Romanian Reports in Physics, Vol. 59, No. 1, P. 87–92, 2007

LASER DIODE INTENSITY NOISE INDUCED BY MODE HOPPING

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(Received February 17, 2006)

Abstract. Despite their advantages, laser diodes exhibit some limitations: multi-mode operation, mode hops and broad linewidth. Mode hopping is directly correlated to the noise in the total optical intensity and it can be easily revealed using a PIN photodiode. There are combinations of laser case temperature and injection current that lead to mode hopping and others for which the laser is stable. Recording such noise characteristics of laser diode has implications for controlling and circumventing mode hopping effects.

Key words: single mode laser diode, mode hopping, intensity noise.

1. INTRODUCTION

Since its invention in 1961, diode lasers have been the most used type of semiconductor lasers. It has found widespread applications in numerous fields ranging from basic research to industrial and domestic photonic systems due to its well known features: mass production, low size, facility in control and operation. However first laser diodes [1], consisting of a simple p-n semiconductor junction, were far away from practical use because they needed high injected currents and cryogenic operating temperatures. Occurrence of metal organic chemical vapor deposition and molecular beam epitaxy led to the development in the early 1990s of more complex semiconductor devices, including single mode laser diodes. Moreover, progresses in engineering of new diode laser materials, covering emission wavelengths from the infrared to the violet, leads to replacement of many bulk lasers with compact, low cost and efficient laser diodes.

Despite of enumerated advantages, the solitary laser diodes have some limitations regarding geometrical and spectral characteristics of the emitted radiation: high divergence and astigmatism, relatively large emitted linewidth and wavelength instabilities due to mode hops. While the geometry of the beam can be easily corrected by means of aspheric lenses or more complicated optical systems, the spectral characteristics make laser diodes not to fulfill the precision required in some applications, such as high resolution spectroscopy. The parameters directly affecting the mode hops are the laser case temperature and injection current.

This paper will present spectral characteristics of laser diodes and how to control laser diode parameters in order to circumvent the mode hops induced noise.

2. LASER DIODES SPECTRAL EMISSION

2.1. SINGLE-MODE LASER DIODE SPECTRUM

Most commercial available laser diodes present in the emitted light spectrum a single transversal mode and more longitudinal modes enveloped by laser's active region gain curve. The strong dependence of the gain profile on the injected laser diode current will determine the number and amplitude of the longitudinal modes. Fig. 1 shows a typical single-mode diode laser spectral profile for two different values of operating current [2]. For small operation currents, near threshold, the shape of the gain curve will favor many equally spaced oscillation modes to coexist simultaneous in the emitted light spectrum (fig.1.a). By increasing the injected current to higher values, the gain curve will develop at an exponential rate and it will select only one lasing cavity mode (fig.1.b).

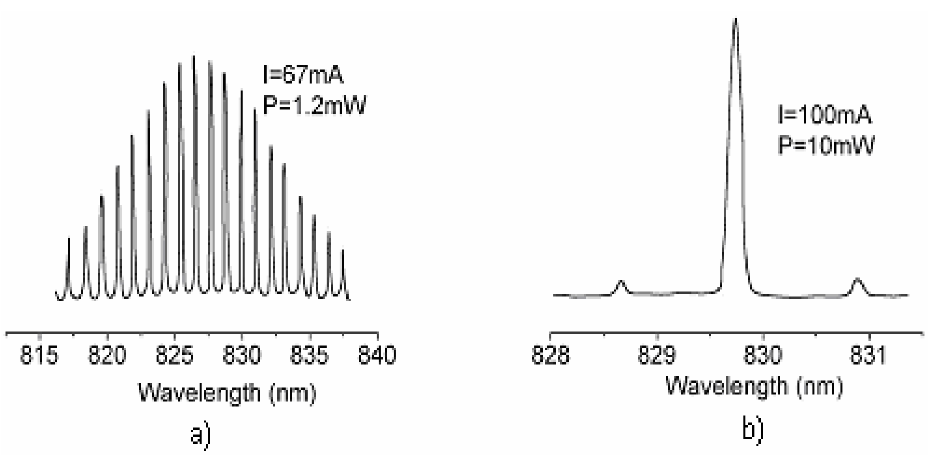

Fig.1 – Spectra of a 830 (nm) single mode laser diode for different operating currents. The oscillation modes are spaced typically at 0.35 (nm) [2].

In this case, the single mode emission of the laser diode is dominated by a strong lorentzian line, roughly 100 times stronger than any other spectral component, with a linewidth around 100MHz.

1.2. SINGLE MODE LASER DIODE MODE HOPS

A very important characteristic of laser diodes is tunability. Tuning can be achieved by changing the laser diode temperature or other external environment parameters [3] such as ambient pressure or the strength of an applied magnetic field. Temperature tuning is the most adequate to use because it is easy to implement electronically under conditions of high stability. By changing the laser diode temperature a coarse wavelength tuning is obtained. Fine tuning is accomplished by modifying the injected laser diode current, resulting in laser diode chip temperature changing by means of Joule heating. Fig. 2 presents the temperature tuning curve for a 780 nm, 5mW single mode laser diode, model HL7806G.

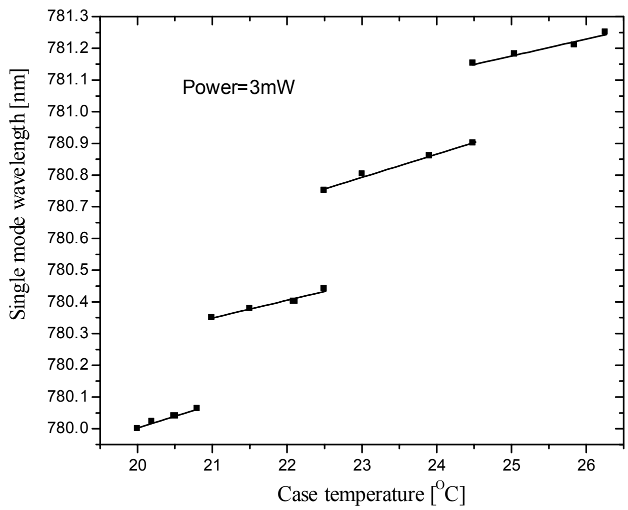

Fig.2 – Temperature dependence of single mode laser diode wavelength at constant emitted power. Continuous tuning range has a slope ~0.06 nmK^{-1} while the discrete jumps of the wavelength are around 0.3 nm.

In semiconductor laser diodes, both refractive index and bandgap temperature dependence imply cavity modes pattern and gain curve dependence on the same parameter. Increasing the temperature, the gain curve will shift to higher wavelengths at a higher rate than the cavity modes. Because of it, when a mode will not exhibit sufficient gain, the lasing wavelength will jump to another mode, where the gain is sufficient for lasing. The mode hopping explains the stair step aspect of the tuning characteristic presented in fig. 2. In AlGaAs laser diodes, the gain curve shifts to longer wavelengths faster than the cavity modes as the laser temperature is increased and so the mode hops take place to a higher wavelength. However, the experimental recorded tuning curves exhibit anomalous mode hops, in direction of shorter wavelengths. It is also possible to observe mode hops over several cavity modes. These kind of mode hops are related with the defects in the structure of the laser diode chip [4].

Thus, although some conclusions over tuning characteristics of laser diodes can be drawn, it is obvious that each laser diode has a unique tuning curve. One important conclusion is that the mode hops generate angstrom sized holes in the diode laser tuning curve. Even if one can move around these holes by judicious changing the temperature and injected current, there will still remain wavelength values unreachable for a given laser diode.

It is also important to note that the tuning characteristic will change in time, due to laser diode ageing.

3. MODES HOPPING INTENSITY NOISE

Under some circumstances, modes hopping appear in an erratic manner, with the laser radiation switching rapidly between wavelengths. During modes hopping the laser diode output optical intensity fluctuates slightly, resulting in a relative intensity noise.

In our experiments we recorded this kind of noise by monitoring the light emitted from a free running HL7806G laser diode using a simple electronic device, a PIN photodetector. It is important to note that, during the measurements, the temperature and the current of the laser diode were very tight controlled.

Fig. 3 presents two time series of the photodetector a. c. voltage recorded for different laser diode injection currents, but for the same case temperature (30^{O}C).

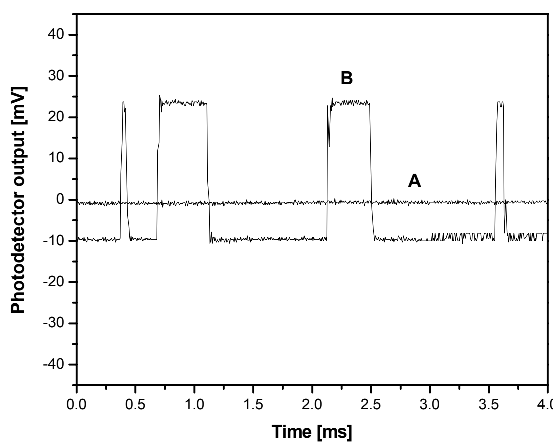

Fig.3 – Photodetector output voltage during modes hopping. Trace B show laser intensity switching between two intensities as the laser switch between the modes. The parameters used in measurements: I_{LD} = 56.8mA, P_{out} = 2.2mW, t = 30^{O}C for trace A and I_{LD} = 59mA, P_{out} = 2.6mW, t=30^{O}C for trace B. The oscilloscope was a.c. coupled.

The lower trace (A) presents an a.c. voltage slightly elevated over the background noise level. This curve corresponds to a stable single mode operation of the laser diode. In contrast, curve B represent the most vigorous mode hopping activity recorded for the tested laser diode during the measurements.

The two curves of fig.3 are plotted on the same time scale. In trace B the total intensity alternates between two distinct levels, spending substantial amounts of time in each level before switching to the other one. In contrast, trace A doesn't reveal any switching of laser diode intensity.

An overall mode hopping influence on the laser diode emitted light intensity can be obtained by scanning the entire range of injected current in the laser diode while maintaining a constant case temperature. Such a noise characteristic is presented in fig.4 and it was obtained by monitoring the output of the laser diode while sweeping the laser diode current with a 10 second linear ramp.

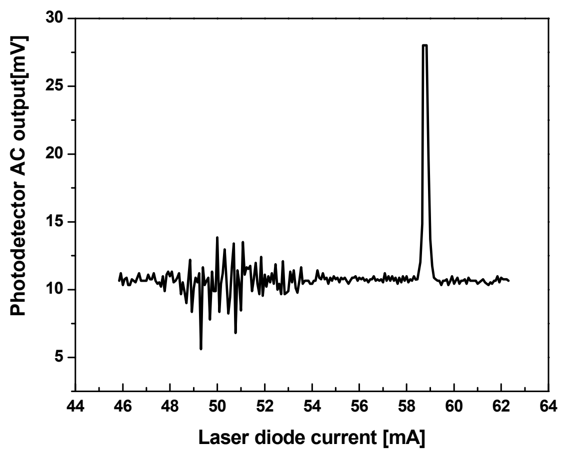

Fig.4 – Laser diode modes hopping intensity noise at constant temperature (30^{O}C).

The laser diode injected current value corresponding to the peak of the alternative photodetector signal recorded in fig.4 has the same value as the current used for recording the curve B in fig.3. This proves that the peak of the alternative signal stands for the maximum mode hopping activity of the laser diode. In fig. 4 is recorded also a region of fluctuations just after the laser diode's threshold current (46.9mA). This is tied to the fact that just over the threshold the laser diode exhibit mode hopping activity due to the presence of many modes with comparable lasing probability in the spectrum of the emitted light (fig.1.a).

Similar noise curves, recorded for different temperatures and superimposed on the same graph, can provide valuable informations for operating laser diodes in stable, mode hops free regions, by proper choosing the injected current and the temperature of the laser case.

4. CONCLUSIONS

Semiconductor lasers find a wide range of applications due to their variety of wavelengths, compact size, low price and ease of control. Even if the laser diode is single mode, the rapid switching of wavelength, known as mode hopping, causes undesirable intensity noise that can limit the performance of these lasers in some applications. The level of intensity noise is directly correlated to the occurrence of mode hopping. A simple, nonspectroscopic method for detecting mode hopping induced noise is presented. Mode hopping occurs for specific values of laser case temperature and injection current and can be circumvented by careful control of these parameters. These findings should prove useful whenever mode hopping is a potential problem.

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