Tuning of the laser diode

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ABSTRACT

Realisation of the optical frequency laser standards is the basis of the length metrology. In accordance with the *mise en pratique* of the definition of the metre there is possible to realise the length unit by means of one of twelve recommended radiations listed in the Recommendation 1 (CI –1997) issued by the CIPM. Technical progress in the laser diode development enables to apply these elements as the length standards. Our article is devoted to the thermoelectric tuning of the laser diode frequency.

Keywords: laser diode, thermal tuning, Littrow resonator, Littman-Metcalf resonator, frequency stabilisation

1. INTRODUCTION

It is known that at the present time in most of metrological institutes a length unit-metre is realised by the radiation of the HeNe laser at the wavelength 633 nm, which optical frequency 473,6 THz is stabilised by the saturated absorption in the vapour of the iodine isotope $^{127}I_2$. According to the Recommendation 1 (CI-1997) issued by the CIPM (Comité International des Poids et Mesures) the unit of length can be realised also by the stabilised radiation of the single mode laser diodes [1], which are based on the semiconductor alloys GaAsP, InGaAs. By the variation of an atomic ratio of alloy components and impurity concentration there is possible to produce the laser diode which emits in requested spectral region. Therefore the laser diodes are replacing the gas lasers in many applications. As is described in literature [2] External Cavity Diode Lasers (ECDL) series 6200 New Focus, Inc. can be used as the newest standard wavelength 633 nm. Our working group tries to realise diode lasers stabilised at the wavelength 780 nm, resp. 778 nm, the second of which is included in the list of recommended radiations mentioned above.

2. SEPARATION OF A LASER DIODE MODES

Laser diodes just like other semiconductor emitting devices LEDs utilize the emission of light during the recombination of excited electrons of the conduction band and holes of the valence band of a semiconductor crystal. When a sufficient large numbers of electrical carriers recombine, an energy in the form of photons (light) is released. This process in the LED is called a spontaneous emission producing photons in a broad range of wavelengths. In a laser diode LD the concentration of recombining carriers is very high and the photons are mostly generated by stimulated emission. In this process, a photon with a certain energy, direction of propagation and phase causes the creation of a second photon of totally identical properties.

Both ends of the laser chip are smooth facets acting as mirrors, forming a Fabry-Perot resonant cavity. This cavity supports several standing waves of different wavelengths, referred as the longitudinal laser modes. The fundamental difference between LED and LD is that LD emits very intensive coherent light at few (one or more) discrete and narrow frequency bands, i.e. resonant frequency-longitudinal modes (Fig.1), and LED emits a broad band of incoherent light over the relatively wide spectral range. The width of one longitudinal mode of LD is about 0,001 nm.

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The single-mode emission can be achieved by employing the frequency selecting element, such as a grating, in order to pick up the desired wavelength from the resonator modes. One way of generating of such a narrow spectral bandwidth is to place the grating directly inside the resonator. This solution is known as the distributed feedback laser DFB (Fig.2a).

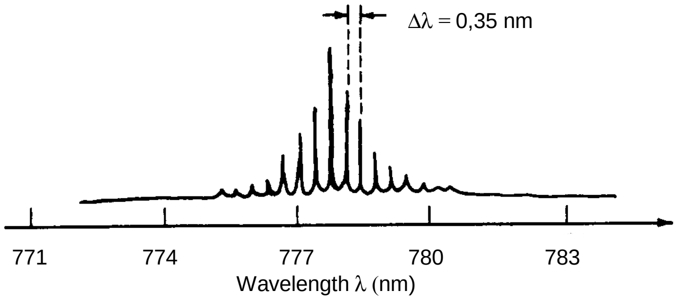

Fig.1 Spectral distribution of GaAsP laser

Other construction is to place the grating parallel to the junction plane. Such a single-mode laser is known as the distributed Bragg reflector DBR (Fig.2b). In both cases the supplied pump energy is comprised in only one mode. The emitted wavelength is fixed by the separation of the grating lines and the frequency can be altered both thermally or by the diode current. The single-mode emission can be also achieved by the external resonator with grating, the so-called external cavity diode laser ECDL. Nowadays, two basic arrangements of external resonators are known: Littrow's [3] and that of

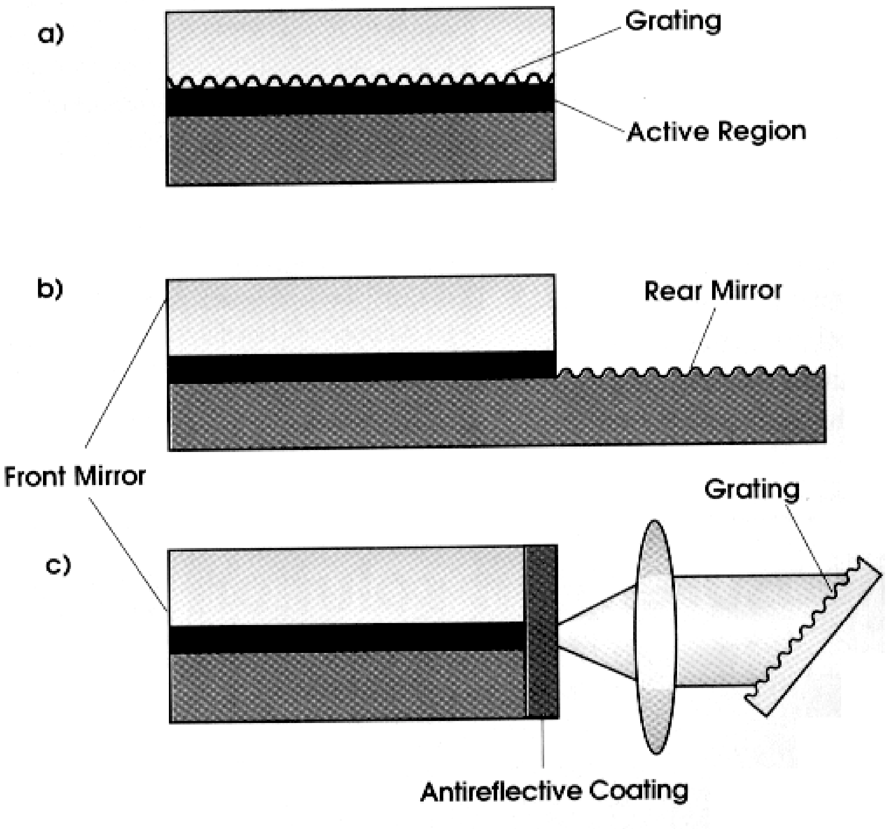

Fig.2 Resonators for single-mode lasers

Littman-Metcalf's [4]. In the Littrow`s construction a slope change of an external grating to the output laser beam (Fig.2c) tunes the single-mode wavelength. In the Littman-Metcalf's resonator the grating has a fixed slope to the output laser beam. The separation of desired mode is ensured by the inclination of the tuning mirror (Fig.3) [5].

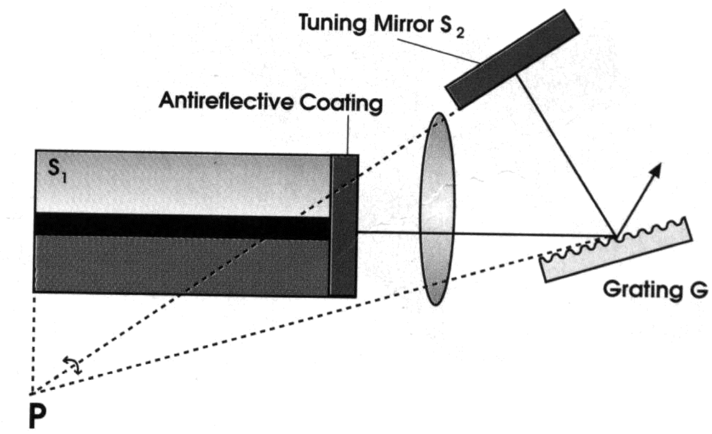

Fig.3 Littman resonator. Turning the mirror S_2 around a point P, the angle between S_2 and G changes , and wavelength is tuned.

3. THERMOELECTRIC TUNING OF THE LASER DIODE WAVELENGTH

To obtain a single mode spectrum, one must suppress the side modes. At low operating currents I_{op} the laser diode emits a multimode spectrum. The side modes are progressively suppressed as the I_{op} increases to some maximum value (Fig.4). The optical spectrum of laser diodes becomes narrower with increasing of the power levels. The corresponding shift of the central wavelength to the higher output optical power is due to internal heating of the chip by the transient current $I_{op.}$

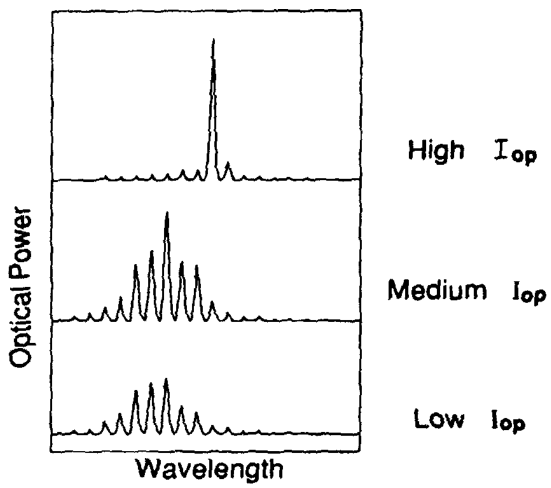

Fig.4 Optical spectra at various operating currents

That causes a change of a band-gap (energy level) in the crystal. If ΔE_g is width of the forbidden band, the dependence of ΔE_g on the absolute temperature T is given by the expression [6]:

$$\Delta E_g = \Delta E_{go}(1-\alpha T) \qquad (1)$$

where ΔE_g is the width of forbidden band at T = 0 K, α is a thermal coefficient ($\alpha > 1.10^{-4}$ K^{-1}) characteristic for the given semiconductive material.

The dependence of emitted wavelength λ on the ΔE_g is given by the following equation:

$$\lambda = \frac{hc}{\Delta E_g} = \frac{1240{,}6}{\Delta E_g} \tag{2}$$

where ΔE_g is in eV and λ in nm.

Increasing of the laser chip temperature causes the narrowing of the energy band gap, while the optical spectrum shifts towards the longer wavelengths. Simultaneously, the laser diode dimension L (cca. 250 μm) of the laser cavity increases as the consequence of thermal extension. It follows:

$$\lambda = \frac{2nL}{q} \quad \text{and} \quad \Delta\lambda = \frac{\lambda^2}{2n_g L} \tag{3}$$

where q is the mode number (see Fig.1), n is the refractive index at the central wavelength λ, n_g is the group index of refraction (mean value n for emitted expressive modes, usually $n_g \geq n$).

The typical wavelength thermal shift is about 0,25nm/°C– 0,3nm/°C for laser diodes in the visible region. In such a way, i.e. by the thermal tuning, there is possible to achieve the requested wavelength in a certain range. The typical tuning curves for some lasers are shown in the Fig.5. The two curves represent the maximum and minimum power over a tuning range of about 0.1 nm (adopted from [2]).

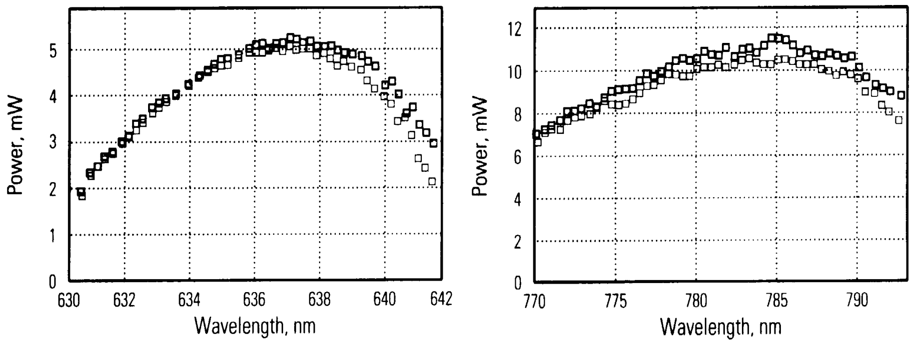

Fig.5 Typical tuning curve of a Model 6304 New Focus, Inc. Typical tuning curve of a Model 6312 New Focus, Inc.

For most of laser diodes, the threshold current (defined as the point where the emission of a higher power coherent light starts, i.e. operates as the laser) increases exponentially with the temperature increase. In accordance with this fact, a tuning of laser is possible only in a narrow spectral band. The minimum tuning range is typically 10 nm for lasers $\lambda \in 632-637\,\text{nm}$, e.g. diode lasers No. 6005, No.6210, No.6211, No.6304, No.6305 (New Focus) and 15 nm for lasers $\lambda = 745-785\,\text{nm}$, e.g. lasers No.6013, No.6224, No.6225, No.6312, No.6313. It is necessary to note that the thermal tuning is accompanied with longitudinal mode hopping (see [8]). For the multimode laser diodes the mode hops are not visible due to the large number of modes and the relatively small energy associated with each mode. For the singlemode laser diode the mode hops manifest very intense (Fig.6).

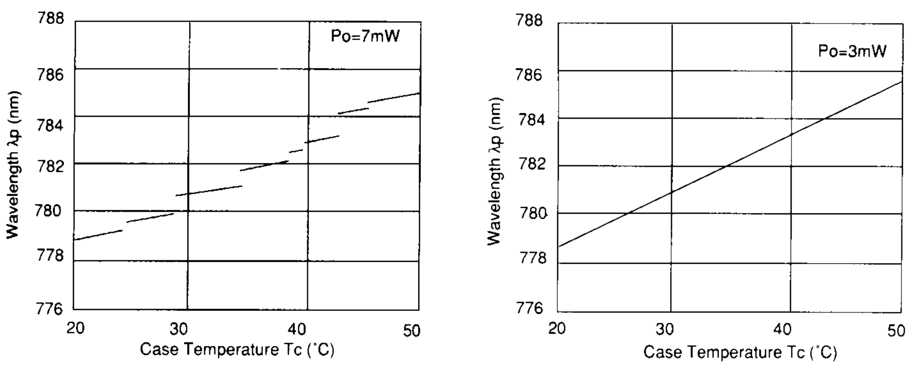

Fig.6 Typical mode hops for the singlemode laser diode Sharp LT027 Typical linear dependence of wavelength vs. temperature for a multimode diode LT023

To avoid these instabilities (discrete points), a laser diode shall be temperature stabilized using a thermoelectric cooler (Peltier element).
The standard laboratory type power supply should not be used to operate laser diodes. For the operation of the laser diodes only power supplies with slow-start circuits (i.e. with current transient suppression and a current limit exceeding the laser diode's maximum current limit) can be used. Laser diode drivers usually serve in two modes of operation, constant current or constant power, with adjustable current limit control. The principal scheme of such driver is shown in the Fig.7.

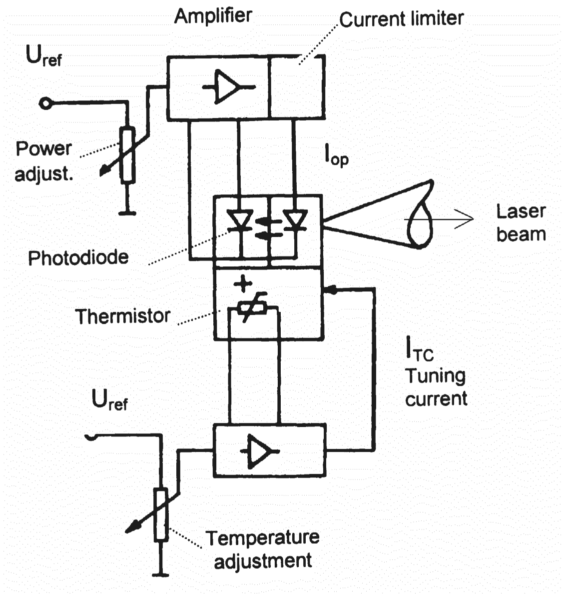

Fig.7 Block diagram of a typical laser diode power control system with optical feedback and thermoelectric tuning

4. FINAL STABILIZATION OF A LASER DIODE FREQUENCY

However, in order to achieve the high frequency stability and reproducibility that all the radiations used for the realisation of the length unit must have, the frequency of a diode laser requires to be somehow locked to the value relatively independent on the various parameters. The most general way of locking the frequency is to use a saturated absorption of laser radiation, passing through the absorbing medium. Some chemical elements, such as an iodine molecule or atomic rubidium have absorption lines possessing a hyperfine structure with a very narrow peaks, which frequencies are well known and therefore may be used for the frequency stabilisation of the laser radiation.
In the case of rubidium, there may be chosen too ways :

1. stabilisation at the one-photon transition (5S – 5P) 384,2 THz (780 nm) in ^{87}Rb
2. stabilisation at the two-photon transition (5S – 5D) 385 THz (778 nm) in ^{85}Rb.

1. The stabilisation at the one-photon transition is well known and is similar to the commonly used frequency stabilisation in the iodine vapour. In this case only particles (atoms Rb or molecules I_2) with the given value of longitudinal velocity interact with the laser beam. When the laser diode frequency is tuned and the value of the absorbing transition is achieved, so that only atoms with zero longitudinal velocity interact, the phenomenon called saturated absorption takes place and the dopplerless peaks occur at the absorbing power curve. This is because of the absorbing medium is inside the resonator cavity, two opposite beams are passing through it and the same atoms interact with both beams. In this case, the probability of the quantum transition is relatively high, but the number of interacting atoms is small.
2. Two-photon transition is the quantum transition between two levels of ^{85}Rb of corresponding frequency 770 THz (389 nm). It corresponds to the simultaneous absorption of two photons (each of

them 385 THz). In the case, that these two photons have opposite directions and the frequency of laser diode is tuned to the half of the transition frequency, the sum of energies of both photons is equal for almost all absorbing particles inside both opposite laser beams. The Doppler shift of two opposite photons is in the sum mutually compensated. The frequency of virtual transition 385 THz (778 nm) is relatively close to the frequency of one-photon transition 384,2 THz (780 nm) and thus the probability of the absorption is slightly different from zero. This small probability is fully compensated by the number of interacting atoms, that is not restricted only to those having a longitudinal velocity equal to zero, i.e. moving perpendicularly to the optical axis. When the frequency of the laser diode is not tuned to the transition frequency, no atom will interact with the beam.

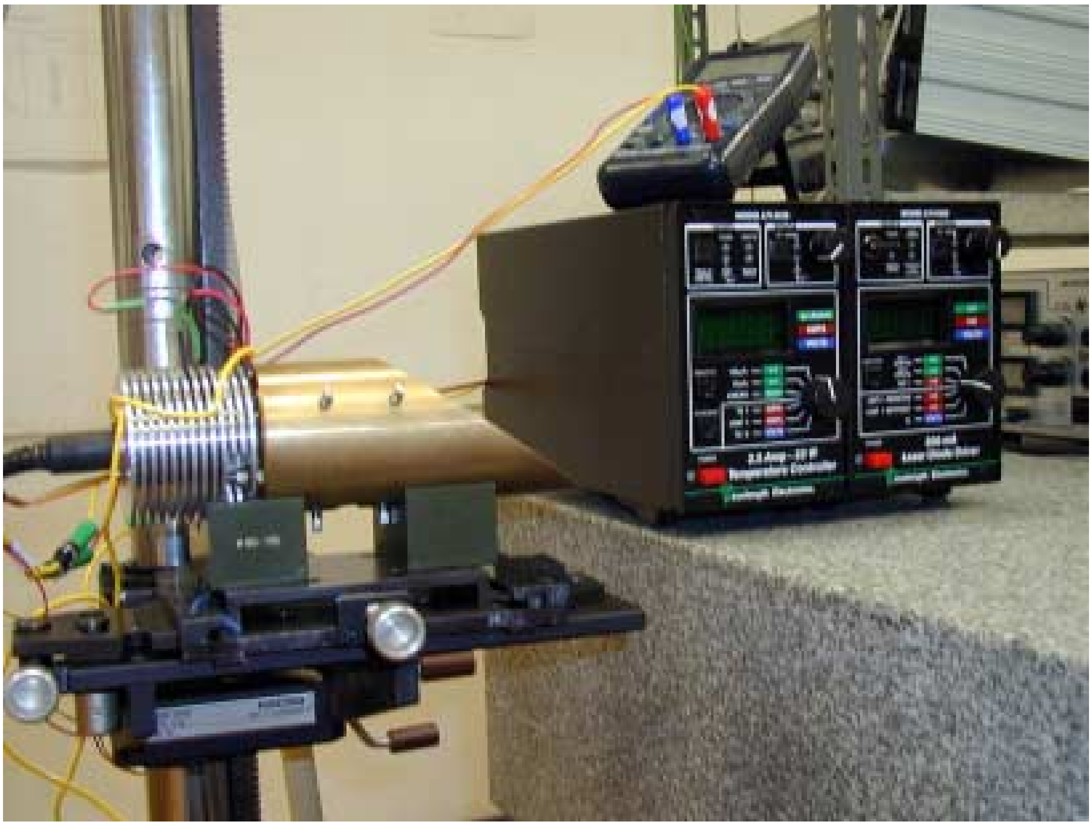

Fig.8 The experimental arrangement of the diode laser with the laser driver and thermoelectric controller built at Slovak institute of metrology in 2000

In the case of using the two-photon transition, the absorbing peak is very narrow and the absorbing curve is not sloping, i.e. no third harmonics technique is necessary for the frequency stabilisation.

5. CONCLUSION

Laser diodes are much smaller, require less voltage, less power supply and due to much higher density of the active medium (comparing to gas lasers) the higher output power can be achieved. They are highly reliable and their lifetime exceeds that of gas lasers. Therefore the laser diodes have found application also in the field of length metrology. Since the stabilisation of frequency for the length metrology purposes is realised only at determined frequencies, corresponding to quantum transitions in chosen atoms, ions or molecules (^{1}H, ^{40}Ca, $^{88}Sr^{+}$, ^{85}Rb, ^{87}Rb, $^{127}I_2$, $^{129}I_2$, CH_4, OsO_4), the laser diode must be tuned to these frequency values. In our article we have described the ECDL technique of the laser mode separation and the method of thermoelectric tuning of the laser diode frequency. Last chapter is devoted to the physical principle of the precise stabilisation of the laser diode frequency. We have focussed on the brief and simplified description of the frequency stabilisation at both one and two photon transition in RBA vapour with frequencies 384,2 Hz and 385 Hz respectively. These research problems are now in the foreground of the length laboratory of Slovak institute of metrology.

This article summarises the new knowledges in the development of the metrological lasers which were described in periodicals [2],[3],[5] and [8].

6. ACKNOWLEDGEMENT

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7. REFERENCES

[1] NAVRATIL, V.: 9th meeting of the Consultative Committee for Metre Definition-CCDM and the equivalence of the national standards. *Metrology and testing* (In Slovak), **3**, No.2, pp.18-20. 1998
[2] NEW FOCUS, Inc.: Tuneable diode lasers for every application. *Catalogue*, Vol.**8**, , pp.14-25, Santa Clara US, 1997/98
[3] KAENDERS, W. Littrow diode lasers catch the attention of industry. Euro Photonics, Dec./ January 1998, pp.30-31
[4] BARTL, J.- NAVRATIL, V.- FIRA, R.: New trends in the realisation of the unit of the quantity of length. *Metrology and testing* (In Slovak), **3**, No.2, pp.7-10, 1998
[5] LUTZ, J.: Antireflection coatings boost laser diodes` range. *Euro Photonics*, pp.42-43, April/ May 1998
[6] BARTL, J.- BARTOK, K.: Increasing of luminous efficiency of LED diodes at the cryogenic temperature. *Proc. Photonics`92*. pp.242-246, Rozvid 1992, Praha
[7] SALEH, B.E.A.- TEICH, M.C.: Fundamentals of photonics. Vol. **3**, pp.480-722, Matfyzpress (In Czech), Praha, 1995,
[8] SEASTAR OPTICS, Inc: Optical Devices & Laser Diode Instrumentation. *Product Catalog.* 1993, p.10