & 1.33E-04 & 5.02E-04 & 267 & 222 \\ 1800 & 4.02E-04 & 1.51E-03 & 636 & 1.42E-04 & 5.02E-04 & 267 & 222 \\ 1800 & 4.02E-04 & 2.03E-03 & 637 & 1.64E-04 & 5.02E-04 & 333 & 196 \\ 2000 & 4.93E-04 & 2.03E-03 & 637 & 1.64E-04 & 5.02E-05 & 67 & 637 \\ 400 & 2.13E-04 & 1.88E-04 & 1372 & 7.09E-05 & 6.27E-05 & 67 & 637 \\ 600 & 2.79E-04 & 3.23E-04 & 1198 & 9.29E-05 & 1.08E-04 & 100 \\ 523 & 600 & 3.37E-04 & 4.74E-04 & 1089 & 1.12E-04 & 1.58E-04 & 133 & 454 \\ 800 & 3.37E-04 & 4.74E-04 & 1089 & 1.12E-04 & 1.58E-04 & 133 & 454 \\ 1000 & 3.92E-04 & 6.38E-04 & 1011 & 1.31E-04 & 2.13E-04 & 167 & 406 \\ 1200 & 4.42E-04 & 8.14E-04 & 9951 & 1.64E-04 & 3.33E-04 & 233 & 342 \\ 1400 & 4.90E-04 & 1.00E-03 & 903 & 1.63E-04 & 3.33E-04 & 267 & 319 \\ 1600 & 5.36E-04 & 1.19E-03 & 864 & 1.79E-04 & 3.98E-04 & 267 & 319 \\ 1600 & 5.36E-04 & 1.64E-03 & 802 & 2.07E-04 & 5.36E-04 & 300 & 300 \\ 1800 & 5.79E-04 & 1.64E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ 2000 & 1.53E-04 & 1.62E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ 1000 & 4.92E-04 & 1.64E-03 & 802 & 2.07E-04 & 1.38E-04 & 167 & 497 \\ 1000 & 4.48E-04 & 5.58E-04 & 1137 & 1.49E-04 & 1.38E-04 & 167 & 497 \\ 1000 & 4.48E-04 & 5.58E-04 & 1137 & 1.49E-04 & 1.38E-04 & 167 & 497 \\ 1000 & 4.48E-04 & 5.58E-04 & 1034 & 1.87E-04 & 2.91E-05 & 33 & 1060 \\ 1200 & 6.0E-04 & 7.11E-04 & 1037 & 1.49E-04 & 2.37E-04 & 200 & 454 \\ 1200 & 5.0EE-04 & 1.04E-03 & 989 & 2.04E-04 & 3.48E-04 & 267 & 333 \\ 1600 & 6.13E-04 & 1.92E-03 & 989 & 2.04E-04 & 2.97E-04 & 3.08 & 333 \\ 1600 & 6.13E-04 & 1.92E-03 & 989 & 2.04E-04 & 2.97E-04 & 300 & 370 \\ 1800 & 6.65E-04 & 1.49E-04 & 1137 & 1.42E-04 & 1.25E-04 & 300 & 370 \\ 1800 & 6.65E-04 & 1.49E-04 & 1137 & 1.42E-04 & 1.25E-04 & 333 & 1206 \\ 400 & 2.68E-04 & 1.49E-04 & 1177 & 1.42E-04 & 1.25E-04 & 333 & 1206 \\ 400 & 2.68E-04 & 1.49E-04 & 1137 & 1.42E-04 & 1.25E-04 & 333 & 1206 \\ 400 & 2.68E-04 & 1.49E-04 & 1177 & 1.42E-04 & 1.25E-04 & 333 & 1206 \\ 400 & 2.68E-04 & 1.49E-04$	8629
$ \begin{array}{c} 1400 & 3.89E-04 & 1.26E-03 & 717 & 1.30E-04 & 4.20E-04 & 267 & 222 \\ 1600 & 4.25E-04 & 1.51E-03 & 636 & 1.42E-04 & 5.87E-04 & 300 & 208 \\ 1800 & 4.60E-04 & 1.76E-03 & 659 & 1.53E-04 & 5.87E-04 & 333 & 196 \\ 2000 & 4.93E-04 & 2.03E-03 & 637 & 1.64E-04 & 6.76E-04 & 333 & 196 \\ 2000 & 2.08 & 1.34E-04 & 7.47E-05 & 1728 & 4.46E-05 & 2.49E-05 & 33 & 882 \\ 600 & 2.79E-04 & 3.23E-04 & 1198 & 9.29E-05 & 1.08E-04 & 100 & 523 \\ 600 & 2.79E-04 & 3.23E-04 & 1198 & 9.29E-05 & 1.08E-04 & 103 & 454 \\ 1000 & 3.92E-04 & 6.38E-04 & 1089 & 1.12E-04 & 2.13E-04 & 167 & 406 \\ 1000 & 3.92E-04 & 6.38E-04 & 1081 & 1.31E-04 & 2.13E-04 & 267 & 319 \\ 1200 & 4.42E-04 & 8.14E-04 & 951 & 1.47E-04 & 2.71E-04 & 220 & 370 \\ 1200 & 4.42E-04 & 8.14E-04 & 951 & 1.47E-04 & 3.98E-04 & 267 & 319 \\ 1600 & 5.36E-04 & 1.19E-03 & 864 & 1.79E-04 & 3.98E-04 & 267 & 319 \\ 1600 & 5.36E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.36E-04 & 330 & 200 \\ 2000 & 6.22E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ 2000 & 6.22E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ 2000 & 6.22E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ 2000 & 6.22E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ 2000 & 6.22E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ 2000 & 6.22E-04 & 1.62E-05 & 1978 & 5.11E-05 & 5.48E-05 & 67 & 772 \\ 1000 & 4.48E-04 & 5.58E-04 & 1570 & 8.11E-05 & 5.48E-05 & 67 & 772 \\ 1000 & 4.48E-04 & 1.24E-03 & 989 & 2.04E-04 & 3.48E-04 & 163 & 554 \\ 1000 & 6.3E-04 & 1.14E-04 & 1246 & 1.29E-04 & 1.38E-04 & 133 & 554 \\ 1000 & 6.3E-04 & 1.04E-03 & 981 & 2.37E-04 & 2.08E-05 & 67 & 332 \\ 1600 & 6.13E-04 & 1.04E-03 & 981 & 2.37E-04 & 2.08E-05 & 67 & 332 \\ 1600 & 6.13E-04 & 1.24E-03 & 981 & 2.37E-04 & 4.68E-04 & 363 & 351 \\ 1000 & 4.25E-04 & 3.76E-04 & 1728 & 8.93E-05 & 4.98E-05 & 67 & 332 \\ 1000 & 4.25E-04 & 3.76E-04 & 1728 & 8.93E-05 & 4.98E-05 & 67 & 332 \\ 1000 & 4.93E-04 & 5.07E-04 & 1728 & 8.93E-05 & 4.38E-04 & 267 & 393 \\ 12000 & 7.30E-04 & 1.41E-03 & 1047 & 2.43E-04 & 3.78E-04 & 308 & 428 \\ 1000 & 6.75E-04 & 5.58E-04 &$	8620
$ \begin{array}{c} 1600 & 4.25E-04 & 1.51E-03 & 636 & 1.42E-04 & 5.87E-04 & 300 & 208 \\ 1800 & 4.69E-04 & 1.76E-03 & 637 & 1.64E-04 & 5.87E-04 & 300 & 208 \\ 2000 & 4.93E-04 & 2.03E-03 & 637 & 1.64E-04 & 6.76E-04 & 333 & 196 \\ \hline \\ 2000 & 200 & 1.34E-04 & 7.47E-05 & 1728 & 4.46E-05 & 2.49E-05 & 33 & 882 \\ 600 & 2.79E-04 & 3.23E-04 & 1372 & 7.09E-05 & 6.27E-05 & 67 & 637 \\ 600 & 2.79E-04 & 3.23E-04 & 1198 & 9.29E-05 & 1.08E-04 & 133 & 454 \\ 800 & 3.37E-04 & 4.74E-04 & 1089 & 1.12E-04 & 1.58E-04 & 133 & 454 \\ 800 & 3.37E-04 & 6.38E-04 & 1011 & 1.31E-04 & 2.13E-04 & 167 & 406 \\ 1200 & 4.42E-04 & 8.14E-04 & 951 & 1.47E-04 & 2.71E-04 & 200 & 370 \\ 1200 & 4.42E-04 & 1.09E-03 & 864 & 1.79E-04 & 3.98E-04 & 267 & 319 \\ 1600 & 5.36E-04 & 1.19E-03 & 864 & 1.79E-04 & 3.98E-04 & 267 & 319 \\ 1600 & 5.36E-04 & 1.61E-03 & 801 & 1.92E-04 & 4.66E-04 & 300 & 300 \\ 2000 & 6.22E-04 & 1.61E-03 & 801 & 1.92E-04 & 4.66E-04 & 300 & 300 \\ 2000 & 1.53E-04 & 6.52E-05 & 1978 & 5.11E-05 & 2.17E-05 & 33 & 1060 \\ 300 & 200 & 1.53E-04 & 6.52E-05 & 1978 & 5.11E-05 & 5.48E-05 & 67 & 772 \\ 400 & 2.43E-04 & 1.64E-03 & 1372 & 1.06E-04 & 9.41E-05 & 100 & 637 \\ 400 & 2.43E-04 & 1.64E-04 & 1570 & 8.11E-05 & 5.48E-04 & 133 & 554 \\ 800 & 3.8EE-04 & 4.14E-04 & 1246 & 1.29E-04 & 1.38E-04 & 167 & 497 \\ 1060 & 4.48E-04 & 5.58E-04 & 1157 & 1.49E-04 & 1.86E-04 & 167 & 497 \\ 1060 & 5.61E-04 & 8.73E-04 & 1089 & 1.69E-04 & 2.37E-04 & 200 & 454 \\ 1400 & 5.61E-04 & 8.73E-05 & 2177 & 5.62E-05 & 1.98E-05 & 67 & 832 \\ 1600 & 6.13E-04 & 1.22E-03 & 989 & 2.04E-04 & 3.48E-04 & 267 \\ 300 & 3.51E-04 & 2.56E-04 & 1510 & 1.17E-04 & 4.68E-04 & 333 & 351 \\ 2000 & 7.12E-04 & 1.41E-03 & 918 & 2.37E-04 & 4.68E-04 & 333 & 351 \\ 2000 & 7.12E-04 & 5.95E-04 & 1510 & 1.17E-04 & 4.68E-04 & 333 & 351 \\ 2000 & 7.38E-04 & 2.56E-04 & 1510 & 1.17E-04 & 3.68E-04 & 267 & 333 & 1266 \\ 800 & 3.51E-04 & 2.56E-04 & 1510 & 1.17E-04 & 3.55E-04 & 233 & 452 \\ 1400 & 6.17E-04 & 7.94E-04 & 1138 & 2.96E-04 & 2.65E-04 & 333 & 452 \\ 1400 & 6.75E-04 & 5.95E-04 & 1372 & 1.42E-04 & 3.70E-04 & 360 & 772 \\ 1000 & 4.93E-04$	8612
$ \begin{array}{c} 1800 & 4.60E-04 & 1.76E-03 & 659 & 1.53E-04 & 5.76E-04 & 333 & 196 \\ 2000 & 4.93E-04 & 2.03E-03 & 637 & 1.64E-04 & 6.76E-04 & 333 & 196 \\ 2000 & 200 & 1.34E-04 & 7.47E-05 & 1728 & 4.46E-05 & 2.49E-05 & 33 & 882 \\ 400 & 2.13E-04 & 1.88E-04 & 1372 & 7.09E-05 & 6.27E-05 & 67 & 637 \\ 400 & 2.19E-04 & 3.23E-04 & 1198 & 9.29E-05 & 1.08E-04 & 108 & 523 \\ 600 & 3.77E-04 & 4.74E-04 & 1089 & 1.12E-04 & 1.58E-04 & 133 & 454 \\ 1000 & 3.92E-04 & 6.38E-04 & 101 & 1.31E-04 & 2.13E-04 & 167 & 406 \\ 1000 & 3.92E-04 & 6.38E-04 & 903 & 1.63E-04 & 3.33E-04 & 233 & 342 \\ 1400 & 4.90E-04 & 1.00E-03 & 903 & 1.63E-04 & 3.98E-04 & 267 & 319 \\ 1600 & 5.36E-04 & 1.19E-03 & 864 & 1.79E-04 & 3.98E-04 & 267 & 319 \\ 1600 & 5.36E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ 2000 & 6.22E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ 2000 & 6.22E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ 2000 & 6.22E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ 2000 & 6.22E-04 & 1.61E-03 & 802 & 2.07E-04 & 1.38E-04 & 133 & 554 \\ 400 & 2.43E-04 & 1.64E-04 & 1570 & 8.11E-05 & 5.48E-05 & 67 & 772 \\ 400 & 2.43E-04 & 1.64E-04 & 1372 & 1.06E-04 & 9.41E-05 & 100 & 637 \\ 800 & 3.86E-04 & 4.14E-04 & 1246 & 1.29E-04 & 1.38E-04 & 103 & 554 \\ 1200 & 5.06E-04 & 7.11E-04 & 1089 & 1.69E-04 & 2.37E-04 & 203 & 426 \\ 1400 & 5.01E-04 & 8.73E-04 & 1034 & 1.87E-04 & 2.91E-04 & 203 & 426 \\ 1400 & 5.01E-04 & 1.94E-03 & 951 & 2.21E-04 & 4.68E-04 & 300 & 370 \\ 1800 & 6.63E-04 & 1.42E-03 & 951 & 2.21E-04 & 4.68E-04 & 333 & 351 \\ 2000 & 7.12E-04 & 1.41E-03 & 918 & 2.37E-04 & 4.68E-04 & 333 & 351 \\ 2000 & 7.12E-04 & 3.93E-05 & 2177 & 5.62E-05 & 1.98E-05 & 67 & 882 \\ 400 & 2.68E-04 & 1.37E & 1.42E-04 & 1.38E-04 & 300 & 370 \\ 2000 & 7.30E-04 & 1.92E-04 & 1372 & 1.42E-04 & 1.69E-04 & 306 & 351 \\ 2000 & 7.30E-04 & 1.92E-04 & 1372 & 1.64E-04 & 1.69E-04 & 167 & 572 \\ 2000 & 7.30E-04 & 1.92E-04 & 1372 & 1.64E-04 & 1.69E-04 & 306 & 428 \\ 2000 & 7.33E-04 & 1.28E-04 & 1372 & 1.64E-04 & 1.69E-04 & 306 & 428 \\ 2000 & 7.33E-04 & 1.28E-04 & 1372 & 1$	8605
2000         4.93E-04         2.03E-03         637         1.64E-04         6.10E           200         200         1.34E-04         7.47E-05         1728         4.46E-05         2.49E-05         33         882           200         200         2.34E-04         1.88E-04         1372         7.09E-05         6.27E-05         67         637           400         2.79E-04         3.23E-04         1198         9.29E-05         1.08E-04         1133         454           400         3.92E-04         6.38E-04         1011         1.31E-04         2.71E-04         200         372           1200         4.42E-04         8.14E-04         951         1.47E-04         2.71E-04         200         372           1200         4.42E-04         8.14E-04         951         1.47E-04         2.71E-04         200         372           1200         4.22E-04         1.00E-03         903         1.63E-04         3.33E-04         203         284           1600         5.36E-04         1.92E-03         802         2.07E-04         4.66E-04         300         300           2000         1.53E-04         6.52E-05         1978         5.11E-05         2.17E-05         33	8599
200         200         1.34E-04         7.47E-05         1728         4.46E-05         2.49E-05         33         882           400         2.13E-04         1.88E-04         1372         7.09E-05         6.62F-05         67         637           600         2.79E-04         3.23E-04         1198         9.29E-05         1.08E-04         100         523           800         3.37E-04         4.74E-04         1089         1.12E-04         1.58E-04         103         454           1000         3.92E-04         6.38E-04         1011         1.31E-04         2.13E-04         20370           1200         4.42E-04         8.14E-04         951         1.47E-04         3.33E-04         203         342           1400         4.90E-04         1.00E-03         903         1.63E-04         3.98E-04         267         319           1600         5.36E-04         1.19E-03         861         1.79E-04         3.98E-04         233         328           2000         6.22E-04         1.61E-03         802         2.07E-04         5.36E-04         333         284           300         208         1.53E-04         6.52E-05         1978         5.11E-05         5.48E-04	
200         1.38E-04         1.88E-04         1372         7.09E-05         1.08E-04         100         523           600         2.79E-04         3.23E-04         1198         9.29E-05         1.08E-04         100         523           800         3.37E-04         4.74E-04         1089         1.12E-04         1.58E-04         133         454           1000         3.92E-04         6.38E-04         1011         1.31E-04         2.17E-04         200         77E-04         200         77E-04         200         77E-04         200         77E-04         200         77E-04         200         333         342           1400         4.90E-04         1.00E-03         903         1.63E-04         3.38E-04         267         319           1600         5.38E-04         1.19E-03         864         1.79E-04         3.98E-04         267         319           1800         5.79E-04         1.61E-03         802         2.07E-04         3.98E-04         267         772           400         2.43E-04         1.57E         8.11E-05         5.41E-05         33         1060         67         772           400         2.43E-04         1.37E         1.49E-04	8732
600         2.79E-04         3.23E-04         1198         9.29E-05         1.03E-04         133         454           800         3.37E-04         4.74E-04         1089         1.12E-04         2.13E-04         167         406           1000         3.92E-04         6.38E-04         1011         1.31E-04         2.13E-04         167         406           1200         4.42E-04         8.14E-04         951         1.47E-04         2.71E-04         200         370           1400         4.90E-04         1.00E-03         903         1.63E-04         3.38E-04         267         319           1600         5.36E-04         1.19E-03         864         1.77E-04         3.98E-04         267         319           1600         5.22E-04         1.61E-03         802         2.07E-04         5.36E-04         333         284           2000         1.53E-04         6.52E-05         1978         5.11E-05         2.17E-05         33         1060           400         2.43E-04         1.64E-04         1570         8.11E-05         5.48E-05         67         772           400         2.43E-04         1.64E-04         129         1.86E-04         167         497	8709
300         3.37E-04         4.74E-04         1089         1.12E-04         1.38E-04         1.63         100           1000         3.92E-04         6.38E-04         1011         1.31E-04         2.71E-04         200         370           1200         4.42E-04         8.14E-04         903         1.63E-04         3.33E-04         233         342           1600         5.36E-04         1.19E-03         864         1.79E-04         3.98E-04         266         300           1800         5.79E-04         1.40E-03         802         2.07E-04         5.36E-04         300         300           2000         6.22E-04         1.61E-03         802         2.07E-04         5.36E-04         100         633           300         200         1.53E-04         6.52E-05         1978         5.11E-05         2.17E-05         33         1060           400         2.43E-04         1.64E-04         1226         1.88E-04         167         497           1000         4.98E-04         5.38E-04         1157         1.49E-04         1.88E-04         167         497           1000         4.48E-04         5.38E-04         1.67         497         1.49E-04         1.88E-04 </td <td>8692</td>	8692
1000         3.92E-04         6.38E-04         1011         1.31E-04         2.17E-04         2.00         376           1200         4.42E-04         8.14E-04         951         1.47E-04         2.71E-04         200         376           1400         4.90E-04         1.00E-03         903         1.63E-04         3.33E-04         233         342           1600         5.36E-04         1.19E-03         864         1.79E-04         3.98E-04         266         300           2000         6.22E-04         1.61E-03         802         2.07E-04         5.36E-04         333         284           300         200         1.53E-04         6.52E-05         1978         5.11E-05         5.48E-05         67         772           400         2.43E-04         1.64E-04         1570         8.11E-05         5.48E-04         133         544           800         3.86E-04         4.14E-04         1246         1.29E-04         1.38E-04         133         544           1200         5.61E-04         7.11E-04         1089         1.69E-04         2.37E-04         200         454           1200         5.61E-04         8.73E-04         1034         1.87E-04         2.91E-	8679
$\begin{array}{c} 1200 & 4.42E-04 & 8.14E-04 & 951 & 1.47E-04 & 2.71E-04 & 2.31E-04 & 2.33 & 342 \\ 1400 & 4.90E-04 & 1.00E-03 & 903 & 1.63E-04 & 3.33E-04 & 267 & 319 \\ 1600 & 5.36E-04 & 1.19E-03 & 864 & 1.79E-04 & 3.98E-04 & 267 & 319 \\ 1600 & 5.79E-04 & 1.40E-03 & 831 & 1.93E-04 & 4.66E-04 & 303 & 284 \\ 2000 & 6.22E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ 2000 & 6.22E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ 400 & 2.43E-04 & 1.64E-04 & 1570 & 8.11E-05 & 5.48E-05 & 67 & 772 \\ 400 & 2.43E-04 & 1.64E-04 & 1372 & 1.06E-04 & 9.41E-05 & 100 & 637 \\ 800 & 3.86E-04 & 4.14E-04 & 1246 & 1.29E-04 & 1.38E-04 & 133 & 554 \\ 800 & 3.86E-04 & 5.58E-04 & 1157 & 1.49E-04 & 1.86E-04 & 167 & 497 \\ 1000 & 4.48E-04 & 5.58E-04 & 1034 & 1.87E-04 & 2.91E-04 & 233 & 420 \\ 1400 & 5.06E-04 & 7.11E-04 & 1089 & 1.69E-04 & 2.37E-04 & 200 & 454 \\ 1200 & 5.06E-04 & 7.11E-04 & 1089 & 1.69E-04 & 3.48E-04 & 267 & 393 \\ 1600 & 6.13E-04 & 1.04E-03 & 989 & 2.04E-04 & 3.48E-04 & 267 & 393 \\ 1600 & 6.13E-04 & 1.04E-03 & 981 & 2.37E-04 & 4.68E-04 & 300 & 370 \\ 2000 & 7.12E-04 & 1.41E-03 & 918 & 2.37E-04 & 4.68E-04 & 333 & 351 \\ 400 & 200 & 1.69E-04 & 5.93E-05 & 2177 & 5.62E-05 & 1.98E-05 & 67 & 882 \\ 400 & 2.68E-04 & 1.41E-03 & 918 & 2.37E-04 & 4.68E-04 & 333 & 351 \\ 2000 & 7.12E-04 & 3.76E-04 & 1273 & 1.64E-04 & 1.25E-04 & 133 & 637 \\ 800 & 4.25E-04 & 3.76E-04 & 1273 & 1.64E-04 & 1.69E-04 & 167 & 572 \\ 1000 & 4.93E-04 & 5.07E-04 & 1273 & 1.64E-04 & 1.69E-04 & 167 & 572 \\ 1000 & 4.93E-04 & 5.07E-04 & 1273 & 1.64E-04 & 2.55E-04 & 233 & 485 \\ 1400 & 6.17E-04 & 7.94E-04 & 1138 & 2.06E-04 & 2.15E-04 & 233 & 485 \\ 1400 & 6.75E-04 & 9.48E-04 & 1089 & 2.25E-04 & 3.16E-04 & 267 & 454 \\ 1600 & 6.75E-04 & 9.48E-04 & 1089 & 2.25E-04 & 3.76E-04 & 267 & 454 \\ 1600 & 6.75E-04 & 9.48E-04 & 1089 & 2.25E-04 & 3.76E-04 & 267 & 454 \\ 1800 & 7.30E-04 & 1.11E-03 & 1047 & 2.43E-04 & 3.70E-04 & 300 & 428 \\ 2000 & 7.83E-04 & 1.28E-05 & 1011 & 2.61E-04 & 4.26E-04 & 333 & 406 \\ 2000 & 7.83E-04 & 1.28E-05 & 1011 & 2.61E-04 & 4.26E-04 & 333 & 406 \\ 2000 & 7.8$	8669
1400       4.90E-04       1.00E-03       903       1.63E-04       3.93E-04       227       319         1600       5.35E-04       1.19E-03       864       1.79E-04       3.98E-04       200       300         2000       6.22E-04       1.61E-03       802       2.07E-04       5.36E-04       333       284         300       2000       6.22E-04       1.61E-03       802       2.07E-04       5.36E-04       333       284         300       2000       6.22E-04       1.64E-04       1570       8.11E-05       5.48E-05       67       772         400       2.43E-04       1.64E-04       1570       8.11E-05       5.48E-04       106       637         500       3.86E-04       4.14E-04       1246       1.29E-04       1.38E-04       133       554         1000       4.48E-04       5.58E-04       1157       1.49E-04       1.86E-04       167       497         1200       5.06E-04       7.11E-04       1089       1.69E-04       2.37E-04       200       454         1400       5.61E-04       8.73E-04       1034       1.87E-04       2.91E-04       333       351         1400       6.63E-04       1.22E-03 </td <td>8660</td>	8660
$\begin{array}{c} 1600 & 5.36E-04 & 1.19E-03 & 864 & 1.79E-04 & 3.00E & 300E \\ 1800 & 5.79E-04 & 1.40E-03 & 831 & 1.93E-04 & 4.66E-04 & 303 & 284 \\ 2000 & 6.22E-04 & 1.61E-03 & 802 & 2.07E-04 & 5.36E-04 & 333 & 284 \\ \hline \\ 300 & 200 & 1.53E-04 & 6.52E-05 & 1978 & 5.11E-05 & 2.17E-05 & 33 & 1060 \\ 400 & 2.43E-04 & 1.64E-04 & 1570 & 8.11E-05 & 5.48E-05 & 67 & 772 \\ 600 & 3.19E-04 & 2.82E-04 & 1372 & 1.06E-04 & 9.41E-05 & 100 & 637 \\ 600 & 3.96E-04 & 4.14E-04 & 1246 & 1.29E-04 & 1.38E-04 & 133 & 554 \\ 800 & 3.86E-04 & 7.11E-04 & 1089 & 1.69E-04 & 2.37E-04 & 200 & 454 \\ 1200 & 5.06E-04 & 7.11E-04 & 1089 & 1.69E-04 & 2.37E-04 & 200 & 454 \\ 1200 & 5.06E-04 & 7.11E-03 & 989 & 2.04E-04 & 3.48E-04 & 267 & 393 \\ 1600 & 6.13E-04 & 1.04E-03 & 989 & 2.04E-04 & 3.48E-04 & 267 & 393 \\ 1600 & 6.63E-04 & 1.42E-03 & 951 & 2.21E-04 & 4.68E-04 & 333 & 351 \\ \hline \\ 400 & 200 & 1.69E-04 & 5.93E-05 & 2177 & 5.62E-05 & 1.98E-05 & 33 & 1206 \\ 400 & 2.68E-04 & 1.49E-04 & 1728 & 8.93E-05 & 4.98E-05 & 67 & 882 \\ 600 & 3.51E-04 & 2.56E-04 & 1510 & 1.17E-04 & 8.55E-05 & 100 & 730 \\ 600 & 3.51E-04 & 2.56E-04 & 1372 & 1.42E-04 & 1.25E-04 & 133 & 637 \\ 800 & 4.25E-04 & 3.76E-04 & 1372 & 1.42E-04 & 1.69E-04 & 167 & 572 \\ 1000 & 4.93E-04 & 5.07E-04 & 1138 & 2.06E-04 & 2.65E-04 & 233 & 485 \\ 1400 & 6.17E-04 & 7.94E-04 & 1138 & 2.06E-04 & 2.65E-04 & 233 & 485 \\ 1400 & 6.17E-04 & 7.94E-04 & 1138 & 2.06E-04 & 2.65E-04 & 233 & 485 \\ 1400 & 6.75E-04 & 9.48E-04 & 1089 & 2.25E-04 & 3.16E-04 & 267 & 454 \\ 1600 & 6.75E-04 & 1.48E-03 & 1087 & 2.43E-04 & 3.70E-04 & 333 & 406 \\ 2000 & 7.83E-04 & 1.28E-03 & 1011 & 2.61E-04 & 4.26E-04 & 333 & 406 \\ 2000 & 7.83E-04 & 1.28E-03 & 1011 & 2.61E-04 & 4.26E-04 & 333 & 406 \\ 2000 & 7.83E-04 & 1.28E-04 & 1862 & 9.62E-05 & 1.83E-05 & 53 \\ 1300 & 7.83E-04 & 1.28E-04 & 1862 & 9.62E-05 & 1.83E-05 & 33 & 1330 \\ 1300 & 7.83E-04 & 1.28E-04 & 1862 & 9.62E-05 & 1.62E-05 & 67 & 976 \\ 1.82E-04 & 1.82E-04 & 1.82E-04 & 1862 & 9.62E-05 & 4.62E-05 & 67 & 976 \\ 1.82E-04 & 1.82E-04 & 1.82E-04 & 1.82E-05 & 533 & 1330 \\ 1.82E-04 & 1.28E-04 & 1.82E-04 & $	8652
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	8645
2000         6.22E-04         1.61E-03         802         2.07E-04         0.000           300         200         1.53E-04         6.52E-05         1978         5.11E-05         2.17E-05         33         1060           400         2.43E-04         1.64E-04         1570         8.11E-05         5.48E-05         67         772           600         3.19E-04         2.82E-04         1372         1.06E-04         9.41E-05         1000         637           600         3.19E-04         2.82E-04         1372         1.06E-04         9.41E-05         1000         637           1000         4.48E-04         5.58E-04         1157         1.49E-04         1.88E-04         167         497           1000         4.48E-04         5.58E-04         1039         1.69E-04         2.37E-04         200         454           1200         5.06E-04         7.3E-04         1034         1.87E-04         2.91E-04         308         370           1800         6.63E-04         1.22E-03         951         2.21E-04         4.68E-04         333         351           2060         7.12E-04         1.41E-03         918         2.37E-04         4.68E-05         67         882 </td <td>8639</td>	8639
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	 0797
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0776 8756
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8716
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8703
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8692
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8683
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8675
1800       6.63E-04       1.22E-03       951       2.21E-04       4.07E-04       333       351         2000       7.12E-04       1.41E-03       918       2.37E-04       4.68E-04       333       351         400       200       1.69E-04       5.93E-05       2177       5.62E-05       1.98E-05       33       1206         400       2.68E-04       1.49E-04       1728       8.93E-05       4.98E-05       67       882         600       3.51E-04       2.56E-04       1510       1.17E-04       8.55E-05       100       730         600       3.51E-04       2.56E-04       1372       1.42E-04       1.25E-04       133       637         800       4.25E-04       3.76E-04       1372       1.64E-04       1.69E-04       167       572         1000       4.93E-04       5.07E-04       1273       1.64E-04       1.69E-04       200       523         1200       5.57E-04       6.46E-04       1198       1.86E-04       2.65E-04       233       485         1400       6.17E-04       7.94E-04       1089       2.25E-04       3.16E-04       267       454         1600       6.75E-04       9.48E-04       1089 </td <td>8669</td>	8669
2000       7.12E-04       1.41E-03       918       2.37E-04       4.08E-04       001         400       200       1.69E-04       5.93E-05       2177       5.62E-05       1.98E-05       33       1206         400       2.68E-04       1.49E-04       1728       8.93E-05       4.98E-05       67       882         400       2.68E-04       1.49E-04       1728       8.93E-05       4.98E-05       100       730         600       3.51E-04       2.56E-04       1510       1.17E-04       8.55E-05       100       730         800       4.25E-04       3.76E-04       1372       1.42E-04       1.25E-04       133       637         1000       4.93E-04       5.07E-04       1273       1.64E-04       1.69E-04       167       572         1000       4.93E-04       5.07E-04       1273       1.64E-04       2.05E-04       233       485         1200       5.57E-04       6.46E-04       1198       1.86E-04       2.65E-04       233       485         1400       6.17E-04       7.94E-04       1089       2.25E-04       3.16E-04       267       454         1600       6.75E-04       9.48E-03       1047       2.43	8663
400       200       1.69E-04       5.93E-05       2177       5.62E-05       1.98E-05       33       1206         400       2.68E-04       1.49E-04       1728       8.93E-05       4.98E-05       67       882         600       3.51E-04       2.56E-04       1510       1.17E-04       8.55E-05       100       730         800       4.25E-04       3.76E-04       1372       1.42E-04       1.25E-04       133       637         1000       4.93E-04       5.07E-04       1372       1.42E-04       1.69E-04       167       572         1000       4.93E-04       5.07E-04       1273       1.64E-04       1.69E-04       200       523         1200       5.57E-04       6.46E-04       1198       1.86E-04       2.15E-04       200       523         1400       6.17E-04       7.94E-04       1138       2.06E-04       2.65E-04       233       485         1600       6.75E-04       9.48E-04       1089       2.25E-04       3.16E-04       267       454         1800       7.30E-04       1.11E-03       1047       2.43E-04       3.70E-04       333       406         2000       7.83E-04       1.28E-03       101	
400       200       1.892-04       3.932-04       1728       8.932-05       4.982-05       67       882         400       2.682-04       1.492-04       1728       8.932-05       4.982-05       100       730         600       3.512-04       2.562-04       1510       1.172-04       8.552-05       100       730         800       4.252-04       3.762-04       1372       1.422-04       1.252-04       133       637         1000       4.932-04       5.072-04       1372       1.422-04       1.252-04       167       572         1000       4.932-04       5.072-04       1273       1.642-04       1.692-04       167       572         1200       5.572-04       6.462-04       1198       1.862-04       2.152-04       200       523         1400       6.172-04       7.942-04       1138       2.062-04       3.162-04       267       454         1600       6.752-04       9.482-04       1089       2.252-04       3.162-04       300       428         1800       7.302-04       1.112-03       1047       2.432-04       3.702-04       333       406         2000       7.832-04       1.282-05       234	8813 8773
400       2.682-04       1.162-04       1.17E-04       8.55E-05       100       7.30         600       3.51E-04       2.56E-04       1372       1.42E-04       1.25E-04       133       637         800       4.25E-04       3.76E-04       1372       1.42E-04       1.25E-04       133       637         1000       4.93E-04       5.07E-04       1273       1.64E-04       1.69E-04       167       572         1000       4.93E-04       5.07E-04       1273       1.64E-04       2.15E-04       200       523         1200       5.57E-04       6.46E-04       1198       1.86E-04       2.15E-04       200       523         1400       6.17E-04       7.94E-04       1138       2.06E-04       2.65E-04       267       454         1600       6.75E-04       9.48E-04       1089       2.25E-04       3.16E-04       267       454         1800       7.30E-04       1.11E-03       1047       2.43E-04       3.70E-04       300       428         2000       7.83E-04       1.28E-03       1011       2.61E-04       4.26E-04       333       406         500       200       1.82E-04       5.50E-05       2345       6	8749
800       3.312-04       3.76E-04       1372       1.42E-04       1.25E-04       133       031         800       4.25E-04       3.76E-04       1273       1.64E-04       1.69E-04       167       572         1000       4.93E-04       5.07E-04       1273       1.64E-04       1.69E-04       167       572         1200       5.57E-04       6.46E-04       1198       1.86E-04       2.15E-04       200       523         1400       6.17E-04       7.94E-04       1138       2.06E-04       2.65E-04       233       485         1400       6.17E-04       7.94E-04       1138       2.06E-04       3.16E-04       267       454         1600       6.75E-04       9.48E-04       1089       2.25E-04       3.70E-04       300       428         1800       7.30E-04       1.11E-03       1047       2.43E-04       3.70E-04       333       406         2000       7.83E-04       1.28E-03       1011       2.61E-04       4.26E-04       333       406         500       200       1.82E-04       5.50E-05       2345       6.06E-05       1.83E-05       33       1330         500       200       1.82E-04       5.50E-0	8732
800       4.252       04       5.07E-04       1273       1.64E-04       1.69E-04       167       512         1000       4.93E-04       5.07E-04       198       1.86E-04       2.15E-04       200       523         1200       5.57E-04       6.46E-04       1198       1.86E-04       2.15E-04       200       523         1400       6.17E-04       7.94E-04       1138       2.06E-04       2.65E-04       233       485         1600       6.75E-04       9.48E-04       1089       2.25E-04       3.16E-04       267       454         1600       6.75E-04       9.48E-04       1089       2.25E-04       3.70E-04       300       428         1800       7.30E-04       1.11E-03       1047       2.43E-04       3.70E-04       333       406         2000       7.83E-04       1.28E-03       1011       2.61E-04       4.26E-04       333       406         500       200       1.82E-04       5.50E-05       2345       6.06E-05       1.83E-05       33       1330         500       200       1.82E-04       5.50E-05       2345       6.06E-05       1.62E-05       67       976	8719
1800       4.952       6.46E-04       1198       1.86E-04       2.15E-04       200         1200       5.57E-04       6.46E-04       1138       2.06E-04       2.65E-04       233       485         1400       6.17E-04       7.94E-04       1138       2.06E-04       2.65E-04       267       454         1600       6.75E-04       9.48E-04       1089       2.25E-04       3.16E-04       267       454         1600       6.75E-04       9.48E-04       1089       2.25E-04       3.16E-04       267       454         1800       7.30E-04       1.11E-03       1047       2.43E-04       3.70E-04       300       428         2000       7.83E-04       1.28E-03       1011       2.61E-04       4.26E-04       333       406         2000       7.83E-04       1.28E-05       2345       6.06E-05       1.83E-05       33       1330         500       200       1.82E-04       5.50E-05       2345       6.06E-05       1.83E-05       33       1330	8709
1200       6.17E-04       7.94E-04       1138       2.06E-04       2.65E-04       2.65         1400       6.17E-04       9.48E-04       1089       2.25E-04       3.16E-04       267       454         1600       6.75E-04       9.48E-04       1089       2.25E-04       3.16E-04       267       454         1800       7.30E-04       1.11E-03       1047       2.43E-04       3.70E-04       300       428         2000       7.83E-04       1.28E-03       1011       2.61E-04       4.26E-04       333       406         2000       7.83E-04       1.28E-05       2345       6.06E-05       1.83E-05       33       1330         500       200       1.82E-04       5.50E-05       2345       6.06E-05       1.83E-05       67       976	8700
1600 6.75E-04 9.48E-04 1089 2.25E-04 3.16E-04 200 428 1800 7.30E-04 1.11E-03 1047 2.43E-04 3.70E-04 300 428 2000 7.83E-04 1.28E-03 1011 2.61E-04 4.26E-04 333 406 2000 7.83E-04 1.28E-03 2345 6.06E-05 1.83E-05 33 1330 500 200 1.82E-04 5.50E-05 2345 6.06E-05 4.62E-05 67 976	8692
1800 7.30E-04 1.11E-03 1047 2.43E-04 3.70E-04 333 406 2000 7.83E-04 1.28E-03 1011 2.61E-04 4.26E-04 333 406 	8685
2000 7.83E-04 1.28E-03 1011 2.61E-04 4.20E 07 101 2000 7.83E-04 1.28E-03 1011 2.61E-04 4.20E 07 1133E-05 500 200 1.82E-04 5.50E-05 2345 6.06E-05 1.83E-05 33 1330 500 200 1.82E-04 1.29E-04 1862 9.62E-05 4.62E-05 67 976	8679
500 200 1.82E-04 5.50E-05 2345 6.06E-05 1.83E-05 33 1330 500 200 1.82E-04 1.29E-04 1862 9.62E-05 4.62E-05 67 976	
500 200 1.025 04 1.295-04 1862 9.62E-05 4.62E-05 67 770	8827 8786
700 9 VAEHNA 1.375 YF 11775 - 586 05 100 STN	8762
400 2.07E 01 100 010 500 3.78E-04 2.38E-04 1626 1.26E-04 7.93E-05 100 010	8745
900 4.58E-04 3.49E-04 1478 1.53E-04 1.16E-04 167 637	8732
1000 5.32E-04 4.70E-04 1372 1.77E-04 1.57E-04 200 583	8722
1200 6.00E-04 6.00E-04 1291 2.00E-04 2.00E-04 233 541	8713
1400 6.65E-04 7.37E-04 1226 2.22E-04 2.46E-04 267 507	8705
1600 7.27E-04 8.80E-04 1173 2.42E-04 2.95E 04 200 478	8698
1800 7.86E-04 1.03E-03 1128 2.62E-04 3.95E-04 333 454	8692
2000 8.44E-04 1.19E-03 1089 2.81E-04 0.901	

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AMPLITUDE (arb units)



Figure 2. Pulse Forming Network with a Single LC Section.



Figure 3. Pulse Forming Network with Multiple LC Sections.

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Experimental Arrangement of Flashlamp-Pumped Cr:GSAG Laser for Rare Earth Laser Pumping. Figure 4.







Figure 6. Typical energy transfer prcesses in Ho<sup>3+</sup> :Cr<sup>3+</sup>:Tm<sup>3+</sup>:YAG crystal.





(0.02 Ho, 0.40 Er, 0.06 Tm), 5 mm x 90 mm rod, C=146.5  $\mu F$ , L=184  $\mu H$ , Flashlamp pulse width (FWHM) = 300  $\mu s$ .





(0.02 Ho, 0.40 Er, 0.06 Tm), 5 mm x 90 mm rod, C=146.5  $\mu F$ , L=184  $\mu H$ , Flashlamp pulse width (FWHM) = 300  $\mu s$ .



Normal mode laser output of Ho:Er:Tm:YAG crystal as a function of electrical input energy with various output mirrors at an operating temperature of 170 K. . თ Figure





Ho:Er:Tm:YAG (0.02 Ho, 0.40 Er, 0.06 Tm), 5 mm x 90 mm rod, T=170 K, with a 10 MCC HR mirror,146.5 $\mu$ F, 184 $\mu$ H, and pulse width of 300 $\mu$ s FWHM. Laser beam angle on the plate = 67.8 degree (Brewster angle).



Figure 11. Loss coefficiency measurement of ZnSe plate in a Ho:Er:Tm:YAG laser resonator with output mirrors of relectivities of 80% and 98%. Ho:Er:Tm:YAG (0.02 Ho, 0.40 Er, 0.06 Tm), 5 mm x 90 mm rod, T=170 K, with a 10 MCC Hr mirror, 146.5 $\mu$ F, 184 $\mu$ H, and pulse width of 300  $\mu$ s FWHM. Laser beam angle on the plate = 67.8 degree (Brewster angle).





1/Slope Efficiency

# Appendix

Computer Programs for Pulse Forming Network Parameter Calculation

Computer Program for Multi-LC-Section Pulse Forming Network Design

PRINT "------10 ----" .... PRINT " 20 MULTISECTION PULSE FORMING NETWORKS PRINT " 30 PRINT " PRINT "-----40 50 ----" 60 PRINT USING 330; "INPUT ", "PULSE ", "TOTAL ", "TOTAL ", VOLT. ", "SECTION", "SE CTION"," RISE "," PEAK ","BLKBODY" PRINT USING 330; "ENERGY", "WIDTH", "CAPACI.", "INDUCT.", " ", "CAPACI.", "I NDUCT."," TIME ","CURRENT"," TEMP. " 80 PRINT USING 330;" J "," usec "," F "," H "," V "," F "," H "," usec "," A "," K " S=7.62 ! ARC LENGTH ( cm ) 90 D=.4 ! BORE DIAMETER ( cm ) 100 FOR E=100 TO 500 STEP 100 110 PRINT "------I=0 120 130 \_\_\_\_\_" FOR To=200 TO 2000 STEP 200 140 150 ! E INPUT ENERGY ! TO PULSE DURATION 160T=To\*10^(-6) PULSE DURATION ( sec ) 170 Ko=4/3\*S/D ! IMPEDENCE PARAMETER 180 Vo=2\*(Ko^2\*E/T)^(1/3) ! SUPPLY VOLTAGE 190 C=.5\*(E\*T^2/Ko^4)^(1/3) ! TOTAL CAPACITANCE 200 L=.5\*(T^4\*Ko^4/E)^(1/3) | INDUCTANCE 210 Lo=L/3 ! SECTION INDUCTANCE Co=C/3 ! SECTION CAPACITANCE 220 I SECTION CAPACITANCE 230 Rt=SQR(Lo\*Co)/10^(-6) ! RISE TIME 240 Zo=SQR(L/C) ! IMPEDENCE 250 K0=(.5\*Vo\*Zo)^(1/2) ! IMPEDANCE PARAMETER 260 270 Ia=.5\*Vo/Zo ! LAMP CURRENT Ip=Vo/(Zo+.02\*S/(3.14\*(D/2)^2)) ! PEAK CURRENT 280 Ca=3.14\*(D/2)^2 ! CROSS SECTION 290 T=((9450\*(D/100)^.03\*(Ia/Ca)^.01)^6+(93\*(D/100)^.27\*(Ia/Ca)^.34)^6)^(1/6) 300 ! TEMPERATURE IF I=0 THEN PRINT USING 340; E, To, C, L, Vo, Co, Lo, Rt, Ip, T 310 IF I<>0 THEN PRINT USING 350; To, C, L, Vo, Co, Lo, Rt, Ip, T 320 IMAGE 68,2X,68,1X,78,2X,78,2X,78,1X,78,3X,78,2X,58,1X,68,1X,78 330 IMAGE 4D,2X,6D,2X,1D.DDE,2X,1D.DDE,2X,4D,2X,1D.DDE,2X,1D.DDE,2X,4D,2X,5D,3 340 X,6D IMAGE 6X,6D,2X,1D.DDE,2X,1D.DDE,2X,4D,2X,1D.DDE,2X,1D.DDE,2X,4D,2X,5D,3X,6 350 D 360 I = 1 NEXT TO 370 NEXT E 380 390 ----" \_ \_ \_ \_ \_ \_ END 400

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Computer Program for Single-LC-Section Pulse Forming Network Design PRINT "------10 \_\_\_\_B PRINT 20 FLASHLAMP PULSE FORMING NETWORK PRINT " 30 PRINT "-----40 50 ----" PRINT USING 350;"PULSE "," PULSE ","CAPACI.","INDUCT. "," VOLT ","EXPLO. \_\_\_\_\_ 60 , LIFE , BLNBUT, " MEMK ", " MEMK " 70 PRINT USING 350; "ENERGY ", " WIDTH ", " ", " ", " ", "ENERG "," "," TEMP.", "WAYELEN.", "CURRENT" 80 PRINT USING 350; " J ", " usec ", " F ", " H ", " V ", " J ","(10^6)", " K ", " nm ", " A " 90 FOR FOR TO FOR STER 100 "," LIFE ","BLKBDY"," PEAK "," PEAK " ","ENERGY FOR Éo≠100 TO 500 STEP 100 90 PRINT "------100 110 ----" 120 FOR To=100 TO 1000 STEP 100 130 T=To/3 !TIME CONSTANT 140 Ko=25 !IMPEDENCE PARAMETER 150 Ke=7.5E4 (EXPLOSION ENERGY CONSTANT 160 A=.8 !CRITICAL DAMPING C=(2\*Eo\*A^4\*(T\*10^(-6))^2\*Ko^(-4))^(1/3) !CAPACITANCE (F) 170 L=(T\*10^(+6))^2/C !INDUCTANCE (H) 180 V=(2\*Eo/C)^(1/2) !VOLTAGE (V) 190 Ex=Ke\*(T\*10^(-6))^(1/2) !EXPLOSION ENERGY 200 I=V^2/Ko^2 !CURRENT 210220 Life=(Eo/Ex)^(-8.5)/10^6 !LIFE OF FLASH 230 Zo=SQR(L/C) !IMPEDANCE 240 Re=.02 !FLASH RESISTIVITY FOR 100uS<t<1mS 250 Le≠7.62 !ARC LENGTH(cm) 260 Bo=.4 !BORE DIAMETER(cm) Rt=Re\*Le/(3.14\*(Bo/2)^2) !FLASH RESISTANCE 270 Ip=V/(Zo+Rt) !PEAK CURRENT 280 Ca=3.14\*(Bo/2)^2 (CROSS SECTION (cm^2) 290 D=Bo/100 !BORE DIAMETER (m) Te=((9450\*D^.03\*(I/Ca)^.01)^6+(93\*D^.27\*(I/Ca)^.34)^6)^(1/6) !TEMPERATURE 300 310 Wm=2.898E6/Te / PEAK WAVELENGTH ( nm ) 320 IF I1=0 THEN PRINT USING 360;Eo,To,C,L,V,E×,Life,Te,Wm,Ip 330 IF I1<>0 THEN PRINT USING 370; To, C, L, V, Ex, Life, Te, Wm, Ip 340 IMAGE 6A,1X,6A,2X,7A,2X,7A,2X,5A,3X,6A,1X,6A,2X,7A,1X,8A,1X,7A IMAGE 6D,1X,4D,2X,1D.DDE,2X,1D.DDE,2X,4D.D,1X,4D.D,2X,2D.DE,2X,4D,1X,6D.D, 350 360 IMAGE 7X,4D,2X,1D.DDE,2X,1D.DDE,2X,4D.D,1X,4D.D,2X,2D.DE,2X,4D,1X,6D.D,2X, 2X,6D 370 6D  $I_{1} = 1$ 380 NEXT TO 390 PRINT "------NEXT EO 400 410 ----" 430 END

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