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Research of High Repetition Rate MOPA Pulse Lasers for Deep Space Exploration

Yanfeng Tang [a], Hongzuo Li [b]
Chang Chun University of Science and Technology, Changchun, Jilin, China
tangyanfeng1980@126.com, [b]lihongzuo@sohu.com

Abstract. This paper presents a master oscillator power-amplifier pulse laser included Q-switched seed source and two-cascaded high gain fiber amplifier. It is realized that the fiber-optical pulse laser with pulse width 3ns, pulse frequency 200 kHz and peak power 1kW. The laser wavelength is selected for 1.06um according to the space laser atmospheric transmission window. It is adopted that full fiber technology to make seed source and amplification, pumping source and amplification of free-space coupled into fiber-coupled way. It can overcome that fiber lasers are vulnerable to changes in external conditions such as vibration, temperature drift and other factors affect, improving long-term stability.

Keywords: Deep space exploration; Space laser communication, High repetition rate, High peak power, Fiber Pulse Laser

Introduction

The deep space exploration has become a hot research topic all over the world with constant expand of human beings. As the research of deep space detection platform, deep space communications that can implement platform remote controlled and large-capacity information transmitted has also become one of the key research technologies [1]. According to the long distance and large amount of information transmission characteristics of deep space exploration, the space laser communication is the preferred mode because it has the advantages of concentrated energy, good security, and large information capacity and interference immunity. In a variety of laser source, fiber-optical pulse laser has become an important communication source in deep space laser communication system because of its small size, light weight and large power. For fiber lasers, to solve the contradiction between the high repetition rate and the peak value power is an important scientific problem. According to the space laser atmospheric transmission window, the wavelength selects for 1.06um. It is adopted that full fiber technology to make seed source and amplification, pumping source and amplification of free-space coupled into fiber-coupled way. It can overcome that fiber lasers are vulnerable to changes in external conditions such as vibration, temperature drift and other factors affect, improving long-term stability.

Repetition rate of fiber-optical pulse laser

Deep space laser communications take fiber-optical pulse laser as the light source and most use PPM modulation. To achieve high-rate PPM modulation, fiber-optical pulse laser is required with high repetition rate and narrow pulse width [2].

$$P_P = W / T \tag{1}$$

$$P_{AV} = W \times F_r \tag{2}$$

Where P_P is the output peak power, W is the pulse energy, T is the pulse width, P_{AV} is the average power, F_{rp} is the repetition rate.

Narrow pulses are expected during the entire F_{rp} range, since background light accumulates less in the narrow slot. When the corresponding average power is in certain circumstances, the narrower the pulse width is, the peak power will be higher. The relationships among communication bit rate (R_b), PPM exponent (M), and the slot width (T_s) are:

$$R_b = (\log_2 M)/MT_S \quad (3)$$

Therefore, the laser pulse width is inversely proportional to the exponent PPM.

For fiber lasers, nanosecond pulses are obtained mainly through Q-switched technology. Q-switched way is divided into two kinds: actively Q-switched and passively Q-switched. Actively Q-switched technology is mainly that acousto-optic switch or electro-optic switch inserted in the cavity modulates Q values to produce short, high, and powerful laser pulses. The pulses width generated is from tens of nanoseconds to a few hundred nanoseconds. Passively Q-switched technology is mainly that saturable absorber (semiconductor material or a crystal sheet mixed with rare earth-doped) is used to modulate Q. Compared with actively Q-switched, the advantages of passively Q-switched are low-cost, compact composition, high peak power, narrow pulse width, etc. So narrow pulse width, high repetition rate, and high power fiber laser is gained from using passively Q-switched technology have important practical significance.

MOPA fiber-optical pulse laser

MOPA ytterbium-doped fiber lasers that use fiber amplifier with high-power pump source to amplify pulse signals generated by master oscillator, which can obtain pulse laser output of high peak power and high repetition rate. MOPA combines the structure and technology advantages of double-clad fiber and the characteristics of the power amplifier, together with its vibration insulation, composition compact and without cooling water and other advantages. MOPA pulse fiber laser structure is shown in Fig. 1.

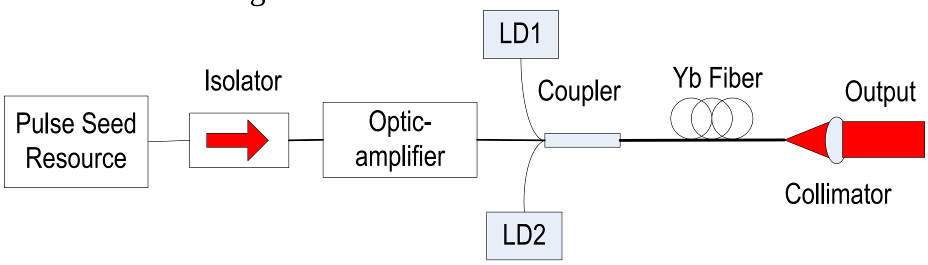

Fig. 1 MOPA fiber-optical pulse laser structure

(1) Seed source of narrow pulse width and high repetition rate

The characteristics of the seed source determine the output characteristics of fiber-optical pulse laser. MOPA seed source can be realized by three kinds of technology, namely fiber acousto-optic Q-switched technology, solid acousto-optic Q-switched technology, and pulse-driven single-mode LD technology [3].

1)The output wavelength of fiber acousto-optic Q-switched pulse laser is around 1070nm, which match with the wavelength bandwidth of ytterbium-doped fiber amplifier. The output of fiber-optical lasers through fiber that is easy for amplification system to weld directly and realize all-fiber structure, but the length of fiber cavity is longer, which is difficult to obtain narrow pulse output.

2)Solid-state Q-switched laser has mature technology, high stability, smooth output pulse waveform, narrow pulse width, but the solid-state Q-switched laser is relatively complex and the output light coupled into the fiber is difficult, the output of the pulses width are instability.

3)Pulse-driven single-mode DFB (Distributed Feed Back semiconductor laser) implements pulse light output through electrical modulation directly and the structure is simple. Pulse width and pulse repetition rate can be tuned independently. However, signal light output power of pulse-driven single-mode LD is too small, usually mW order, so multi-stages amplification are required in order to obtain high output power. And DFB semiconductor seed source of the pulse is easy to integrate with optical amplifiers. In this paper, MOPA uses pulse DFB semiconductor laser as the seed source, whose wavelength is 1064nm, optical pulse width is 5ns-500ns, and repetition rate is 200 kHz.

(2) High-gain ytterbium-doped fiber amplifier

To achieve high output power, a multi-stage amplifier is adopted after the DFB pulse seed source. Amplifier uses two-stage amplification: the first stage is pre-amplifier and the second stage is main amplifier. Main amplifier uses high-gain double-clad ytterbium-doped fiber and side of multi-channel pump coupling technology, which can achieve the output peak power of 1kW.

Double-clad fiber compared with the ordinary single-mode fiber, increases an inner cladding. The refractive index of fiber core is slightly greater than that of inner cladding, the inner cladding refractive index is greater than that of outer cladding, and the inner cladding become a multi-mode pump light transmission waveguide. Inner cladding numerical aperture is larger and its size usually from tens to hundreds of microns, which can match higher power semiconductor pumped lasers very well, then get a higher pump power. Pumped light transmit continuously through fiber core in the inner cladding. When the fiber core is doped, the pump light will be absorbed by the dopant ions, which can be stimulated transition and produce laser. The fiber-core of double-clad fiber generally has a smaller diameter and numerical aperture, which can form a single-mode laser transmission waveguide.

Fiber bundle of parametric cone surface pumped technology provides double- clad gain fiber with high-power pump. The pump couplers arrange lots of multimode pump fibers in a fiber bundle to the center and draw the fiber bundle into the fiber bundle taper with appropriate length in accordance with the taper angle. The end diameter of the fiber bundle cone should be matched with the inner cladding layer of double-clad fiber. Cut the end of the fiber bundle cone flat and fuse with the double-clad fiber to form multimode pump coupler of fiber bundle of pyrometric cone. Thus, fuse the pump fiber of the coupler with the output pigtail of high-power semiconductor pumped module, which can couple pump light directly into the inner cladding of the double-clad fiber [4, 5].

MOPA fiber-optical pulse laser simulation and experiment

This paper uses a professional simulation software for optical communication to achieve the simulation of the pulse laser researched in the paper. The simulation result is shown in Figure2.

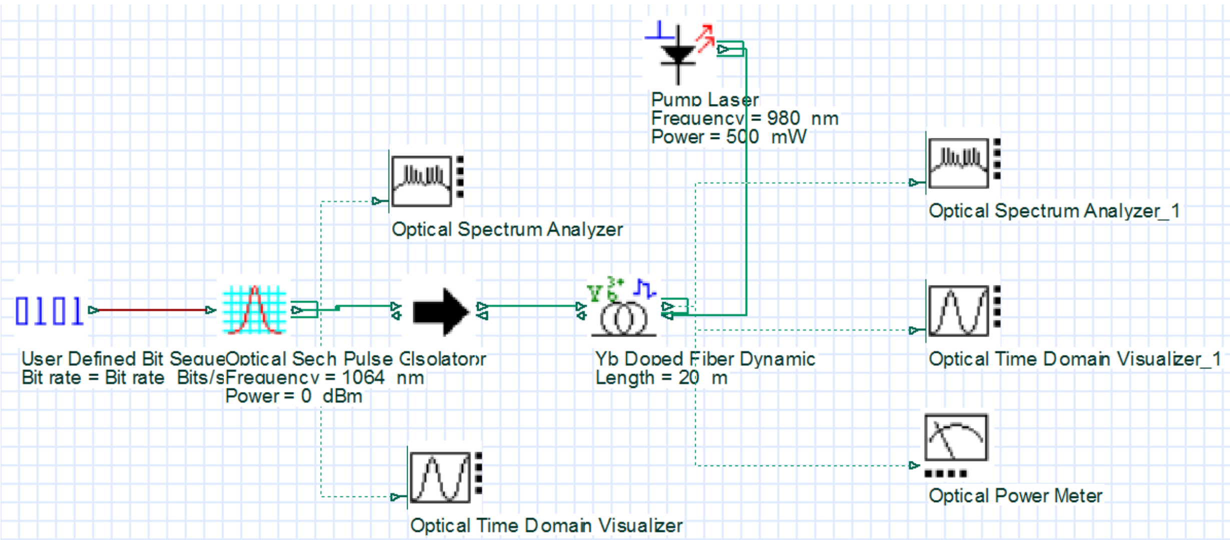

Fig. 2 the MOPA pulse laser simulation system

The simulation system comprises a1064nm high repetition rate pulse laser, a bit generator, an optical isolator, a power amplifier, 20m ytterbium-doped fiber, a fiber coupler, a 980nm high power pump laser. The simulation system completes some measurements of wavelength, pulse width and peak power by some virtual devices presented with the software, such as optical power meter, optical spectrum analyzer and optical time domain visualizer. The simulation result is shown in fig. 3, fig. 4 and fig. 5.

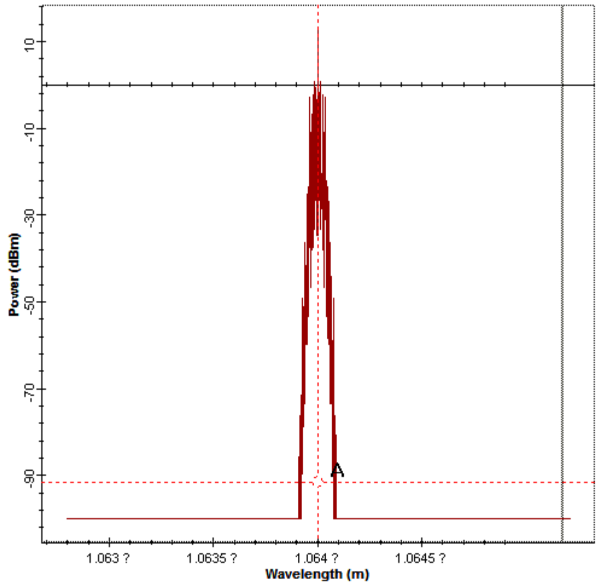

Fig. 3 Seed resource wavelength simulation result

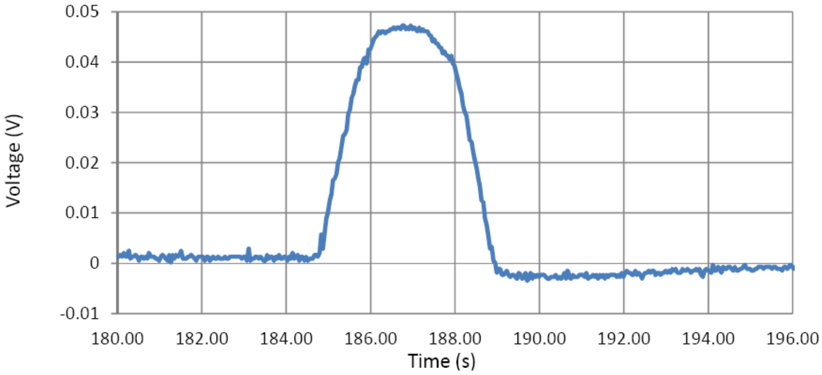

Fig. 4 optical pulse width simulation result

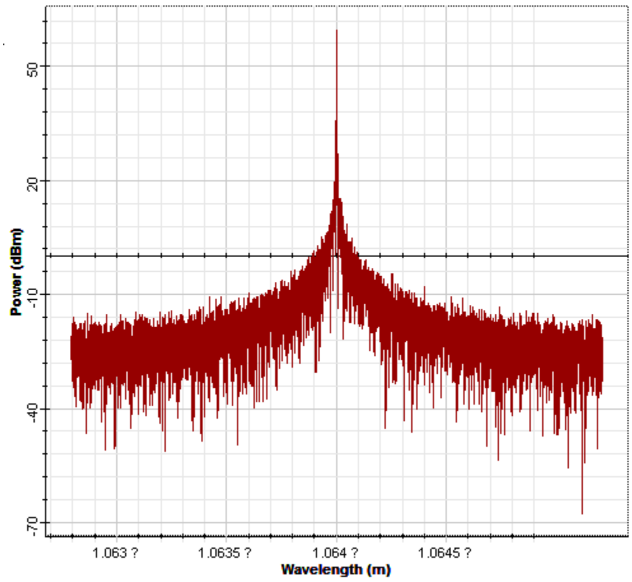

Fig. 5 MOPA output peak power simulation result

The MOPA fiber-optical pulse laser experiment test device is built and testing system block diagram is shown in Fig. 6. And there consists of signal generator, fast photo detector, oscilloscopes, spectrograph in the system. Various performance indicators of fiber-optical pulse laser are tested, and the results are shown in Fig. 7.

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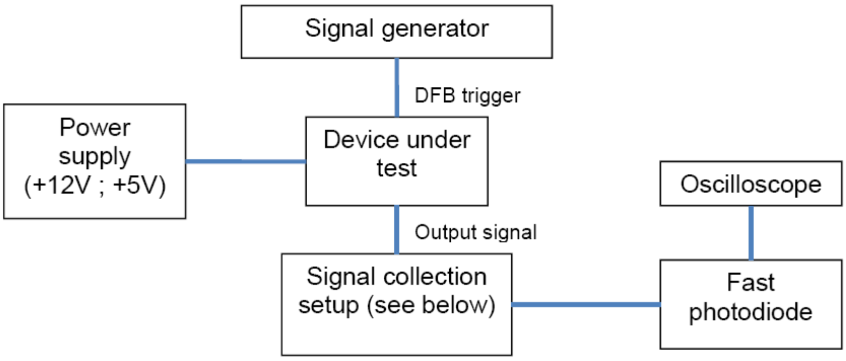

Fig. 6 testing system block diagram

Performance test results turn out to be that peak power is 1kW, pulse width is 3ns, and repetition rate is 200 kHz.

Fig. 7 Repetition rate test results

Summary

In this paper, high repetition rate fiber-optical pulse laser based on MOPA were designed according to the needs of deep space detection space laser communication. And its repetition rate is up to 200 kHz, the minimum pulse width is 3ns and peak power is up to 1kW. The all-fiber pulse laser can meet the needs of high speed, long-distance communication in deep space laser communications.

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