Conference materials
UDC 53.082.534
DOI: https://doi.org/10.18721/JPM.163.220

Compact solid-state laser with diode optical pumping and high frequency stability

V.V. Naumova[1,2]✉, O.A. Orlov[2]

[1] Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia;

[2] D.I. Mendeleev Institute for Metrology, St. Petersburg, Russia

✉ vika_025898@mail.ru

Abstract. Continuous single-frequency solid-state lasers with intracavity frequency doubling Nd^{+3}/YVO/KTP, whose frequency is stabilized along the absorption lines of molecular iodine, are currently widely used in laser interferometers. The paper describes a small-sized laser with frequency instability at the level of 10-12 with an averaging time of 1 second. It has been shown that this level of stability is limited by the amplitude noise of the laser, which in turn are determined by fluctuations in the laser pumping. Reducing the amplitude noise and increasing the signal-to-noise ratio in the stabilization system made it possible to further increase the frequency stability of laser radiation.

Keywords: solid-state laser, laser diode, amplitude noise, Bragg grating

Citation: Naumova V.V., Orlov O.A., Compact solid-state laser with diode optical pumping and high frequency stability, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 16 (3.2) (2023) 120–124. DOI: https://doi.org/10.18721/JPM.163.220

Материалы конференции
УДК 53.082.534
DOI: https://doi.org/10.18721/JPM.163.220

Компактный твердотельный лазер с диодной оптической накачкой и высокой частотной стабильностью

В.В. Наумова[1,2]✉, О.А. Орлов[2]

[1] Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия;

[2] Всероссийский НИИ метрологии имени Д. И. Менделеева, Санкт-Петербург, Россия

✉ vika_025898@mail.ru

Аннотация. Непрерывные одночастотные твердотельные лазеры с внутрирезонансным удвоением частоты Nd^{+3}/YVO/KTP, частота которых стабилизирована по линиям поглощения молекулярного йода, в настоящее время широко используется в лазерных интерферометрах. В работе описан малогабаритный лазер с нестабильностью частоты на уровне 10–12 при времени усреднения в 1 секунду. Было показано, что это уровень стабильности ограничивается амплитудными шумами лазера, которые в свою очередь определяются флуктуациями лазерной накачки. Уменьшение амплитудных шумов и повышение отношения сигнал/шум в системе стабилизации позволило дополнительно повысить частотную стабильность лазерного излучения

Ключевые слова: твердотельный лазер, лазерный диод, амплитудный шум, решетка Брэгга

Ссылка при цитировании: Наумова В.В., Орлов О.А. Компактный твердотельный лазер с диодной оптической накачкой и высокой частотной стабильностью // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2023. Т. 3.2 № .16. С. 120–124. DOI: https://doi.org/10.18721/JPM.163.220

Introduction

In modern science and technology, optical measurements are increasingly being used to solve various tasks [1–5]. A special place among them is occupied by measurements using various lasers [7–10]. An iodine-stabilized diode-pumped solid-state laser (DPSS laser) with a wavelength of 532 nm is not only a good secondary frequency standard but is also a good laser source with a wavelength (frequency) for implementing a meter using laser interferometry.

Many of the lasers usually described in all references are quite large (all the optical parts of the laser systems were arranged on a 45 cm × 45 cm breadboard) [11–13]. The compactness and low weight of the laser (the dimensions of the laser head, which includes an iodine spectroscopy scheme, are 80 mm × 116 mm × 130 mm with a mass of about 1.5 kg) can be critical parameters for use in laser displacement interferometry, for example, in industrial laser interferometers and in absolute ballistic gravimeters.

The paper describes a small-sized laser with frequency instability at the level of 10^{-12} with an averaging time of 1 second.

It has been shown that this level of stability is limited by the amplitude noise of the laser, which in turn are determined by fluctuations in the laser pumping. Reducing the amplitude noise and increasing the signal-to-noise ratio in the stabilization system made it possible to further increase the frequency stability of laser radiation.

Solid-state laser design

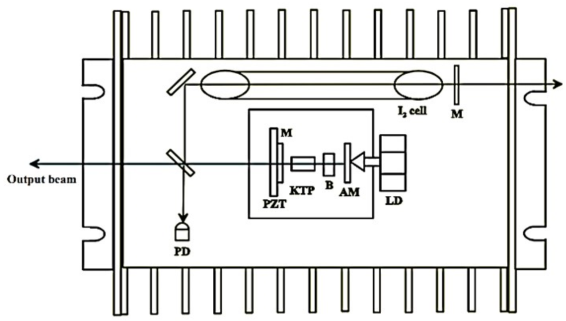

Fig. 1. Optical scheme of Nd^{+3}/YVO/KTP/I_2 iodine stabilized laser resonator with a wavelength of 532 nm

Fig. 1 shows the optical scheme of the developed laser resonator.

This linear resonator consists of a laser diode LD with a wavelength of 808 nm, a plate of the active medium Nd: YVO_4 AM, a Brewster plate B, a nonlinear crystal KTP ($KTiOPO_4$) with frequency doubling and a mirror of the output coupler M mounted on a piezoelectric disk PZT (lead zirconate titanate). The active medium Nd: YVO_4, illuminated by a laser diode, generates radiation with a wavelength of 1064 nm. The Single-Frequency TO-Can Laser Diode is based on quantum well epitaxial layer growth and a highly reliable ridge waveguide structure with external volume holographic grating (VHG) feedback. This single-transverse mode laser diode features high optical output power and produces a wavelength stabilized spectrum with a single frequency narrow linewidth (0.8 pm) over the operating power range of approximately 400 to 500 mW (SMSR 42.5 dB). The intracavitary KTP crystal doubles the frequency of this radiation. PD is a photodetector.

The optical length of the linear resonator is about 17 mm, which corresponds to an intermode frequency interval of about 10 GHz. Single-mode generation at a single frequency is provided in the range of about 400 GHz (along the luminescence line) by a birefringent interference Lyot filter formed by a birefringent KTP crystal and a Brewster plate.

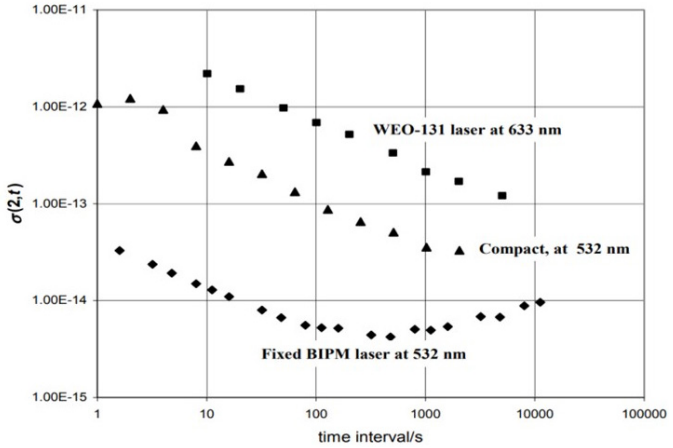

Fig. 2. Allan deviations of $Nd:YVO_4/KTP/I_2$ compact laser at 532 nm

The temperatures of the active medium plate, the KTP crystal, the laser diode and the resonator are regulated with instability within 2 mK. The frequency tuning range with the KTP temperature is about 100 GHz (at twice the frequency, which corresponds to a wavelength of 532 nm).

The dimensions of the laser head, which includes an iodine spectroscopy scheme, are 80 mm × 116 mm × 130 mm with a mass of about 1.5 kg.

The third harmonic method [14, 15] with a modulation frequency of 3.3 kHz is used to stabilize the frequency. An electronic unit for the power supply, five temperature control systems for laser elements and an iodine cell element, as well as servo electronics for frequency stabilization.

Amplitude noise

Several such type lasers were developed [11–13]. But in general, it was a laboratory installation, mounted on optical tables which are difficult for transportation.

To stabilize the frequency of the output radiation in these lasers, the binding of the output radiation to the absorption lines of molecular iodine is used. For the stable operation of the servo system, it is necessary to ensure a sufficient signal-to-noise ratio. In stationary installations, the length of the iodine cell is increased for these purposes. The best results were achieved with a 2m iodine cell (BIPM).

In our case, the length of the iodine cell is limited by the size of the transported radiator and is 10 cm. On such a cell, it was possible to stabilize the laser frequency at the level of 10^{-12} with an averaging time of 1 s. The frequency stability of the compact laser was measured using a stationary $Nd:YAG/MgO:LiNbO_3$/I2 BIPM laser at 532 nm.

The Allan deviations of the compact $Nd:YVO_4/KTP/I_2$ laser, stationary BIPM laser and $He\text{-}Ne/I_2$ WEO 131 laser at 633 nm (manufactured by Winters Electro-Optics, Inc.) are shown in Fig. 2.

As studies have shown, the main contribution to the amplitude noise of the laser, which limits the SNR ratio, is the parasitic modulation of optical pumping in DPSS lasers.

Typically, DPSS lasers use multimode LDs with a power of 0.5 – 2 W for pumping. The generation spectrum of these diodes is wider than the absorption line of the active medium of 0.1 nm. Several LD modes are placed in the absorption line.

In these lasers, the phenomenon of mode competition is observed, which leads to a change in the amplitude of individual longitudinal modes. At the same time, the total intensity of the LD radiation remains constant and is determined by the pump current.

To observe this phenomenon and the selection of LD, an installation was assembled in which the level and modulation of the power absorbed in the active medium can be recorded and recorded. It has been shown that the relative parasitic modulation of radiation in the pump radiation increases greatly after passing through the active medium. The level of this modulation differs for different LD batches. In Fig. 3, the spectrum of parasitic modulation of the pumping power of a typical multimode LD is shown.

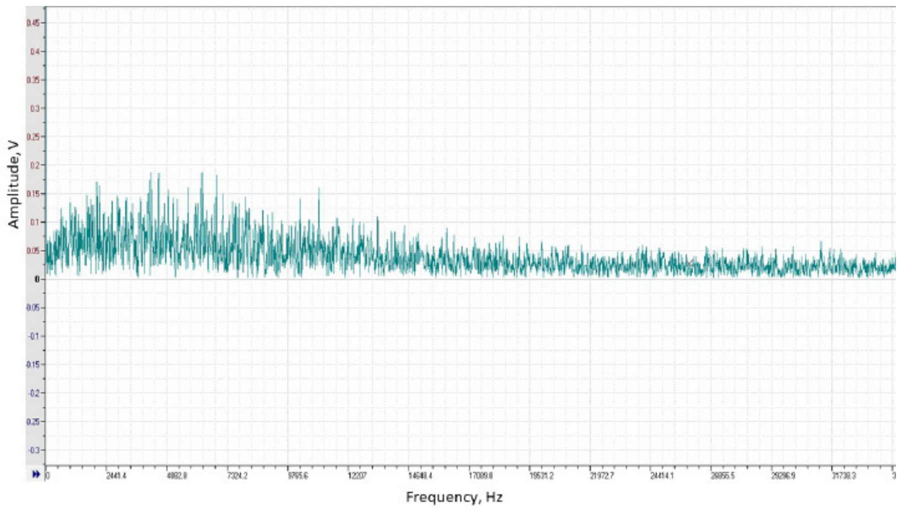

Fig. 3. Spectrum of parasitic modulation of the pumping power of typical multimode LD

In addition, it should be noted that SS lasers are characterized by the presence of relaxation oscillations caused by Q-factor modulation of the resonator or pumping. The frequency of the peak of relaxation oscillations is determined by the laser parameters. The presence of these oscillations causes additional amplification of parasitic modulation, which at its peak can reach several orders of magnitude.

All this can negatively affect the operation of the servo system, which stabilizes the frequency by a signal of 1 and 3 harmonics at a modulation frequency of 10 kHz.

Recently, single-frequency LDs with a power of 0.5 watts have appeared. To ensure the selection of longitudinal modes, a volumetric Bragg lattice is used. In Fig. 4, the spectrum of parasitic modulation of the pumping power for a single-frequency LD is shown. They are significantly lower than those of conventional LDs.

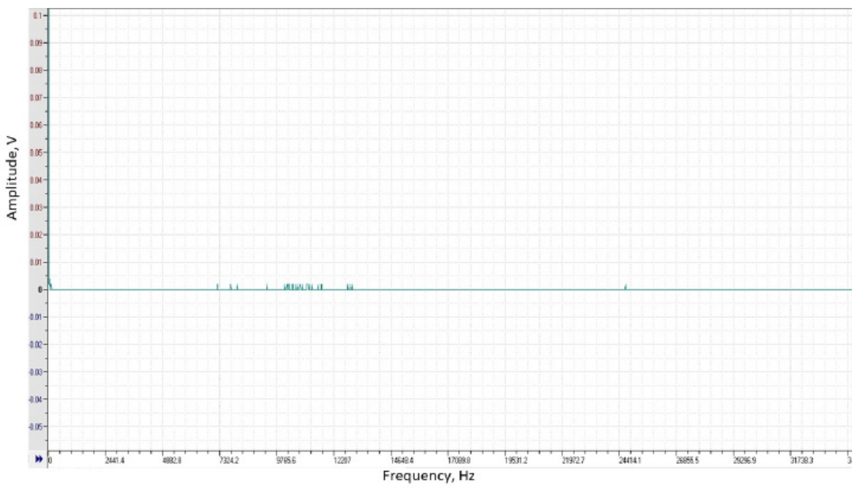

Fig. 3. Spectrum of parasitic modulation of pumping power for single-frequency LD

Conclusion

A compact solid-state Nd: $YVO_4/KTP/I_2$ diode-pumped, iodine-stabilized laser at a wavelength of 532 nm was developed and investigated. Metrological (frequency stability and reproducibility) and technical (laser power, size and weight of laser blocks) characteristics suggest that such lasers will find wide application in laser displacement interferometry, including laser interferometers for absolute ballistic gravimeters, as well as portable secondary frequency standards in the visible optical frequency range.

REFERENCES

1. **Mazing M., Zaitceva A., Kislyakov Y., Kondakova N., Avdyushenko S.,** Monitoring of oxygen supply of human tissues using a noninvasive optical system based on a multi-channel integrated spectrum analyzer, International Journal of Pharmaceutical Research. 12(2020) 1974–1978.

2. **Davydov V., Vakorina D., Provodin D., Ryabogina N., Stepanenkov G.,** New Method for State Express Control of Unstable Hydrocarbon Media and Its Mixtures, Energies, 16 (6) (2023) 2529.

3. **Smirnov K.J., Glinushkin A.P.,** Long–range night vision camera based on SWIR photocathode, Journal of Physics: Conference Series. 1695(1) (2020) 012090.

4. **Smirnov K.J., Tushavin G.V., Glagolev S.F.,** Temperature investigations of inp/ingaas based photocathodes," Proceedings of the 2018 IEEE International Conference on Electrical Engineering and Photonics, (EExPolytech–2018), vol. 8564416 (2018) 209–211.

5. **Yakusheva M.A., Davydov R.V., Isakova D.D.,** Features of signal absorption fronts of laser radiation in rapid diagnosis of human health, Proceedings of 8th International Conference on Information Technology and Nanotechnology (2022) 1–5.

6. **Davydov V. V., Dudkin V. I., E.N. Velichko E. N., Karseev A.Yu.,** Fiber-optic system for simulating accidents in the cooling circuits of a nuclear power plant, Journal of Optical Technology (A Translation of Opticheskii Zhurnal). 82(3) (2015) 132–135.

7. **Davydov V.V., Kruzhalov S.V., Grebenikova N.M., Smirnov K.Y.,** Method for Determining Defects on the Inner Walls of Tubing from the Velocity Distribution of the Flowing Fluid, Measurement Techniques. 61(4) (2018) 365–372.

8. **Davydov V., Porfir'eva E., Davydov R.,** Nondestructive Method for Testing Elasticity of Walls of Human Veins and Arteries, Russian Journal of Nondestructive Testing. 58(9) (2022) 847–857.

9. **Davydov R., Zaitceva A., Davydov V., Isakova D., Mazing M.,** New Methodology of Human Health Express Diagnostics Based on Pulse Wave Measurements and Occlusion Test, Journal of Personalized Medicine. 13(3) (2023) 443.

10. **Grevtseva A.S., Smirnov K.J., Greshnevikov K.V., Davydov V.V., Rud V.Yu., Glinushkin A.P.,** Method of assessment the degree of reliability of the pulse wave image in the rapid diagnosis of the human condition, Journal of Physics: Conference Series. 1368(2) (2019) 022072.

11. **Feng-Lei H., Ishikawa J., Yoon T. H., Ma L-S., Ye J., Hall J.,** Portable I2-stabilized Nd:YAG laser for wavelength standards at 532 nm and 1064 nm, Recent Developments in Optical Gauge Block Metrology. 1 (1998) 2–10.

12. **Feng-Lei H., Ishikawa J., Yoda J., Ye J., Ma L-S., John L.,** Portable I2-stabilized Nd:YAG laser for wavelength standards at 532 nm and 1064 nm, IEEE Transaction of instrumentation and measurement. 48(2) (1999) 532–536.

13. **Gaizerano G., Bava E., Bisi M., Bertinetto F., Svelto C.,** Frequency stabilization of frequency-doubled Nd:YAG lasers at 532 nm by frequency modulation spectroscopy technique, IEEE Transaction of instrumentation and measurement. 48(2) (1999) 540–543.

14. **Okhapkin M.V., Skvortsov M.N., Belkin A.M., Kvashnin N.L., Bagaev S.N.,** Tunable single-frequency diode-pumped Nd:YAG ring laser at 1064/532 nm for optical frequency standard applications, Optics communications. 203(2002) 359–362.

15. **Bitou Y., Sasaki K., Iwasaki S., Hong F-L.,** Compact I2-stabilized frequency doubled Nd:YAG laser for long gauge block interferometer, Japanese Journal of Applied Physics. 42(2) (2003) 2867–2871.

THE AUTHORS

NAUMOVA Victoria V.
vika_025898@mail.ru
ORCID: 0000-0002-6577-1223

ORLOV Oleg A.
oorl@mail.ru

Received 24.07.2023. Approved after reviewing 17.08.2023. Accepted 02.09.2023.