The interference method for measuring small shift of the wavelength of laser radiation

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Abstract. We experimentally investigate a shift of the interference pattern in dependence from wavelength of coherent light beam propagating through the anisotropic crystal. This method allows us to measure the wavelength of coherent radiation with accurate to $10^{-2}$ nm.

1. Introduction

The simplest devices for light spectral investigation are prisms and diffraction gratings. But low optical resolution limits their practical applications in problems where more accurate measurements are needed. Higher optical resolution could be achieved with use of Fabry-Perot interferometer, which for instance allows observing of hyperfine structure of green line of mercury lamp [1]. The theoretical and experimental observations of the spatial mode coupling of mode-locked semiconductor lasers of Fabry-Perot were compared [2].

The most popular application of Fabry-Perot interferometer have found as laser resonator. It is well known that in interference experiments the position of interference fringes depends on optical path difference of interfering beams. Fabry-Perot interferometer enables observation of longitudinal modes of He-Ne laser. Measuring the shift of interference fringes it is possible to measure refractive index, object size, mechanical movement.

The semiconductor lasers have opened new prospects in the field of communications and now are getting more powerful and efficient and have found many applications in contemporary science and industry [3]. They are compact, easy integrated and their characteristics are continuously improved.

The output of a semiconductor laser spectrum depends strongly on the temperature and injection current of latter. Mode hopping occurs for specific values of temperature and injection current. This means that mode hopping is eliminated by careful control of these parameters. The stability map is a reliable method of determining the values of parameters resulting in stability [4].

Conoscopic patterns which are the result of interference of ordinary and extraordinary waves, when the plane of oscillations coincides with the external polarizer, are also known for studying anisotropic crystals.

Such method was also used to measure the spatial coherence through the polarization interferometer [5]. However, the above mentioned two methods require fixed wavelength (or frequency) of radiation. In the second case, immersion liquid and the second crystal are also required.

In this paper we propose interferometer based on anisotropic crystal which allows to measure radiation wavelength shift with accuracy $\sim 1$ Å by measuring interference fringe shift. Such high resolution is obtained by dispersion difference between interfering two beams with orthogonal polarizations. Particularly in calcite crystal the change of 40 nm wavelength leads to 0.002 change of index of refraction. With 1 nm change of wavelength in crystal with 2 cm length the optical path
difference changes as much as $\lambda/2$ which causes half stripe shifts of interference fringes. The change of shift with 1/10 part we can measure 1 Å wavelength shift. The same result could be obtained with the use of spectrophotometer with diffraction gratings which has 1000 grids on 1 mm. Experimental and theoretical study of this method was also carried out.

2. Experiment

Characteristics of 2 types of lasers are investigated in the following (our) work:

1. HLDPM-650-3 injection red laser (wavelength is 0.65µm, power is 3mWatt)
2. Neodymium laser with the semiconductor pumping (wavelength is 0.9µm) (second harmonic 0.53 µm)

The spectral measurements of these lasers were made by means of OSA spectral analyzer (high and low regimes from generation threshold, figure 1).

After passing through the light emitting diode, the beam gets the analyzer. In figure 1, the vertical axis is the output power. The accuracy of measurements of wavelength is about 0.01 - 0.2nm.

The above mentioned first type lasers almost are constantly and have multimode structure in the low regime below threshold, which width is 10 - 12nm and there are a few longitudinal and transversal modes in the high regime above threshold. Parallel to the current increase strengthening and mode hopping take place from one mode to the other (figure 1).
Separate mode width is 0.05 nm. The distance between modes (nearest modes or in general) is 0.1-1 nm (transversal and longitudinal modes). This distance has the following form

$$\Delta \lambda = \frac{\lambda^2}{2Ln},$$

where L is the thickness of the crystal, n is refractive index. In this experiment with L = 1 mm and n = 3.5, the spectrum is compressed above of threshold 200 times.

The results of detailed measurements, when we used uniaxial crystal placed between crossed polarizers, are presented in the following part of this study (Figure 2).

Figure 2. The experimental scheme for measuring the shift of spectral and interference lines
1. semiconductor laser, 2. polarization interferometer, 3, 7, 9. diaphragm, 4, 10. CCD cameras, 5, 11. screen, 6. lens, 8. MDR-2 diffraction spectrometer.

The shift of the wavelength of the semiconductor laser occurred when the pumping current or the temperature were changed. We used Iceland spar crystal cut parallel to the optical axis. The polarization of radiation forms 45° with this axis. A big difference of path is achieved while changing the difference between refractive indices of ordinary and extraordinary rays. It results in the shift of the interference lines (figure 3).

Subangstrom measurement accuracy is achieved in the case of 2 cm crystal. The accuracy of these measurements is verified by means of a diffraction spectrometer of MDR-2 series with 1200 lines/mm grating (approximately with the same resolution as for the case of polarization interferometer) and a CCD camera.

The shifts of modes are depicted in figure 4.
Output signal was detected by a digital camera and was analyzed using Lab View software. Knowing the dependence of the difference $\Delta n(\lambda)$ of refraction indices of ordinary and extraordinary rays, it is possible to define the difference in processes $\Delta x$ between two rays. The $\Delta x$ is equal to $\Delta n(\lambda) \cdot d$ and depends on direction of propagation of radiation. The distance of nearest maximum lines of the pattern corresponds to the wavelength ($\Delta x = \lambda$), figure 5.
Figure 5. The shift of interference lines depending on the changes of the wavelength of a) “red” and b) “green” lasers [7].
Temperature dependence of shift of semiconductor laser is shown in figure 6.

![Temperature dependence of shift of semiconductor laser](image)

Figure 6. The dependence of displacement of spectral lines on the temperature of “red” laser.

Particularly for 3 cm KDP crystal we get 1nm change of wavelength. If the minimum displacement of lines is 1/10, the change of wavelength is equal to 0.1nm. This accuracy may be achieved by means of a diffraction spectrometer with the 1000 line/mm grating.

3. Conclusion

The measurements involving spectrometer with diffraction grating and optical spectral analyzer (OSA) were measured for establishing the proposed method depending on pumping current and temperature. The accuracy of these measurements is 0.01 nm which corresponds to 1/10 part of the line displacement length. Thus, this method is effective for measuring even a very small displacement of the wavelength of a coherent or partly coherent laser radiation.

4. References

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