High performance of semiconductor optical amplifier available for cold atom physics research

Qianli Ma (马千里)*, Lin Xia (夏 林), Bo Lu (鹿 博), Wei Xiong (熊 炜), Yin Zhang (张 胤), Xiaoji Zhou (周小计), and Xuzong Chen (陈徐宗)

Institute of Quantum Electronics, School of Electronics Engineering and Computer Science, Peking University, Beijing 100871

**E-mail: qianli830505@yahoo.com.cn*

Received April 10, 2008

We present a novel design of a compact, stable, and easy-adjustable semiconductor optical amplifier (SOA) system. This SOA system is capable of providing up to 560-mW laser power at the wavelength of 852 nm. For the continuous-wave (CW) seeding laser, the amplification gain can reach 18 dB. We add amplitude modulation onto the CW laser and measure the modulation amplification between seeding and output laser. The amplification gain remains constant within the frequency range from 10 Hz to 1 MHz. The whole system could work in ultra-stable condition: for CW seeding laser, the fluctuation of output power is less than 0.33% in several hours.

OCIS codes: 140.4480, 140.2020, 140.3325.

doi: 10.3788/COL20090701.0046.

Solid-state optical amplifier is designed to provide large gains for low-power laser within its own gaining spectrum[1]. Typically, it could amplify continuous-wave (CW) radiation from just a few milliwatts to more than 500 mW, without changes in polarization and linewidth[2−7]. Amplification of femtosecond pulses with semiconductor optical amplifier (SOA) has also been one of the numerously investigated subjects[8]. SOA has been widely used in cold atom physics research, such as Bose-Einstein condensation (BEC)[9−12], optical lattice[13−15], and optical frequency standard[16]. For our research in atomic physics, we need high-power and ultra-stable CW laser sources, so we design a three-dimensional (3D) precisely adjustable and steadily working SOA to generate optical periodic potentials in BEC.

Our SOA system, as shown in Fig. 1, enjoys advantages in compactness, stability, and 3D adjustment. The integrated optical part of SOA system consists of one SOA diode (Sacher, TPA-840-500), two aspheric lenses (f = 3 mm, numerical aperture (NA) = 0.6), and one cylindrical lens (f = 50 mm). The active gain region of SOA diode is 2750 μm long, with 3-μm input aperture and 190-μm output aperture.

The C-mount SOA diode needs one fixed mount with firm electrical connection while coupling lens needs enough space to be adjusted. In our system, SOA diode is screwed onto a homemade diode holder which has both ample space for laser passing through and big thermal sink to dissipate heat. The mounting plate for two lenses is capable of 3D fine adjustment. As shown in Fig. 1(a), different dimension has different adjust fineness: in the x- and y-direction, the minimum step of precise adjustment is 20 μm; meanwhile, to meet the need of high amplification rate, the adjusting fineness in z-direction is improved to 5 μm by using ultrafine screws. All of the adjustments are accessible from the outside without the need of real contact to SOA diode.

Since the magnitude and wavelength variation of the SOA gain were closely influenced by thermal stability, the diode holder was screwed onto one brass heat sink base of the size 60×86 (mm) and both of them were attached onto one 40×40 (mm) thermal energy converter. With the thermal control ability of 5 W, the temperature fluctuations could be limited within 0.01 °C.

The SOA diode needs precise and ultra-low-noise current up to 2 A to provide stable high-power laser. One homemade constant current driver was used to supply the current. To insulate the SOA diode from the outside electromagnetic environment, different part within the system was connected to distinct ground: the current driver was float ground and all the other parts had firm connection with the earth. In this way, the current noise reached the lowest root-mean-square (rms) level: $\Delta I_{\rm rms}$ = 10 μA with working current of 2 A (less than 5×10^{-6}).

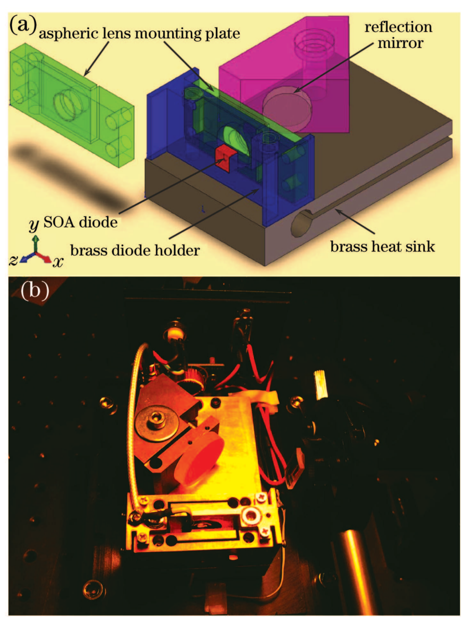

Fig. 1. Experimental setup of SOA system. (a) Exploded mechanical design draft; (b) photograph of the optical part.

Alignment plays a key role in the amplification process of SOA system because the small input aperture requires careful mode matching between the injection beam and amplified spontaneous emission (ASE) light. The alignment setup consists of fine adjusting for two aspheric lenses in three dimensions. Alignment defines the beam quality of both front coupling light and back output laser. For the input light, the holding plate allows the ASE light to be well collimated, and the shape and divergence of ASE light help to ensure whether the seed laser could be fully injected into the SOA diode. The x-direction of output beam is collimated only by the aspheric lens screwed into the mounting plate; but the light in y-direction needs to be adjusted by cylindrical lens. Calculated from the divergent angle and the focal length we used for collimation, the focal distance of output beam in x-direction was 50 mm. Then one cylindrical lens with 50-mm focal length was put right at the focus point to correct the beam. In this way, the output beam had a nearly circular shape.

As shown in Fig. 2, one external cavity diode laser (ECDL) provides seeding laser for the SOA diode. The confocal telescope is used for mode matching and reshaping the seeding laser; the beam cross section after the telescope is just 1/4 of the original one. The output beam owns high propagation quality: the beam divergence angle is less than 2 mrad, the M^2 factor is 1.7, and in the frequency range, the output laser has a linewidth of 25 MHz and a frequency stability of 10^{-7} which are the same with those of the seeding laser, respectively. To detect the amplification ability of alternating current (AC) modulation on seeding laser, amplitude modulation is added onto the CW-ECDL seed laser. The modulation amplification information is detected by photodiode (PD) and avalanche photodiode (APD) in low- and high-frequency regions, respectively. SOA diode is highly flimsy and just a few milliwatts of back-coming light can cause permanent damage to the diode, so the Faraday isolator of the SOA system should be no less than 60 dB.

The output power of SOA depends on the polarization of seeding laser. In our system, the amplified polarization axis lies in the x-direction. The HWP was carefully turned to change the polarization axis of the seeding beam while maintaining seeding power to be constant. At the same time, we measured the output power of the SOA system. As shown in Fig. 3, when the polarization of linear seeding laser parallels with the diode's amplification axis, the output power would get its maximal level. When the polarization axis of HWP is turned, which means the axis of the linear polarized beam altered, the output power will fall down accordingly. When the beam polarization axis turns right at 90 °C, the output power reaches its minimum level.

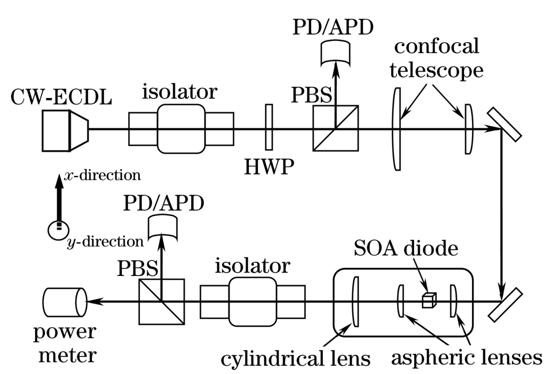

Fig. 2. Schematic of the experimental working system. PBS: polarized beam splitter; HWP: half wave plate.

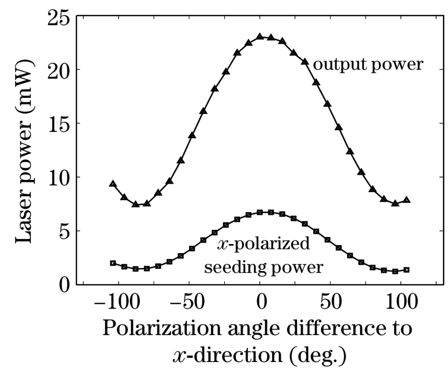

Fig. 3. Output power of SOA system versus polarization of the seeding beam. T_{SOA} = 20 °C, I_{SOA} = 0.5 A, $P_{seeding}$ = 9 mW.

Figures 4 and 5 show the output power of SOA versus CW seeding laser at two different temperatures. From the datasheet, the output power will be higher when SOA diode works at a lower temperature. Comparing the two plots, there is a 5% – 10% increase in power through lowering the temperature by 2 °C.

Figure 6 shows the amplification gain versus amplitude modulation frequency on seeding laser. The current modulation of 1-V magnitude from 10 Hz to 1 MHz being added onto the CW-ECDL, then a PD was used to detect the modulation amplification in low-frequency region

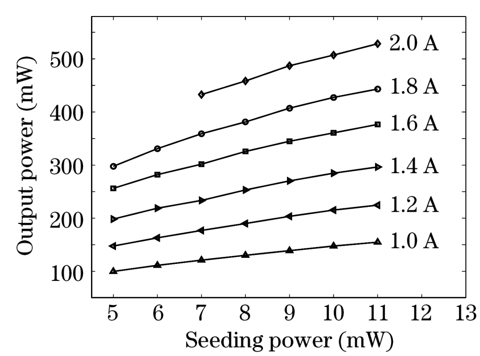

Fig. 4. Output power of SOA versus seeding power with different working currents at 20 °C.

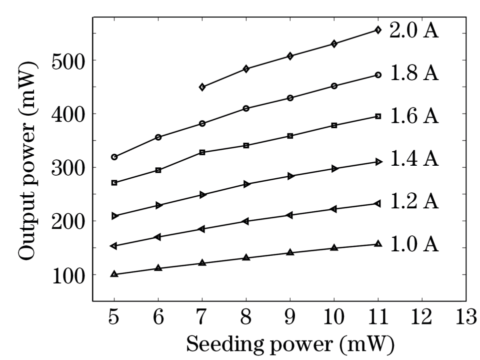

Fig. 5. Output power of SOA versus seeding power with different working currents at 18 °C.

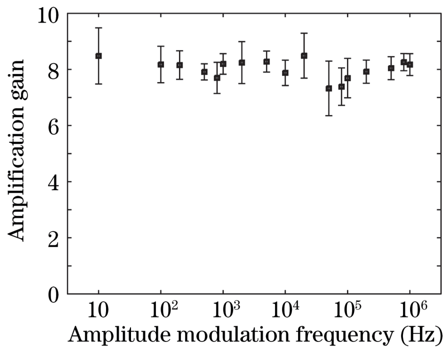

Fig. 6. Amplification gain versus amplitude modulation frequency on seeding laser. $T_{SOA} = 20$ °C, $I_{SOA} = 0.5$ A, $P_{seeding} = 7$ mW.

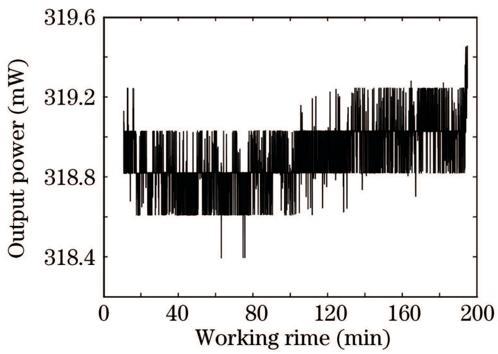

Fig. 7. Fluctuation of output power versus working time. $T_{SOA} = 20$ °C, $I_{SOA} = 1.5$ A, $P_{seeding} = 9$ mW.

(10 Hz—20 kHz); but for high-frequency region (50 kHz—1 MHz), APD was used for detection. The amplification rate versus frequency remains at the similar level, and because of different sensors, we got inflexion points between 20 and 50 kHz.

As shown in Fig. 7, with 9-mW CW-ECDL seeding laser and working current of 1.5 A, the output power was measured in about 170 min by optical power meter (Thorlabs, PM-100). After the whole system reaches thermal equilibrium, the output power remains steady for nearly 3 h. Figure 7 shows that the fluctuation of output power is 1.06 mW, which is 0.33% of the average output power within the test timescale.

In conclusion, we proposed a novel design of SOA system and made an amplification system which owns merits in mechanical compactness, optical integration, and reduced space consumption. Our SOA system could be adjusted in three dimensions and work stably, which provides a useful device for cold atom physics research. Various kinds of test were performed onto the whole system and all the results showed that our system could match commercial products in features of amplification rate and long-time stability.

The authors acknowledge Mr. Xianghui Qi, Mr. Lin Yi, and Miss Guirong Sun for helpful discussion about the design of SOA system. This work was supported by the National "973" Program of China (No. 2005CB724503, 2006CB921401, and 2006CB921402) and the National Natural Science Foundation of China (No. 60490280 and 10574005).

References

1. D. Voigt, E. C. Schilder, R. J. C. Spreeuw, and H. B. van Linden, Appl. Phy. B **72,** 279 (2001).
2. J. H. Marquardt, F. C. Cruz, M. Stephens, C. W. Oates, L. W. Hollberg, J. C. Bergquist, D. F. Welch, D. Mehuys, and S. Sanders, Proc. SPIE **2834,** 34 (1996).
3. X. Teng, H. Zhang, H. Jiang, and J. Yang, Semicond. Optoelectron. (in Chinese) **28,** 757 (2007).
4. X. Zhang, D. Huang, J. Sun, D. Liu, and H. Yi, Acta Opt. Sin. (in Chinese) **21,** 1256 (2001).
5. T. Jiang and Y. Chen, Laser Optoelectron. Prog. (in Chinese) **37,** (8) 40 (2000).
6. Y. Ye, X. Zheng, H. Zhang, Y. Chu, Y. Li, and Y. Guo, Acta Opt. Sin. (in Chinese) **22,** 436 (2002).
7. R. A. Nyman, G. Varoquaux, B. Villier, D. Sacchet, F. Moron, Y. Le Coq, A. Aspect, and P. Bouyer, Rev. Sci. Instrum. **77,** 033105 (2006).
8. G. P. Agrawal and N. A. Olsson, IEEE J. Quantum Electron. **25,** 2297 (1989).
9. W. Ketterle, Rev. Mod. Phys. **74,** 1131 (2002).
10. E. A. Cornell and C. E. Wieman, Rev. Mod. Phys. **74,** 875 (2002).
11. F. Yang, L. Xia, X.-J. Zhou, X.-Q. Ma, and X.-Z. Chen, Chin. Phys. Lett. **22,** 1596 (2005).
12. X.-Q. Ma, S. Chen, F. Yang, L. Xia, X.-J. Zhou, Y.-Q. Wang, and X.-Z. Chen, Chin. Phys. Lett. **22,** 1106 (2005).
13. M. Greiner, O. Mandel, T. Esslinger, T. W. Hänsch, and I. Bloch, Nature **415,** 39 (2002).
14. O. Morsch and M. Oberthaler, Rev. Mod. Phys. **78,** 179 (2006).
15. I. Bloch, J. Phys. B. **38,** S629 (2005).
16. F. C. Cruz, M. C. Stowe, and J. Ye, Opt. Lett. **31,** 1337 (2006).