Single frequency ytterbium fiber laser and phosphosilicate Raman fiber laser

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1. Single frequency ytterbium fiber laser system

As we know, there are many important applications for single frequency fiber lasers, such as coherent optical communications, wavelength division multiplexing (WDM) system, high-resolution atomic and molecular spectroscopy and so on. Especially, single frequency 1064 nm laser can be used as a laser source in laser interferometric gravitational wave detector. Narrow linewidth 1083 nm laser is an efficient laser source for helium pumping.

Usually a single frequency master oscillator power amplifier (MOPA) system can provide high power, very narrow linewidth laser source for gravitational wave detector system, however, the master laser is the solid-state laser. A Very complex optical coupling system must be introduced between the master laser and the fiber amplifier, which leads to two problems: 1. the coupling efficiency is not so high, laser power is lost partly in the coupling system; 2. there are some optical reflection because of the complex optical elements, which is easy to produce laser oscillation in the fiber amplifier. Such laser oscillation is very dangerous for the amplifier, particularly when it operates at high power.

In order to prevent the above problems, we proposed to construct single frequency fiber laser as the master laser source. Based on this fiber laser, we can construct an all-fiber master oscillator power amplifier (MOPA) system for laser interferometric gravitational wave detector.

In addition, narrow linewidth laser at 1083 nm can be used to pump helium gas. Helium atoms absorb this laser and will become hyperpolarized helium gas (HPG) through radio frequency (RF) discharge in the helium gas. This HPG can be applied in a very broad range of disciplines: Material sciences, Chemistry, Biology, Medicine and so on. Among these potential applications, the opportunity to image the air spaces of human lungs has immediately risen of considerable interest.

Usually there are several approaches to produce single frequency fiber laser: long traveling-wave fiber ring lasers; short linear cavity distributed reflector (DBR) fiber lasers and distributed feedback (DFB) fiber laser. Ring fiber lasers need many optical elements in the cavity, which make the system complex and expensive. DBR fiber laser can not produce high power because of the short fiber cavity. As for the DFB fiber laser, it needs special grating writing technology, this is not easy to be completed in ordinary laboratories.

In our work, we proposed to produce single frequency fiber laser based on a very simple linear cavity. In the laser cavity, we introduced loop mirror filter (LMF) to discriminate and select laser longitudinal modes, and introduced polarization controller (PC) to suppress the spatial hole burning (SHB) effect, as shown in figure 1.

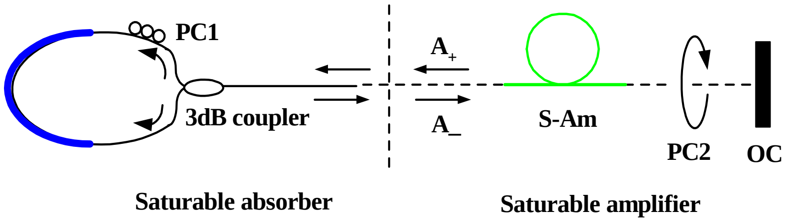

Fig. 1 The laser oscillator is composed by two sections. The first one is the laser gain section (the right section). In this one, PC2 is used to control the wave polarization and eliminate the SHB effect. The second one is the saturable absorber section (the left section), it is a LMF (loop mirror with saturable absorber) act as a very narrow filter.

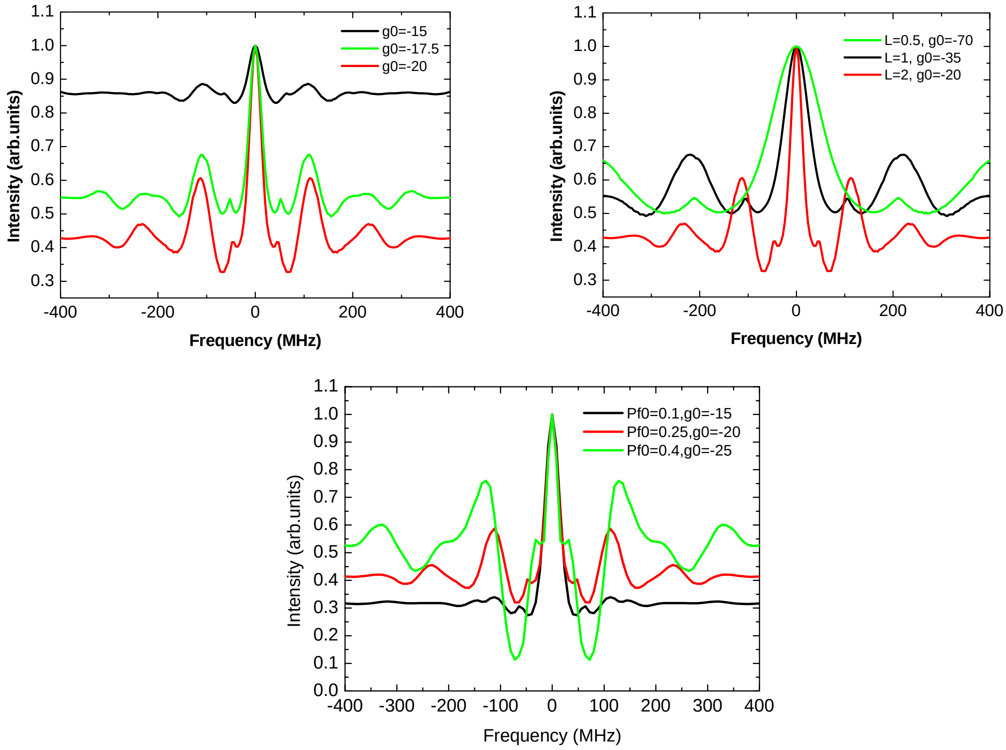

Fig. 2 The calculated profile of the dynamic Bragg grating, (a) Fiber length and the power of mode pump is given, the frequency modulation become stronger when the absorption coeffiecient become larger; (b) The power of pump mode is given, when the fiber length

become longer, the bandwidth of the grating become narrow; (c) Fiber length is given, when pump power increased, other channel become stronger.

LMF is the fiber loop mirror with saturable absorber (SA), in which counterpropagating waves interfere with each other, and the interference pattern can engender dynamic Bragg grating. This grating is an absorption grating, which bandwidth is inverse proportional to the length of SA. Usually the bandwidth range covers sub-MHz to GHz, which is much narrower than the normal FBG's. In addition, the center wavelength of the grating is determined by the laser wavelength in it, in this way the wavelength can be changed easily by changing the laser wavelength. The simulation result about the dynamic grating is shown in figure 2. For linear laser cavity, it is easy to arouse spatial hole burning (SHB) effect in the gain fiber because of the interference of the counterpropagating laser waves. As we know the SHB effect is deathful obstacle for single-frequency generation. If we make the polarization states of the counterpropagating waves perpendicular, we can destroy the interference of the laser waves, as thus, SHB effect can be restrain to some extent.

According to the above advisement, we introduced LMF into the linear fiber cavity to discriminate and select laser longitudinal modes, at the same time introduced polarization controller (PC) in the gain fiber section to control the polarization states of the counterpropagating laser waves. The total linear cavity is composed of LMF, ytterbium fiber as the gain material and FBG at 1064 nm as the output coupler. Stable single-frequency 1064 nm laser was generated by optimizing the polarization states of the laser waves in the cavity. We measured and analyzed the laser frequency with a scanning Fabry-Perot interferometer, which had a free spectral range (FSR) of 6 GHz and resolution of 150 kHz. The output power can go up to 14 mW when optimized the gain fiber length, the SA length and the reflectivity of the output coupler FBG, respectively. This laser can be wavelength tuned about 1 nm when tuning the temperature of the output coupler FBG.

Based on the almost same experiment configuration, single-frequency 1083 nm laser was produced when using output coupler FBG at 1083 nm. The maximum output power was 14 mW under the optimum fiber cavity configuration. We measured the linewidth of this laser using delayed self-heterodyning method with 25 km delay fiber. It showed that the laser linewidth was as narrow as 2 kHz. The single frequency signal and heterodyning signal of SF 1083 nm laser is shown in figure 3. After the single-frequency laser source, we constructed ytterbium fiber amplifier to amplify the laser signal. The gain fiber of the amplifier is optimized to be 5 m, and it is backward pumped. In this way, the fiber laser oscillator and amplifier come into being all-fiber MOPA system. 177 mW single-frequency laser at 1083 nm was produced from this system eventually. The Schematic of the SF 1083 nm MOPA system is shown in figure 4, the corresponding result is shown in figure 5.

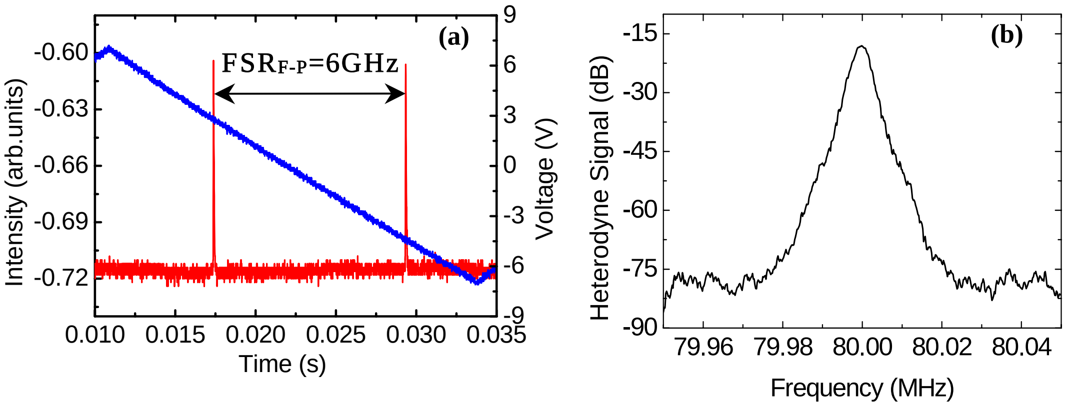

Fig. 3 (a) Single frequency operation verified using a scanning Fabry-Perot interferometer with a free spectral range (FSR) of 6GHz and a resolution of 150KHz. (b) Lineshape of the heterodyne signal measured using delayed self-heterodyne method with 25 km delay fiber. From the signal taken 3 dB down from the maximum value we estimate the FWHM of the laser spectral linewidth is about 2 KHz.

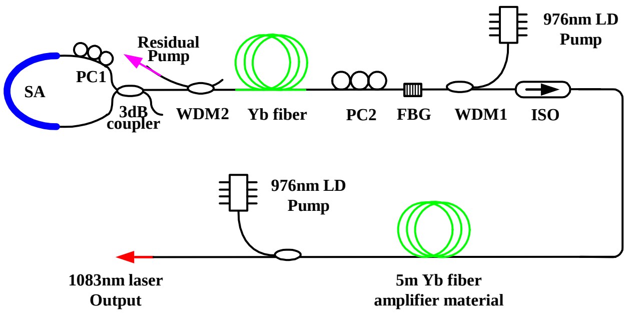

Fig. 4 Experiment setup of the single frequency ytterbium MOPA fiber laser, which is composed by two sections. The above section is the laser oscillator, the low section is the fiber amplifier.

2. High power Raman fiber laser at 1178 nm

Laser sources in the yellow-orange spectra are particularly of interest for applications in metrology, medicine, biology, display technology and so on. Especially, the 589 nm atomic sodium-resonance radiation can produce a laser guide star (LGS) in astronomy.

Atmospheric turbulence blurs the light from distant stars and galaxies. In order to remove this blurring when observe the astronomical object, scientists adopt adaptive optics that needs reference object besides the astronomical object. Using a laser beam to create an artificial “star” as the reference object is a wonderful idea. A yellow laser tuned to the wavelength of 589 nm can excite sodium atoms at an altitude of ~100 km in the Earth's atmosphere to make a artificial “star”.

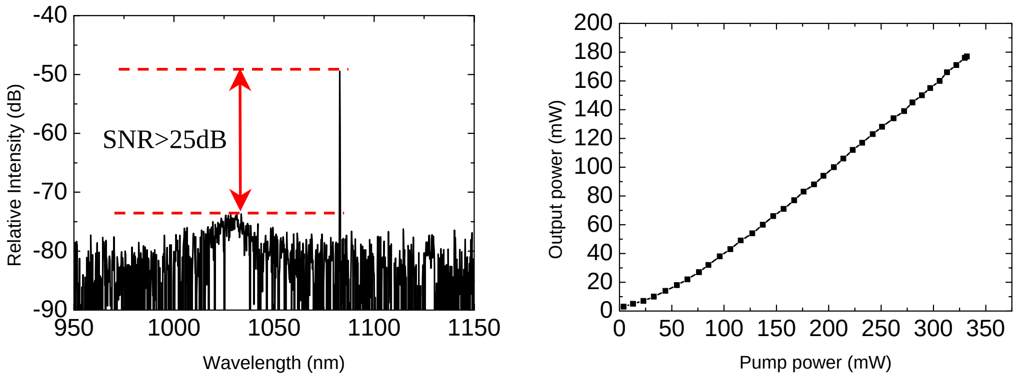

Fig. 5 (Left) Optical spectrum of the master oscillator power amplifier (MOPA) fiber laser. The signal-to-noise ratio (SNR) of the 1083nm laser is larger than 25 dB. (Right) 1083nm output power versus pump power for given 4.25 mW signal input power.

At present, there are some methods to produce 589 nm yellow laser: Argon-ion pumped cw dye-jet laser; Solid-state Nd:YAG lasers with sum-frequency generation(SFG); Nd fiber lasers with SFG. In our experiment, we proposed to develop 589 nm laser based on Raman fiber laser and frequency doubling technology. Firstly, we generate 1178 nm Raman laser based on phosphosilicate fiber pumped by 1100 nm fiber laser. Next, 1178 nm laser is converted to 589 nm laser by frequency doubling technology.

As the other part of our work, we have generated high power 1178 nm laser using phosphosilicate RFL, figure 6 shows the schematic of the experiment setup. Because the phosphosilicate fiber has very broad Raman spectrum, it is easy to transform the pump laser wavelength to some special wavelength. We made use of the Raman shift of 601 cm^{-1} of phosphosilicate fiber to produce 1178 nm laser, the pump source was a 20 W, 1100 nm ytterbium doped double clad fiber laser. The maximum output power of 10.5 W is produced from this Raman fiber laser. Figure 7 shows the experiment results. The laser wavelength is converted to 589 nm light by frequency doubling technology, as shown in figure 8. This orange yellow laser can be used as the laser source for laser guided star (LGS) in astronomy.

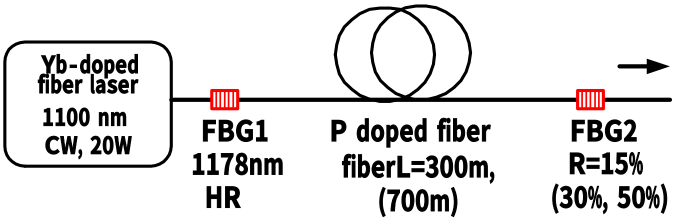

Fig. 6 Experiment setup of Raman fiber laser: The fiber length is 300m (700m), the reflectivity of FBG2 is 15% (30%, 50%) at 1178nm, respectively.

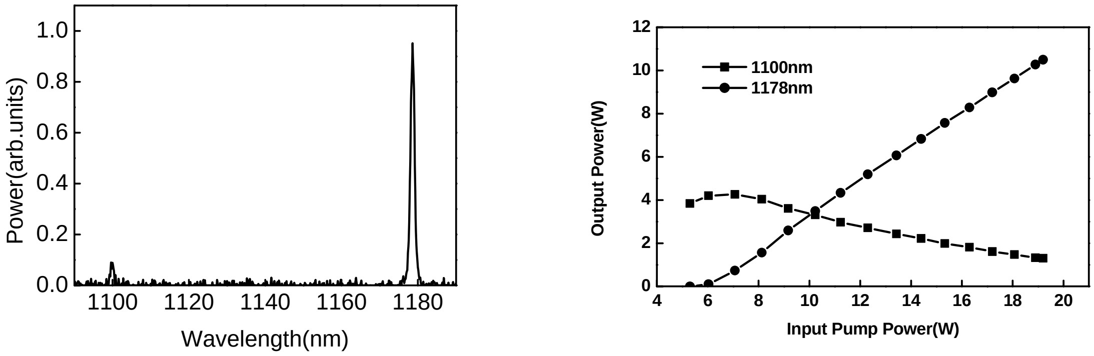

Fig. 7 (Left) Output spectrum from the Raman fiber laser. The Raman laser at 1178 nm, the residual pump laser wavelength is 1100 nm. (Right) Evolution of the output powers for the residual pump, the Stokes lights as the pump power is enhanced.

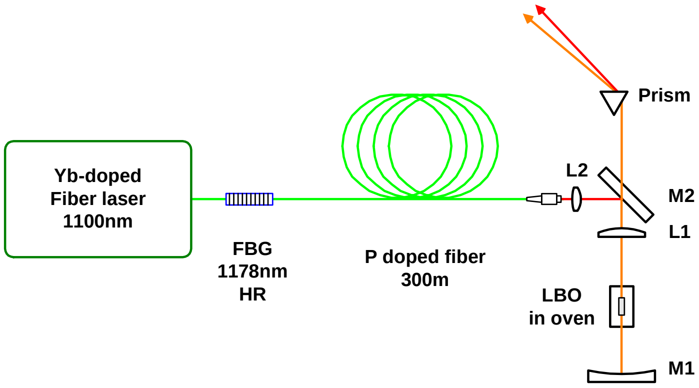

Fig. 8 Schematic of the experimental setup for frequency doubling of 1178 nm laser. Cavity is formed by FBG, M1. M2 is a dichroic mirror through which visible lights escape from the cavity.