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SOLAR PUMPED LASER MICROTHRUSTER

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Abstract. The development of microsatellites requires the development of engines to modify their orbit. It is natural to use solar energy to drive such engines. For an unlimited energy source the optimal thruster must use a minimal amount of expendable material to minimize launch costs. This requires the ejected material to have the maximal velocity and, hence, the ejected atoms must be as light as possible and be ejected by as high an energy density source as possible. Such a propulsion can be induced by pulses from an ultra-short laser. The ultra-short laser provides the high-energy concentration and high-ejected velocity. We suggest a microthruster system comprised of an inflatable solar concentrator, a solar panel, and a diode-pumped fiber laser. We will describe the system design and give weight estimates.

Keywords: microthrusters, fiber lasers, diode pump
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The ability to maneuver to change the orbit or escape a collision with space debris is very attractive for every satellite. Conventional motors take a lot of weight and require fuel with substantial additional weight. It is very attractive to find more suitable alternatives especially for light microsatellites. Recently [1] it was suggested to use a laser situated on the satellite to ablate some material and to produce the thrust. Specifically, [1] suggested use of a diode laser to ablate the material. But the light of diode laser is difficult to focus sufficiently to get the high intensity required for ablation. Increasing the spot size increases the energy requirements and weight. Also the diode lasers are inefficient to use in the pulsed regime.

We suggest using a diode pump fiber laser for the ablation driver. This scheme provides efficiency, flexibility and lightweight. The laser power supply can be produced from the solar panel of satellite or separate, lightweight solar system. The scheme of the propulsion system is presented on Fig.1.

The crucial part of the system is the diode pump fiber laser. In order to move the satellite in all possible directions one must have, generally, six independent motors to thrust satellite in x, y, z directions forward and back. In laser scheme it can be achieved with one laser with energy delivered via fibers to different locations where the ablation material will be located. It is naturally to use solar energy to pump the laser. The cheap light inflatable mirror concentrates the solar radiation on the multi-junction solar panel with efficiency over 40% [2]. The electricity is used to pump the fiber laser, which is focused on the thruster. For average operational power ~1wt the required concentrator size is~15 cm and solar panel~1 cm. The total weight of the system can be few hundreds gram. When the laser is idle the system can be used for satellite needs. Alternately, the existing power system of satellite can be used to pump the laser.

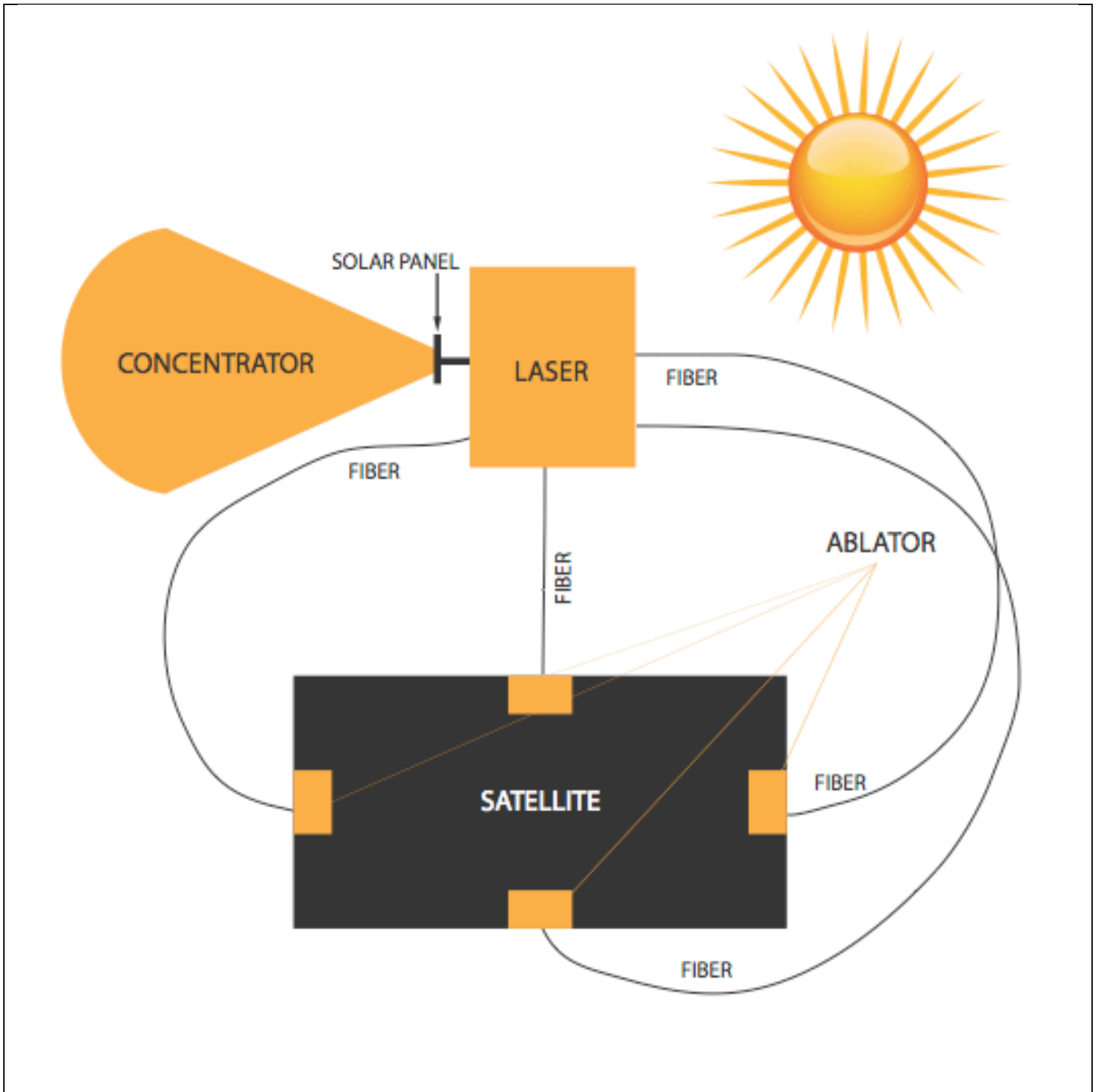

FIGURE 1. The scheme of laser based propulsion system

Consider first the requirements for the laser system and ablators. Usually, the propulsion efficiency is described in terms of momentum coupling C_m, the ratio of acquired momentum to the incident laser efficiency [3]. The maximum of C_m corresponds to the maximum momentum produced for the fixed laser energy. For our situation the energy is not limited, the limited quantity is the amount of ablated material. For the best use of it the material must be ejected with the maximal possible velocity, in other terms we must operate in regime highest specific momentum [1]. For this it is desirable to have high energy density in each laser pulse, which is best achieved in the short pulse regime. The ablator must be as light as possible. We suggest lithium hydrate LiH as an option. The ablator can be placed in a refractory metal pipe to increase the directionality of ejected material and the propulsion efficiency. Below we present the possible point design for the laser based on modern technology.

The optimal laser can be diode pumped short pulse fiber laser with high, 5% conversion efficiency of electricity in laser radiation (50% electrical-optical in the diode laser and 10% optical to optical conversion efficiency in the fiber laser as it would operate at low repetition rate (<2kHz) and high pulse energy yielding 10%X50%=5% overall electrical to optical efficiency). This efficiency would increase with increasing repetition rate yielding up to 40% electrical to optical efficiency at >100kHz repetition rate. The distance from the laser to the target is short and one can afford to use multimode pulses from large area fibers. In this case, the pulse energy is not limited by self-focusing to 4MW peak powers as in conventional single mode fibers. Instead the pulse energy is limited only by damage to ~40J/cm^2 for 1ns pulses. Thus a 200μm core fiber could have an output energy per pulse as high as 10mJ. The typical optimal pulse duration will be in nanosecond range. The laser would consist of a simple master oscillator power amplifier design. A nominal design might start with a small Q-switched solid-state micro laser producing 10-50μJ pulses that would be focused into a 200μm core multimode Yb doped optical fiber with a target gain of 1000X. This fiber would be pumped by a 200W-2kW diode laser array coupled to the cladding by a simple lens duct. The final power of the diode array would be determined by the desired repetition rate of the laser with higher repetition rate lasers being desired from an efficiency stand point. For 200W of pump power a 1-2kHz, 10mJ/pulse device with 5% conversion efficiency could be constructed. For 2kW of pump power, a 10-20kHz, 10mJ/pulse devices with 25% conversion efficiency could be constructed. The fiber cladding would be constructed to be large enough to be compatible with the diode laser array brightness and the length would be required to be short enough to ensure other non-linear effects such as stimulated Raman scattering do not degrade the output pulses. The combination of length and cladding size may result in a design trade-off, although recent breakthroughs in fibers with high Yb doping concentrations has begun to mitigate this issue significantly. The conventional laser design can be stripped down for our applications. Because the time to change the orbit is not limited the laser can operates in heat capacity mode, without external cooling. Such a laser might operate at power for up to 5 seconds prior to being turned off for cooling. The small thrust produced by the single pulse will provide the high accuracy of satellite movements. In this time using the scheme described above, 100-1000J of total laser energy could be delivered to the lithium hydrate target in the short pulse form required to achieve the desired thrust. The laser elements must be thermally connected with main satellite for the general radiation cooling. Total system weight can be within 5 pounds.

Let us estimate the thrust produced by such a propulsion system. The optimal fluence F for maximum coupling C_m~5 dyn sec/J is given by [3]

$$F = 2.5\sqrt{\tau(n\sec)}J/cm^2 \qquad (1)$$

The numerical coefficient in (1) is related to interaction with Al, but it is not sensitive to material. For a 10 mJ pulse with a 1 ns pulse duration the optimal fluence is achieved with a laser spot diameter of 700 μm. The momentum produced by one pulse with above coupling coefficient M~0.05 dyn sec. For one hundred joules train it will be M ~500 dyn sec. For a 5 sec pulse train it will produce a thrust of ~1 mN.

The paper [1] indicates the desirable parameters of propulsion system-thrust per axis>100 μN, weight per axis ~1 kg, specific impulse ~500 sec. Because we have one laser for all axis we satisfy both weight and thrust requirements. There are no doubts that the ejected velocity (specific impulse) will be very high. It can be even higher for tighter focusing and lower coupling efficiency. The problem, which must be studied, is the material ejection after the pulse termination. Evaluation of post pulse material ablation requires experimental investigation.

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