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Stabilized semiconductor laser source for high-resolution interferometry

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Abstract
We have assembled an experimental iodine stabilized Distributed Bragg Reflector (DBR) diode based laser system lasing at a wavelength that is in a close proximity to the wavelength of a stabilized He-Ne lasers traditionally used for metrological applications (λ=632.9 nm in vacuum). The aim was to verify whether such a system could be used as an alternative to the He-Ne laser while yielding wider optical frequency tuning range, higher output power and high frequency modulation capability. We have measured the basic characteristics of the laser source and then we have compared the performance of the laser system with that of a traditional frequency stabilized He-Ne laser with a series of experimental arrangements similar to those usually found in laser interferometry and displacement metrology applications. The results indicate that DBR diode laser system provides a good laser source for applications in dimensional (nano)metrology since it provides more output power and advanced tunability options than stabilized He-Ne lasers while maintaining fundamental requirements such as the frequency stability, coherence length and also a defined traceability.

Diode laser, optical metrology, laser interferometry, iodine stabilization, DBR

1. Background

He-Ne lasers working at 633 nm wavelength are popular sources of laser radiation for length metrology. They gained their popularity due to narrow spectral emission line (down to several kHz), superb Gaussian beam profile, a stable operation of the output optical power and good visibility that allows for precise setup adjustment. On the other hand, they feature only a small tuning range of their optical frequency and the small output power also limits the laser beam delivery by a single He-Ne laser.

Recent progress in laser diode manufacturing enabled the production of Distributed Bragg Reflector (DBR) laser diodes lasing at 633 nm. This opens the possibility for alternative laser systems for metrology that feature a comparable performance in the terms of the spectral linewidth, the frequency stability and noise figures and bring the additional benefits such as optical frequency tunability, higher output power and operational reliability.

We present an experimental verification of the performance of a laser system based on a DBR laser diode lasing at 633 nm that is frequency stabilized onto a molecular iodine transition. We have assembled the setup which comprises the laser, beam shaping and collimation and fibre-coupling optics, an iodine cell and related electronics. We have also assembled the experimental test-beds incorporating several interferometric setups that were used to measure key characteristics of the DBR diode laser: stability and noise of the measured displacement. The particular properties are experimentally compared to those of a traditional He-Ne laser in order to assess the usability of the DBR diode laser in typical applications in the field of length metrology.

2. Methods

2.1. Laser setup

The laser setup (see Figure 1.) consists of the laser head (LH) that houses the laser diode (LD) with integrated thermal control elements (TH; a thermistor and a Peltier cell). The laser beam is expanded (BE), passed through a Faraday isolator (OFI), coupled (C1) into a PM optical fibre and split (FS1) between the laser output and the stabilization part, where it is split again (FS2). Part of the light passes through the iodine-filled glass cell (I2 CELL) and is sensed with a photodiode (PD2) and the other part is monitored directly (C2 + PD1).

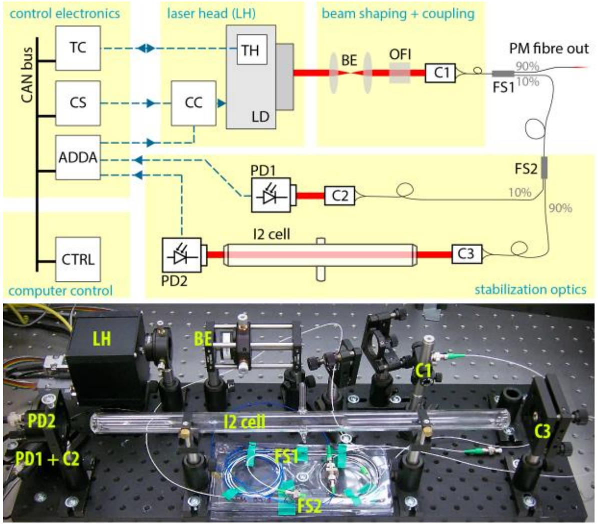

Figure 1. Overview of the laser system setup and a photo.

The dedicated control electronics comprises a temperature controller (TC) that controls the diode chip operation temperature, an ultra-low noise power supply (CS) for the current controller (CC) that drives the diode injection current and an analogue control module (ADDA) that samples the signals from the photodiodes and drives the CC [2]. The entire system is controlled by a PC software (CTRL).

2.2. Frequency stabilization

The laser system utilizes the absorption lines of molecular iodine as an absolute frequency reference [3,4]. The traditional linear spectroscopy technique is used in conjunction with the first harmonic detection technique. We employ this combination for sake of robustness and stability of the frequency locking. Unlike the field of optical frequency standards, where the ultimate and absolute frequency precision and stability is required, in the field of the dimensional metrology the reliability of the frequency stabilization is typically significantly more crucial.

2.3. Interferometric testbed

The interferometric testbed setup is a vital part of instrumentation that allows for a comparison of the newly developed stabilized DBR diode laser and a traditional He-Ne laser working at 633 nm wavelength. The interferometric measurements have been performed using the NPL Plane Mirror Differential Optical Interferometer [5] and electronics developed at NPL. The optical arrangement is differential, based on Jamin beamsplitter with dielectric coatings to achieve the phase shift between the two beams.

3. Experimentation

We have carried out several sets of measurements in order to verify the fundamental parameters of the laser system as well as its feasibility for use in dimensional nanometrology. In the majority of experiments we have compared the performance of the diode-based laser setup to that of a traditional He-Ne laser in order to obtain a direct comparison.

The upper plot in Figure 2. shows the observed one-sigma displacement error for He-Ne laser The standard deviation hovers around 10 pm throughout the measurement range. The lower chart shows the same measurements made using the DBR diode laser. Here the stability is getting worse towards the far end of translation range (as indicated by the dashed line). The non-stability increases approximately by 1.05 pm per 1 mm (in terms of standard deviation increase) of measurement mirror displacement. We attribute this increase to the combination of the amplitude and frequency noise of the laser source (LD).

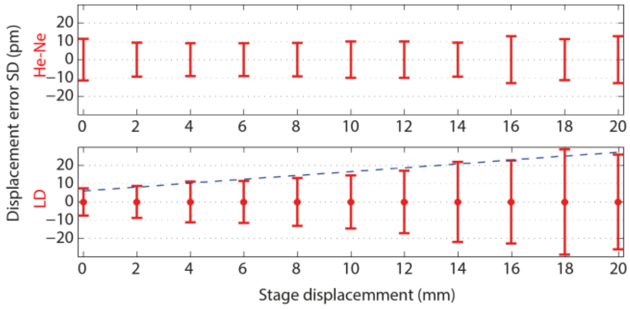

Figure 2. Displacement measurement stability σ with a reference He-Ne laser (top) and the DBR diode laser (bottom) over *T* = 600 seconds with the bandwidth of 3 Hz - 15 kHz. Dashed line indicates the contribution of laser-source induced noise to displacement which grows with increased optical path difference.

Figure 3 shows the noise spectra, expressed in the terms of power spectral density, observed within the measurement. It has shown that the most significant contributions to the noise are common for both lasers.

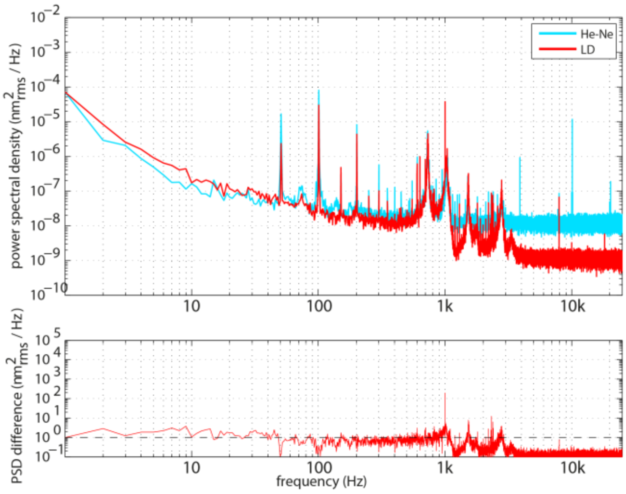

Figure 3. Noise spectra: DBR diode laser v. He-Ne.

3. Conclusion

We have assembled an experimental laser system, based on a narrow-linewidth DBR laser diode lasing at the wavelength of 633 nanometres and demonstrated that it is a feasible alternative to traditional frequency stabilized He-Ne lasers in nanometrology, especially where high output power and also the wide-band mode-hop free wavelength tuning options can bring significant benefits, i.e. in multi-axis displacement metrology [6] or absolute homodyne interferometry [7].

We expect that our future effort will lead towards these challenges in which several issues such as improvement of coupling efficiency (probably with a new version of the LD), intensity stability incorporation or achieving a more compact form factor need to be addressed.

Acknowledgements

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