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Perspective of Solar Pumping of Solid State Lasers for ESA Missions

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Executive Summary

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EXECUTIVE SUMMARY

The use of lasers for space missions has been increasing in the past and will dramatically increase in the future. Lasers in space often fulfill tasks that cannot be accomplished by other means. Examples are measuring distances of millions of kilometers with nanometer precision, detecting trace gases in the atmosphere of Earth from a satellite, or transmitting data between satellites over distances of some 10,000 km at very high rates. With the exception of semiconductor lasers, almost all of the lasers used in space are optically pumped solid state lasers. These lasers provide higher powers and better beam quality than semiconductor lasers and are therefore indispensable. However, they rely on optical excitation which is usually provided by a large number of low-power semiconductor lasers. The semiconductor lasers in turn operate on electrical energy that is generated by solar panels. It is therefore sensible to investigate whether direct excitation of solid state lasers with focused light from the Sun is possible. This solar pumping of solid state lasers has been thoroughly investigated in this study, with particular emphasis on its applicability to ESA missions.

The basic idea behind solar pumping of solid state lasers is simple and convincing: To short-cut the process of converting the energy of visible solar radiation to electrical energy and the subsequent conversion of this electrical energy to near-infrared or visible laser radiation by semiconductor lasers. Using solar radiation for directly pumping solid state lasers instead of light from the semiconductor lasers would eliminate the two conversion steps from light energy to electrical energy and backwards. By eliminating these two conversion steps, one could hope for simpler, more robust systems that have higher efficiencies.

Despite the obviously attractive idea of solar pumping of solid state lasers for space mission, our study shows that there are tremendous obstacles that have to be overcome in order to make solar pumping competitive with conventional pumping schemes. The reasons are manifold: Solar radiation needs to be concentrated to very high intensities in order to achieve the laser threshold when pumping currently available laser materials. This concentration process requires precise pointing of the optics towards the Sun, unlike a solar-electrical panel that only needs coarse pointing. The concentration process leads to tremendous heat loads in very small volumes, in the concentrator itself as well as in the pumped laser crystal. The high heat load in the laser crystal requires special cooling schemes, degrades the performance of the laser, and bears the risk of catastrophic failure due to material limitations. Another disadvantage of solar pumping is the lack of energy storage. Electrical energy can easily be stored in capacitors and batteries in order to bridge periods where solar radiation is not available due to the orientation of the satellite or because of occultation of the Sun by a planet. Since energy storage is not possible for directly solar pumped lasers, uninterrupted laser emission will not be possible for most orbits. Finally, solar-pumped lasers lack in technology development because there are currently no commercial applications on Earth.

Lasers for space missions generally require diffraction-limited beam quality. This is difficult to achieve when the heat load of the laser crystal is high such as in direct solar pumping. The heat load under direct solar pumping is very similar to that for pumping by arc discharge lamps that were used before the advent of semiconductor lasers. The high heat load leads to very low efficiency, stability, and output power of diffraction-limited lamp-pumped lasers. In order to circumvent the problem of high heat load, we developed concepts for two-stage solar pumping. Solar radiation is used to pump a multimode laser and the output of this laser is used to pump a diffraction-limited laser. This scheme has the ad-

vantage that the diffraction-limited laser is pumped by spectrally narrow and spatially coherent radiation that produces a much lower the heat load. Thus, the solar-pumped laser acts as a replacement for the semiconductor arrays which are currently used for pumping solid state lasers. We have identified the following two-stage laser systems that fulfill typical mission requirements and have reasonable efficiencies:

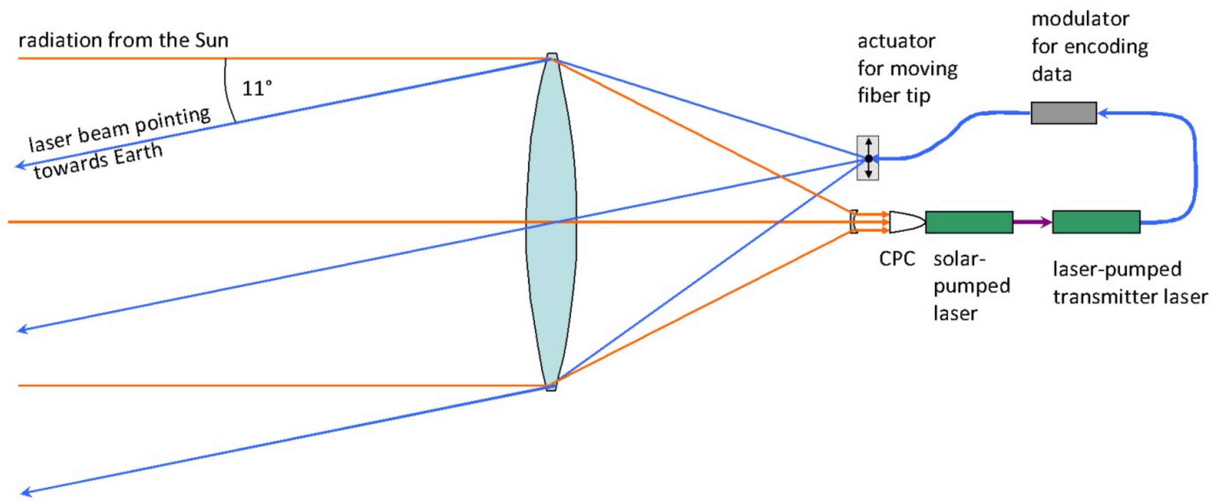
- A solar-pumped Alexandrite laser operating at 748 nm or a solar-pumped Ti:Sapphire laser operating at 808 nm pump a Nd:YAG non-planar ring laser that operates at 1064 nm and produces 0.5 W of diffraction-limited and frequency-stabilized output. The system is designed to meet the specifications of metrology missions such as GAIA, GRACE-FO, or LISA Pathfinder.

- A solar-pumped Nd:YAG laser operating at 1064 nm pumps an Er-Yb fiber laser system (master oscillator and power amplifier) that produces laser pulses at 1550 nm which are suitable for data transmission at a rate of 50 Mbit/s from Lagrange L2 to Earth or 1 Mbit/s from Mercury to Earth using pulse-position modulation.

Calculating the efficiency of solar-pumped lasers is very difficult because some of the required material parameters are not known well enough. Nevertheless, our calculations indicate that these solar-pumped lasers need solar collectors with an aperture that is larger than the photovoltaic panels that would be needed for providing the electrical energy for conventional, semiconductor-laser pumped solid state lasers. A solar collector will be very heavy compared to a photovoltaic panel and has the additional drawback that it needs accurate pointing towards the Sun. This means that solar pumping will most likely not be competitive with conventional electric pumping.

In light of the many fundamental disadvantages of solar pumped lasers for space missions, we tried to come up with special missions where these disadvantages do not come into play and were instead directly solar pumped lasers can have specific advantages. The most promising mission seems to be laser data transmission from the Lagrange point L2 to Earth. In this case, occultation can be avoided completely. In addition, the large and heavy optics that is required for concentrating solar radiation could double as the optical antenna for the laser communication terminal. The figure on the next page shows the general layout of such a system.

Our study shows that a compelling case for intense research and development of solar-pumped lasers for space currently cannot be made. Opportunities for solar-pumped lasers in space could arise if new laser gain media with lower thresholds would be discovered. While this does not seem likely, refinement of already known materials could also lead to lower thresholds. This could, for example, happen if large-scale terrestrial applications of solar-pumped lasers would emerge. In either case, a materials science program should be set up in order to provide accurate data for modelling solar-pumped lasers. In a second step, an engineering program should be set up that is concerned with laser system architectures, in particular conduction cooling of the laser crystal and the technical issues of the solar collector.



The figure shows the layout of a solar-pumped laser communication system at the Lagrange point L2. A refracting optical system is shown for clarity but a reflecting system could be used as well. The primary lens of the optical system is used for collecting light from the Sun and focusing it onto a compound parabolic concentrator (CPC) that further concentrates it and directs it onto the gain medium of the solar-pumped laser. The solar-pumped laser subsequently pumps the transmitter laser. The modulated beam of the fiber-coupled transmitter laser is expanded and then collimated by the large primary lens. An actuator in the focal plane of the lens moves the exit aperture of the fiber in order to compensate for the orbital motion of the satellite.