D46

SOLAR DRIVEN LASERS FOR POWER SATELLITE APPLICATIONS

R. Taussig, P. Cassady and E. Klosterman
MSNW, Inc., 2755 Northrup Way, Bellevue, Washington 98004

N82 22722

Introduction. Multi-megawatt lasers appear to be technologically feasible for space power transmission in the 1990s time frame. Solar driven lasers based on conventional gas dynamic and electric discharge laser concepts (GDLs and EDLs) have been investigated to determine the feasibility of using existing laser technology for this application. With conventional solar photocells as the power source the GDL and EDL lasers do not appear to be as efficient as microwaves in transmitting power back to earth. However, for relatively new and untested laser concepts such as the solar optically pumped laser (OPL) and free electron laser (FEL) much higher laser efficiencies may be achievable, leading to a laser SPS system competitive with the microwave SPS. Because of their compact transmitters and receivers, lasers may have an advantage in better economies of scale for smaller SPS sizes than the microwave SPS. Further, laster light wavelengths longer than 2.5 microns may be considerably safer and have less impact on the earth's environment (e.g., communications) than microwaves. For these reasons one should consider the laser as a serious power transmission option.

Results from a brief survey of solar powered, space-based lasers are given below to gain some perspective on the types of lasers reasonable for power transmission. A preliminary selection of candidate lasers for SPS application was made on the basis of scalability to high powers (1 MW and greater), relative weights, efficiency (better than 1%), and safety (wavelengths greater than 2.5μ). The preliminary list includes CO and CO_2 EDLs, direct optically pumped lasers (e.g., CF_3I, etc.), indirect optically pumped lasers (e.g., CO/CO_2 mixing laser), and free electron lasers (FELs).

Electric Discharge Lasers. Several previous studies have focused on solar powered, closed cycle EDLs for power transmission. The EDL requires electric power both to drive the high voltage discharge which pumps the laser medium to an excited state before it lases, and to circulate the lasant through a cooling loop which extracts the waste heat and returns it to its original state. Either photocells or perhaps a more efficient solar thermal power cycle can be used to produce the electricity. Table 1 summarizes the characteristics of the EDL and other 1 MW cw solar powered lasers, where electricity in each case is assumed to be produced by a 25% efficient solar thermal Brayton cycle power system. Monson has shown how to optimize the closed cycle flow conditions for minimum flow loop compressor power per unit laser power output. His results are employed to keep the total laser system weight small.

Direct Optically Pumped Lasers. A preliminary consideration of the direct optically pumped lasers in a previous study suggested that the only class of direct optically pumped lasers with reasonable efficiency capable of high power operation are those utilizing CF_3I, C_3F_7I, C_4F_9I, and $(CF_3)_2AsI$. These molecules photodisscoiate in the near UV of sunlight. With proper filtering, only the solar wavelengths appropriate for pumping the molecules need to be focused on the lasant. Concentration ratios on the order of 100 appear adequate to pump the heavier versions of these iodine molecules leaving an excited I* which lases at 1.315μ. Unfortunately, this wavelength is smaller than the safety limit of 2.5μ for retinal damage. The dissociated fragments of these molecules also polymerize so that in a closed cycle lasant for space, a substantial amount of

Table 1

1 MW cw Output Solar-Powered Laser Candidates

Type	Lasant	λ Laser	η_T Transmission Efficiency	η_L Laser Solar Efficiency	η_{total}**	Mass
Electric Discharge (EDL)	CO (Supersonic)	~ 5μ	57% (94%)*	5.7% +	2%	17 x 10^3 kg
	CO_2 (Subsonic)	9.26μ	80% (90%)	3.8%	1%	20 x 10^3 kg
Direct Optically Pumped (OPL)	CF_3* (Subsonic) Dissociation	1.315μ	95% (est)	0.5%	.2%	60 x 10^3 kg
Blackbody Optically Pumped (OPL)	CO/CO_2(Subsonic) Mixing	9.114μ	83% (95%)	15.4%	6%	30 x 10^3 kg
CATALAC (FEL)	Relativistic Electron Beam	Tunable $\lambda > 2.5\mu$	95% (est)	0.4 ~ 1.2%	.5%	80 x 10^3 kg
Storage Ring (FEL)			95% (est)	6 ~ 20%	8%	14 x 10^3 kg

* to ground (to 2 km elevation)

\+ 25% conversion from solar to electricity assumed

** $\eta_{total} = \eta_L \eta_T \eta_G$ where $\eta_G = 0.4$ and η_T(2 km) energy must be invested to break apart the polymerized fragments and reconstitute the original molecule. The overall efficiency of this type of laser, not including the energy needed for reconsitution of the lasant, is approximately 0.5% (laser power ÷ solar power).

Indirect Optically Pumped Lasers. Three indirect optically pumped lasers have been examined:

- Static CO_2 laser
- Flowing CO laser (subsonic)
- Mixing CO/CO_2 laser (subsonic)

Of these three only the last one combines the features of scalability, high efficiency, and laser wavelength suitable for atmospheric transmission. At this stage CO lasers appear to transmit successfully only on isolated lines and, since the CO laser is relatively inefficient when operated in a single line mode, it has not been considered further. The indirect optically pumped laser (IOPL) uses a solar heated blackbody cavity to pump the lasant. The advantages of the cavity are reduced radiative losses, a downshift in the peak of the pump radiation toward the infra-red absorption lines of CO and CO_2, an increase in the irradiation of the lasant to a full 4Π steradians, and refilling the spectral lines absorbed by the lasant through radiative re-emmission of a full blackbody spectra by the cavity walls. As in the direct optically pumped case, the IOPL needs electricity or mechanical power only for circulating coolants and moving the lasant through the laser optical cavity. From Table 1 it appears initially that this class of laser will be quite lightweight. The mixing gas version is shown in Figure 1. Initial gain experiments have been performed indicating the viability of the blackbody radiation pump method. Further research is needed to demonstrate the complete laser concept.

Free Electron Lasers. We have also investigated three possible versions of the free electron laser: the CATALAC FEL, the Double FEL, and the Storage Ring FEL. The CATALEC FEL, illustrated schematically in Figure 2, is based on a concept developed at LASL to help recapture some of the energy left over in the electrons as they exit from the laser cavity. These electrons are recirculated through the rf-linac 180° out of phase with the next bunches of electrons to be accelerated. The electrons are declerated and return most of their remaining energy to the accelerating field. The linac therefore behaves as a catalyst for transferring the energy of decelerating electrons to those being accelerated. The spent electrons are collected at the other end of the linac with approximately 8 MeV energies and the accelerated electrons emerge with energies on the order of 50 MeV.

No high power FELS have been built in the wavelength range suitable for atmospheric propagation so that this laser technology must be regarded as extremely tentative. Elementary gain and oscillator experiments have been performed by Madey and his co-workers at Stanford which indicate that the principle will work. Several larger FEL experiments for 1μ lasers are now in the planning stage and are due to come on line in late 1980 or 1981. Nevertheless, a substantial amount of theoretical analysis has been performed which permits us to carry out elementary scaling calculations; the results of these are included in Table 1 for the CATALAC FEL which operates essentially as a once-through device with good energy recover, and for the storage ring FEL. The double FEL is, at present, too sensitive to assumptions made regarding low losses of the standing EM wave used as the virtual wiggler field.

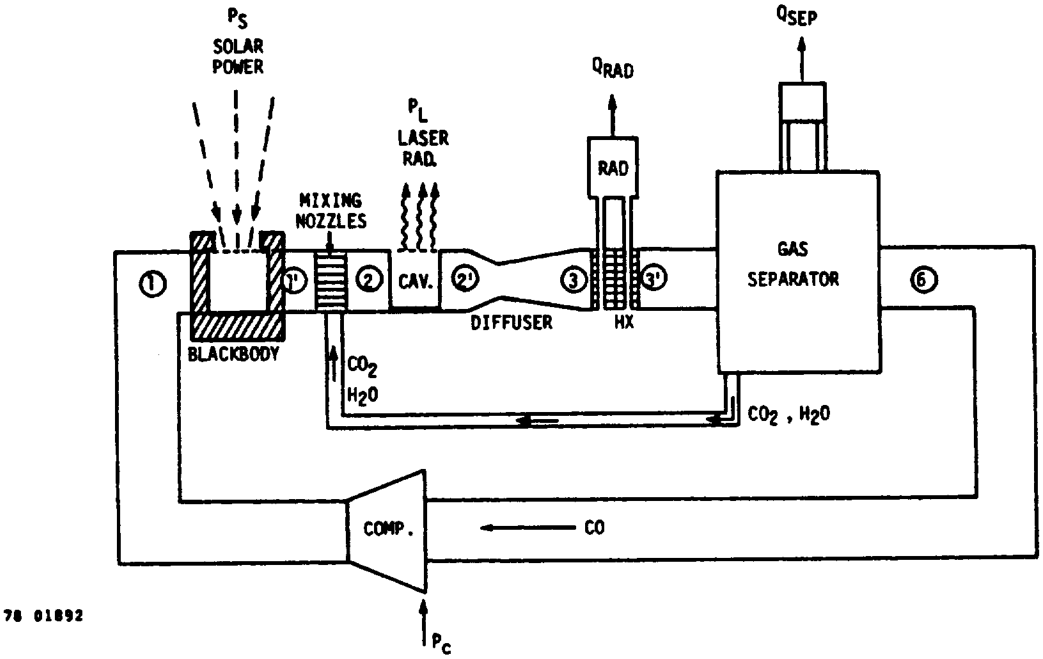

Figure 1. Indirect Optically Pumped CO/CO_2 Mixing Laser

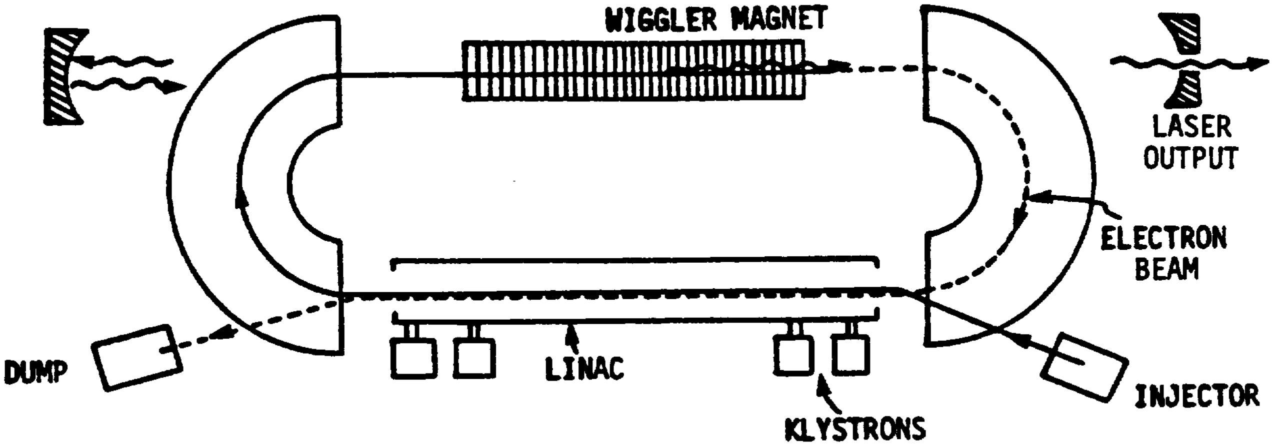

Figure 2. The CATALAC Free Electron Laser Concepts