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DIODE LASER FREQUENCY STANDARD FOR LASER INTERFEROMETRY

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Abstract: Diode lasers are becoming increasingly important in length metrology. We demonstrate construction of a simple single-frequency diode laser 632,8 nm, used as a frequency standard in the laser interferometers. We present two different systems applied for frequency stabilization of diode laser . For diode laser used as the secondary standard, the system stabilizes diode temperature, the frequency stability of the laser reaches value 1 part in 10^6. For diode laser used as the primary standard is developed stabilization system using narrow absorption in iodine , the frequency stability of constructed diode laser reaches value 1 part in 10^{10} .

Keywords: diode laser, frequency stabilization, laser standard

1. INTRODUCTION

Laser interferometers are intended for high – precision measurement of distance and displacements. The wavelength of laser radiation is used as an initial scale or length unit.

Secondary standards, the form of internal – mirror frequency stabilized He-Ne 632.8 nm lasers are routinely used to perform high – precision length measurements [1]. These lasers have a frequency uncertainty of around 1 part in 10^8, which allows for measurements of end standards up to around 100 m in length with an overall accuracy of around 1 μm. The He-Ne laser has a frequency control servo system, which is based on different physical effects [2]. Therefore, its frequency stability and value of the wavelength can differ, and secondary standards must be regularly calibrated. The calibration of stabilized lasers is performed using heterodyne method [3], comparing radiation frequency with radiation of iodine stabilized He-Ne primary frequency standard [4]. The frequency uncertainty reaches level of around 1 part in 10^{12}.

Diode lasers are becoming an important tool for dimensional metrology. However, in many cases, a diode laser is not as well suited for length measurement as He-Ne laser. The He-Ne laser has better beam quality, wavelength stability and coherence. A number of characteristics distinguish diode lasers from He-Ne lasers. Laser diodes, which are small and rugged as well as efficient sources of coherent light that may be applied in laser interferometers. Often a simple diode laser is used as a high-tech replacement for a well-colimated flashlight in a measuring system . In this case the diode is indeed inexpensive and has a small size, high efficiency and low heat generation radiation source allowing the laser to be package within a small volume while not greatly heating its surroundings.

When a good wavelength standard is required , as in laser interferometers, unstabilized diode laser can't be used because of its wavelength with relative uncertainty of several percent. Though diode laser can run in a single longitudinal mode, they usually have a linewidth of a order of 50 MHz, for near infrared wavelengths and several hundred MHz for visible wavelengths. The wavelength of a diode laser is determined primarily by the bandgap of the semiconductor material though there is also dependence on diode temperature and current density. This way the frequency stability of visible diode lasers, used as frequency standard in laser interferometer, has to be improved by applying active system of laser frequency stabilization. The frequency of diode laser might be stabilized using two different systems. The frequency stability one part in 10^6 is achieved for secondary diode laser standard by stabilization of injection current and temperature of diode within 0.05°C [5] .The frequency stability of one part in 10^{10} might be achieved for primary 632,8 diode laser standard using frequency stabilization system against saturated absorption in iodine $^{127}I_2$. Laser diodes stabilized to narrow absorption features are among the "recommended radiations" recognized by international agreement, in accordance with the primary wavelength standards for realization of the unit of length [6].

2. DIODE LASER FREQUENCY STABILIZATION SYSTEM

The laser frequency stabilization systems presented in this paper were developed in order to improve single mode 632.8 nm diode laser frequency stability. Frequency stabilized diode lasers might be used in laser interferometers as a standard, instead of stabilized He-Ne laser, because the parameters of its radiation (wavelength, power and frequency stability) are comparable to 632.8 nm He-Ne standards.

2.1. The 632.8 nm single mode diode laser

Two commercially available diode laser were used in scientific investigation resulting in development of a simple laser frequency standard. HL6339G (HITACHI) chip emitting 5 mW of output power in single longitudinal mode (MQW structure) at 632.8 nm. The wavelength of laser is

nearly equal to He-Ne gas laser but the diode laser has low operating current of 55 mA and operating voltage of 2.3 V.
The CircuLaser PS028 emitts 15 mW of output power in multi longitudinal modes at 633 nm . The used diode laser is integrated with internal cylindrical microlenses which beam corrects and suppress side-mode. The primary function of the integrated microlens is to circularize the otherwise elliptical output beam of the laser. In addition, the microlens provides a weak optical feedback that is enough to force the laser to operate in a single longitudinal mode [7]. The wavelength of laser could be tuned , by changing the laser diode’s current or temperature, to 632,8 nm. Used diode had operating an current of 75 mA and operating voltage 2.7 V.
The frequency and spectral purity of both lasers were monitored using a wavemeter and an optical spectrum analyzer.
The diode lasers were placed in a specially constructed envelope in order to stabilize laser temperature and decrease the influence of external noise on beam parameters.

2.2. The laser diode temperature and current stabilization system

The laser diode requires a stable low-noise current supply and temperature stabilization for proper operation as secondary standard. We constructed a suitable electronic system for stabilization these diode parameters. Block diagram of developed system is presented in Fig.1.
In order to develop the secondary diode laser standard was required to stabilize its frequency and reach stability of one part in 10^6.

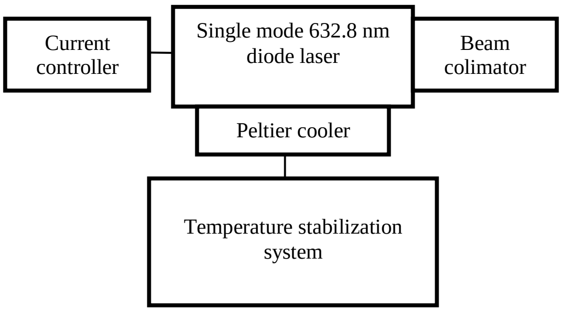

Fig. 1. The frequency stabilization system for secondary diode laser standard

Frequency stabilization system consists of a diode current controller and a diode junction temperature stabilization system. The laser driver ic-NZ (produced by icHaus) was used as diode laser current controller. The controller, presented in Fig.2., stabilized diode current with accuracy of 1 μA at 55 mA point. The current modulation is feasible in the range of 1 MHz.

For the diode temperature stabilization a system based on Peltier cooler, presented in Fig.3., was used. The whole assembly was placed on an aluminium plate. Peltier theromoelectric cooler element was used between this plate and a heatsink. A Pt100 temperature sensor was placed in a small hole drilled in aluminium plate close to diode laser The temperature of the junction was stabilized to 22 °C within 0.05 °C. For this temperature the diode laser wavelenght is adjusted to 632.8 nm.

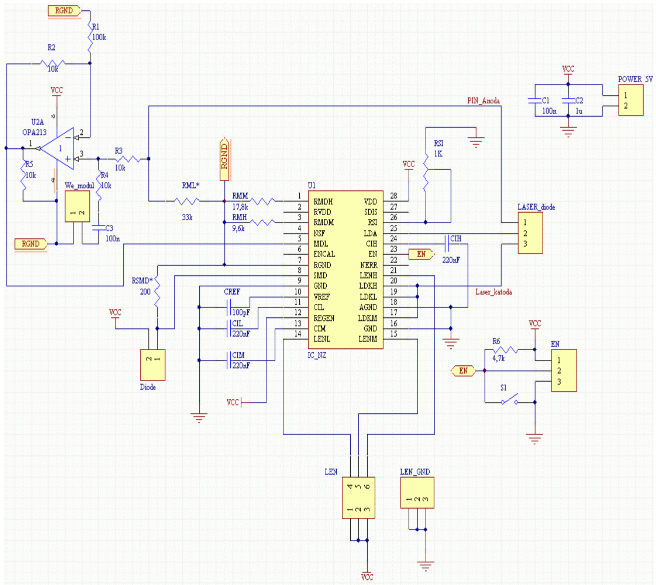

Fig. 2. The diode laser current controller.

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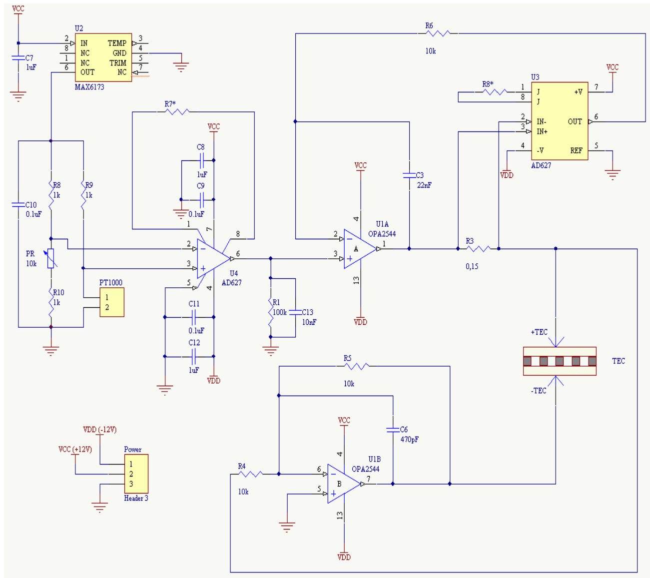

Fig. 3. The diode temperature stabilization system

2.3 Stabilization system against saturated absorption of iodine.

Using the 632.8 nm diode laser as a primary standard is possible, if its frequency stability is better than one part in 10^{10}. For applications where the means of passive stabilization do not provide sufficient frequency stability, the laser can be actively stabilized on a more stable reference [7]. A good frequency reference should be reproducible and thus virtually independent of external perturbations, such as temperature and pressure variations , or electric and magnetic fields. For that reasons, molecules with no permanent dipole moment, such as the iodine (I_2)

molecule, are the most suitable ones [8]. The 632.8 nm diode frequency stabilization system against saturated absorption of iodine, presented in Fig. 4., was developed to achive frequency stability suitable for primary frequency standard.

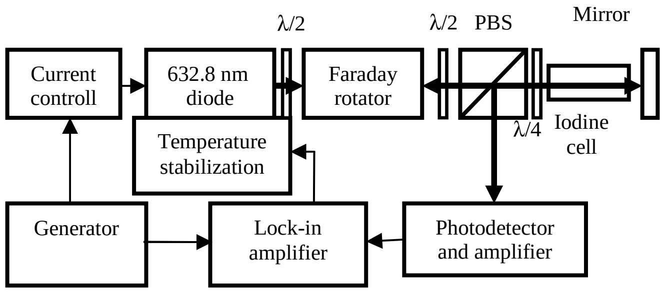

Fig.4. The frequency stabilization system against saturated absorption in iodine.

The output of the 632.8 nm single mode diode laser is directed as a pump beam for saturation spectroscopy in the iodine cell. A mirror reflects the pump beam back as a probe beam and a quarter-wave plate changes beam polarization so that a small part of the output beam goes to the photodetector, which is used for frequency locking. The standard third-harmonic technique [9] is used to detect the Doppler-free iodine spectrum and to lock the laser frequency to the hyperfine components. In the system 100 mm iodine cell was used . The saturating and probe beam powers were in the ratio 10:1 and focused into the iodine cell using a pair of lenses. The temperature of the iodine cold-finger were controlled by ±0.05 °C by a thermo-electric cooler, the cell walls were at room temperature. An example of the spectra obtained form this system is shown in Fig. 5., cold-finger temperature was 15 °C.

Fig. 5. Hyperfine spectrum of the 6-3, P(33) line of $^{127}I_2$.

3. MEASUREMENTS OF THE STABILIZED DIODE LASER 632,8 nm FREQUENCY STABILITY

In practice, the laser frequency stability can be determined using various techniques, most commonly heterodyne or homodyne beat frequency measurements [10] . We measured the frequency stability of the developed diode laser using beat spectrum observed between the examined laser and He-Ne iodine stabilized frequency standard. The He-Ne laser was operated in accordance with the recommendations of the Comite International des Poids et Measure(CIMP), absolute frequency was known to 12 kHz (standard uncertainty). The block diagram of the used measurement system is presented in Fig. 6. The system consists of the four blocks:

- standard frequency of the iodine stabilized He-Ne 633nm laser
- optoelectronic unit to select and amplify the frequency difference signal
- microprocessor system to measure the frequency difference and calculate the Allan standard deviation
- computer to collect and record data

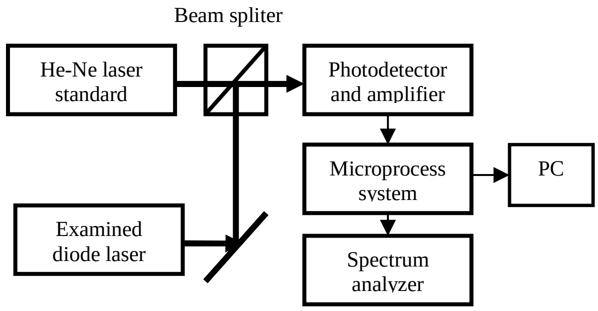

Fig.5. The relative frequency stability measurement system

The stabilized diode laser 632,8 nm relative frequency stability was characterized by recording the Allan standard deviation [11] of the two lasers. In the case where one laser is significantly noiser than other (the diode laser is noiser than He-Ne laser) the combined Allan standard deviation is dominated by the noisy laser and can be taken as a true representation of that laser's performance.

The frequency stability was measured for the both developed frequency stabilized diode lasers 632,8 nm. The Allan standard deviation was measured for sampling time from 1 ms to 100 s.
The measured frequency stability of the diode laser with stabilized current and temperature was one part in 10^6, which corresponds to a 100 MHz linewidth.
The measured frequency stability of the diode laser stabilized against saturated absorption in iodine reached one part in 10^{10}, which corresponds to a 10 kHz linewidth.

4. CONCLUSION

We have presented details of the construction and parameters measurements of the simple and compact frequency stabilized 632,8 nm diode laser .

The frequency stabilized 632.8 nm diode laser might be used in laser interferometers as a secondary or primary standard. The frequency stability for secondary diode standard is one part in 10^6,which allows for using it for measurement of a distance up to 1 m with resolution of 1 μm. To extend measured distance, stabilization of 632.8 nm diode laser against saturated absorption in iodine is required. The developed 632,8 nm diode laser stabilized against saturated absorption in iodine has relative frequency stability one part in 10^8-10^{10} which allows to extend the range of distance measurements.

The frequency stabilized 632.8 nm diode laser can be used as a primary standard for laser interferometer wavelength calibration but this requires improvement of its frequency stability by optimizing the parameters of stabilization system.

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