Solar Pumped High Power Solid State Laser for Space Applications

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Highly coherent laser light provides a nearly optimal means of transmitting power in space. The simplest most direct means of converting sunlight to coherent laser light is a solar pumped laser oscillator. A key need for broadly useful space solar power is a robust solid state laser oscillator capable of operating efficiently in near Earth space at output powers in the multi hundred kilowatt range.

The principal challenges in realizing such solar pumped laser oscillators are: (1) the need to remove heat from the solid state laser material without introducing unacceptable thermal shock, thermal lensing, or thermal stress induced birefringence to a degree that improves on current removal rates by several orders of magnitude and (2) to introduce sunlight at an effective concentration (kW/cm^2 of laser cross sectional area) that is several orders of magnitude higher than currently available while tolerating a pointing error of the spacecraft of several degrees.

We discuss strategies for addressing these challenges. The need to remove the high densities of heat, e.g., 30 kW/cm3, while keeping the thermal shock, thermal lensing and thermal stress induced birefringence loss sufficiently low is addressed in terms of a novel use of diamond integrated with the laser material, such as Ti: sapphire in a manner such that the waste heat is removed from the laser medium in an axial direction and in the diamond in a radial direction.

We discuss means for concentrating sunlight to an effective areal density of the order of 30 kW/cm^2. The method integrates conventional imaging optics, non-imaging optics and nonlinear optics. In effect we use a method that combines some of the methods of optical pumping solid state materials and optical fiber, but also address laser media having areas sufficiently large, e.g., 1 cm diameter to handle the multi-hundred kilowatt level powers needed for space solar power.

The optical power is generated as the lowest order Gaussian mode of an approximately confocal resonator. The anticipated beam quality is high, corresponding to a beam quality factor, M2, near unity. Transmission through space is primarily a matter of designing beam expanders that will provide an aperture size appropriate to the distance of transmission since the beam is diffraction limited. For example, an aperture of 1m diameter will provide a Rayleigh distance for light at 0.8 microns of ~ 1 Mm (mega meter). Larger apertures give longer Rayleigh distances with the distance increasing quadratically with aperture diameter.

The low rate of beam expansion offers opportunities for beaming optical power to remote locations, as from low Earth orbit, or geostationary orbit to Earth, to other

locations in near Earth space. The Earth moon distance, 380 Mm, would require apertures accommodating Gaussian beam radii of~10 m at the moon and at Earth for light at 0.8 microns. Efficient high quality imaging requires an aperture of ~4 times the beam radius at the aperture.

The magnitude of the power generated, hundreds of kilowatts to gigawatts, in the version of these solar pumped laser oscillators scaled to high average power is such as to offer sources that can be considered as a supplement or alternative to space nuclear power sources. The projected power to mass ratio, order of kW per kg, is favorable. There is no need to replenish fuel or to discard dangerous waste products. The structure can be highly modular and composed of components that are easily stored and transported.

The geometry of the structure, constructed in the simplest format, tends to be long and pencil like. This is a useful geometry that lends itself to stabilization of a satellite, e.g., in a gravity gradient stabilized orbit. The length of the structure depends on the amount of power sought. In general, our designs suggest that power output scales quadratically with the length of the structure. A nominal design yields roughly 100 kW for a length of ~100 m.

The operating temperature is preferably low, e.g., 100K, to take advantage of the improved thermal properties of materials such as sapphire and diamond which are used to facilitate heat removal with minimal optical distortion of the laser material. The important issue of removing heat radiatively from the structure by thermal radiation as characterized by the Stefan-Boltzmann law is addressed.

The collection of sunlight so as to achieve adequate intensity for supporting laser action is particularly important. A novel strategy that utilizes several imaging and non imaging methods is identified and examples of structures designed for optimizing performance are given. This achievement of the needed high intensity and the needed rate of heat removal are both necessary to access the multi-hundred kilowatt average power offered by the design.

Application of the highly coherent laser to production of alternative energy forms, such as hydrogen, as by UV photolysis of water by frequency tripled and quadrupled laser light and electrical power, as by monochromatic illumination of specifically constructed photovoltaic cells, is also briefly addressed. Theoretical limits on conversion of the laser power to these alternative power forms are examined. From a fundamental point of view we find that this highly coherent laser light produced at high average power offers an interesting potential for transporting energy that can be efficiently converted to a variety of useful alternative forms.