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Research on applications of rectangular beam in micro laser propulsion

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ABSTRACT

Micro laser propulsion is a new technology with brilliant future. In order to reduce the thruster mass and volume further, laser bar is introduced into the micro laser propulsion field. A new kind of 220 × 20 μm rectangular beam of 808 nm was obtained by oval lens compressing the light of diode at fast axes and slow axes. The effect of laser power, energy and coating thickness of double base propellant on propulsion performance was studied. Propulsion performance of double base propellant under static and dynamic mode shows some different characters. Compared to round beam, the new beam prefers to produce higher impulse. Ablation efficiency of DBP shows better performance in short laser duration. The combination of power density and energy density decides the laser propulsion performance. The new rectangular beam is appropriate for millisecond micro-laser propulsion.

1. Introduction

Spacecraft constellation is progressing rapidly where, rather than launching a single large spacecraft, the mission is accomplished by a fleet of several smaller microspacecraft, with the payload distributed among the micro-craft to reduce mission risk [1]. The new trend demands that micro/nano class satellite is efficiently equipped with enough driving force for attitude control and orbit transfer. Among the micro-propulsion technologies, micro laser propulsion is an up-rising star emerging in 2000 [2,3]. With the advantages of low mass, efficient, small impulse bit, big impulse range, no nozzle and no gas tanks, it has shown great potential to be the first macroscopic application of laser ablation to space propulsion since Kantrowitz came up with the laser ablation propulsion concept in 1972 [4].

Micro laser plasma thrust (LPT) can be classified by the principle of light paths as reflection mode (R mode) and transmission mode (T mode) [5]. In T mode, laser light focused on the transparent side of a multilayer fuel tape and the beam ablates the specially prepared absorbing coating on the opposite side of the tape producing the ablation jet. It has been studied widely, because it can avoid contamination of the illumination optics [6–11].

Ablation polymers have been developed from passive to energetic materials. A large scale of materials including commercial and special designed polymers has been tested [11–13]. It has shown in previous studies that the propulsion performance depends on hybrid utilization of laser energy and chemical energy stored in the fuel. As one of the best candidates of ablation materials, glycidyl azide polymer (GAP) has been applied as the tape coating materials for the prototype msLPT, which has demonstrated C_m = 300 dyn/W at P = 5 W, τ = 2 ms [14].

In this paper, in order to reduce the thruster mass and volume further, diode laser bar is introduced, as shown in Fig. 1. The laser beam is compressed by elliptical lens to rectangular facet. Traditional energetic material double base propellant (DBP) is used as the ablation material. The propulsion performance of the new micro-thruster was studied.

2. Experimental

2.1. Diode laser bar

In order to save mass and volume, laser diode bar (JDL-BAB-30-19-808, JENOPTIK) containing 19 emitters with wavelength of 808 nm is adapted. The light from the elements has a typical diffraction-limited 36° divergence angle in the direction perpendicular to the array and a 6° multimode divergence angle parallel to the array, with substantial astigmatism. As shown in Fig. 2, ten micro elliptical lenses are integrated side by side to compress the beam.

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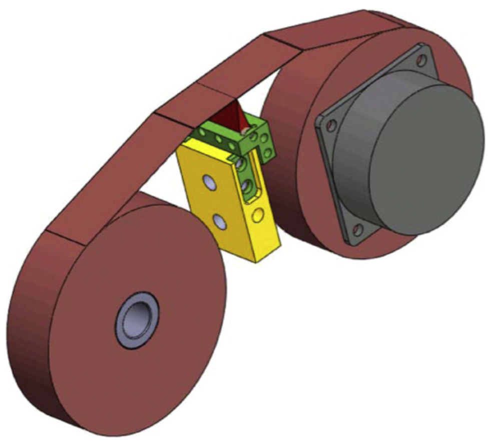

Fig. 1. Scheme of the LPT thruster.

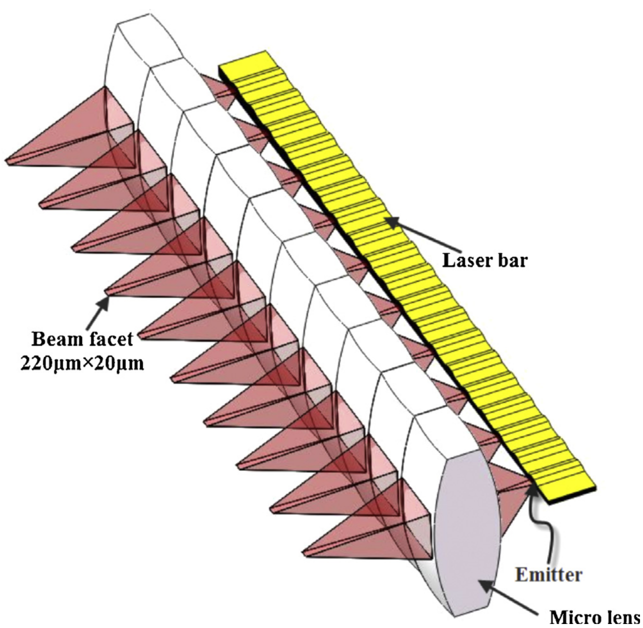

Fig. 2. Structure of the laser bar and the micro lenses array.

Limited by the size of micro-lens, only ten non-adjacent emitters are used. The beam facet is 220 × 20 μm. The maximum output power of single emitter is 2 W, which can be changed. The emitters illuminate by turn at work. The pulse duration and frequency were controlled by circuit board and computer software. By comparison, a fiber diode with 50 μm diameter round beam is also applied.

2.2. Materials

As a kind of traditional energetic materials, double base propellant (DBP), based on nitrocellulose and nitroglycerin, has the advantage of high explosion thermal, low thermal conductivity, easy handling and so on. Caijian [15,16] firstly uses DBP as a micro-propulsion propellant and DBP shows better performance than inert polymer. BOPP (Biaxially Oriented Polypropylene) has excellent toughness, optical damage resistance and outgassing properties. The optical transmission of BOPP is 90%.

Because DBP is a no adhesive material, substrate BOPP is preprocessed. By adding polyacrylate on the surface of BOPP, the composite BOPP film meets the requirements of high optical transparency and good compatibility with DBP. In order to enhance the absorption of the propellant, 3 wt.% carbon nanoparticles are added to the solution. DBP is solved in ethyl acetate (10–15 wt.%). The solution is sprayed on the composite BOPP film.

2.3. Thruster work mode

The experiments are run in "T-mode". Two thruster work modes named static and dynamic mode can be realized by software control. Laser irradiates when fuel is immobile at static mode. In dynamic mode, at first, the motor work for one second, then the laser work to simulate the real work condition of the thruster. The fuel moves in fast axe direction. Tape velocity is 5.1 mm/s.

2.4. Measurements

An improved torsion balance was employed to measure the impulse, as shown in Fig. 3. Both arms of the balance contain a copper sheet of 40 μm. Small copper flag pendulum of one side was mounted very close to the fuel where the jet forms. Calibration experiments show that when the distance is in 1 mm between the target and the flag, there is no obvious error between the improved torsion balance and the impulse stand as in Ref. [5]. With this device, the impulse of laser duration from 100 μs to milliseconds per single shot was measured. The test pressure is under 5 Pa and does not rise significantly with single shot.

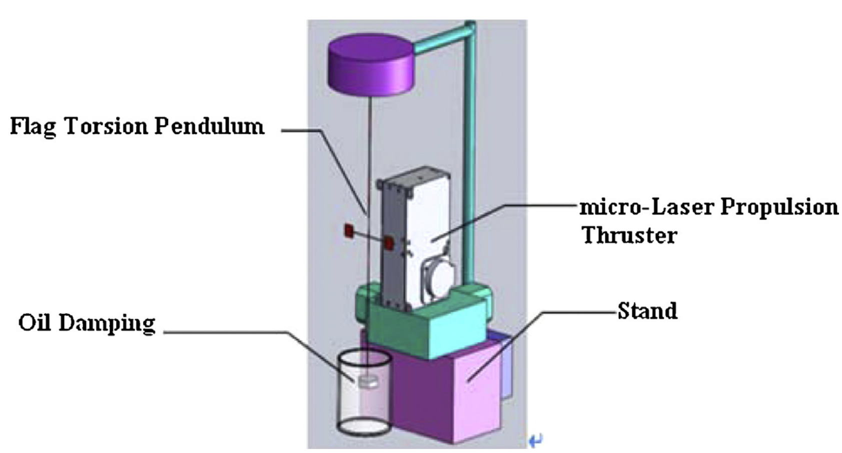

Fig. 3. Scheme of measurement device.