ISSN 1062-8738, Bulletin of the Russian Academy of Sciences: Physics, 2009, Vol. 73, No. 2, pp. 278–280. © Allerton Press, Inc., 2009.
Original Russian Text © A.A. Kovalev, V.V. Preobrazhenskii, M.A. Putyato, O.P. Pchelyakov, N.N. Rubtsova, 2009, published in Izvestiya Rossiiskoi Akademii Nauk. Seriya Fizicheskaya, 2009, Vol. 73, No. 2, pp. 290–291.

Reflective Interferometer for Investigation of the Amplitude–Phase Characteristics of Semiconductor Nanostructures

A. A. Kovalev, V. V. Preobrazhenskii, M. A. Putyato, O. P. Pchelyakov, and N. N. Rubtsova

Institute of Semiconductor Physics, Siberian Branch, Russian Academy of Sciences, pr. Akademika Lavrent'eva 13, Novosibirsk, 630090 Russia

e-mail: rubtsova@isp.nsc.ru

Abstract—It is proposed to apply a reflective interferometer in measurements of the spectral dependence of the phase of reflection of mirrors based on multilayer semiconductor nanostructures. The interferometer has been tested on the semiconductor mirror initiating the self-locking mode of a Nd^{3+}: $KGd(WO_4)_2$ laser. The technique proposed can be applied in a wide wavelength range and has a higher sensitivity for measuring the phase characteristics in comparison with the conventional two-beam interferometers.

DOI: 10.3103/S1062873809020348

INTRODUCTION

Compact lasers operating in the ultrashort-pulse mode are of great interest. A necessary condition for implementing this mode is the compensation of positive group-delay dispersion of the laser optical elements. Currently, this problem is successfully solved using special mirrors with peculiar spectral characteristics (for example, mirrors based on a Gires–Tournois interferometer [1, 2]) or the so-called mirrors with chirp [3] or double chirp [4]. In fabrication of such elements, it is necessary to carefully control the phase and amplitude mirror characteristics. The conventional approach uses two-beam instruments (Michelson, Sagnac, or Mach–Zehnder interferometers) [5]. This approach is implemented in various techniques: white-light interferometers with subsequent Fourier transformation [6] or direct measurement of phase shifts at different wavelengths [7] (this technique provides the best measurement accuracy).

In this study, a new technique is proposed, which is based on multipath interferometry. It can be used for a wide class of laser optical elements and provides a significant increase in the spectral resolution and accuracy in measurements of phase characteristics. This method uses the concept of reflective interferometer [8], which has already found application in some original devices.

DESIGN OF A REFLECTIVE INTERFEROMETER

Figure 1 shows a reflective interferometer formed by a sample studied (rear mirror) and a thin metal layer on the substrate (front mirror). Both mirrors are fixed at piezoelectric cells. A modulating voltage, providing a shift by a tenth of the intermodal distance, is applied to the piezoelectric cell of the front mirror. The second piezoelectric cell is made of bimorphic piezoelectric ceramic. It provides linear displacement of the sample. An element without hysteresis in the range of voltages from 0 to 100 V and with a sensitivity $\approx dl/dU = 3.378 \times 10^{-2}$ μm V^{-1} is used.

The reflective interferometer is characterized by the wavelength dependence of its reflectivity. Figure 2 shows good agreement between the experimental data (circles) for a simple sample (nickel film) and the

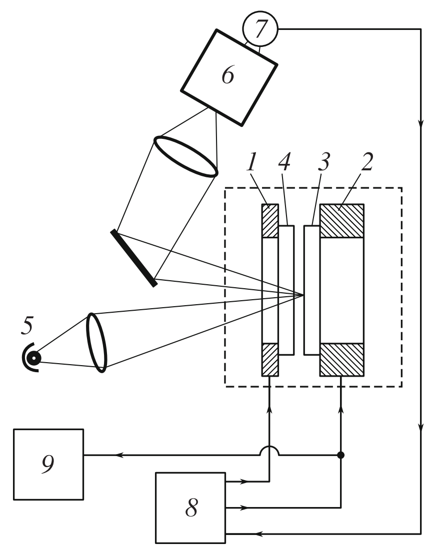

Fig. 1. Design of the reflective interferometer: (*1*) piezoelectric ceramic modulating the interferometer base, (*2*) piezoelectric ceramic controlling the position of the (*3*) sample, (*4*) front mirror of the interferometer, (*5*) light source, (*6*) monochromator, (*7*) photodetector, (*8*) self-tuning unit, and (*9*) digital voltmeter.

results of calculation (filled squares) of the interferometer reflectivity. The minima of the reflectivity near zero correspond to the case of phase matching [8], which is experimentally realized with the use of a sample in the form of a Ni film with a thickness of 5 nm, deposited on a quartz substrate; the film parameters are $n = 2.872$ and $\kappa = 5.152$ [9]. The interferometer base is 26.405 μm and the mirror is a deposited aluminum film with a reflectivity of 0.95. The finess of this reflective interferometer turned out to be much higher than that for two-beam interferometers. This fact guarantees more exact tuning of the radiation wavelength into a certain part of the spectral reflective curve of the interferometer. Further increase in the spectral resolution can be obtained by increasing the mirror reflectivity with the use of a combination of a metal film with a dielectric coating.

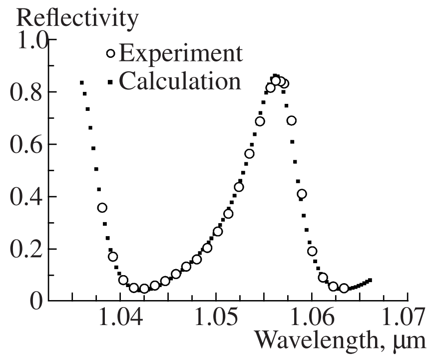

Fig. 2. Wavelength dependence of the reflectivity: (filled squares) calculated and experimental (circles) data for a nickel film sample. Good correspondence between the theory and experiment and high sharpness of the interferometer can be seen.

MEASUREMENT RESULTS

The essence of the measuring procedure is successive determination of the values of voltage corresponding to the reflectivity peaks for the reflective interferometer, according with the tuning of the monochromator to the next wavelength. The reflective interferometer phase can be written as $4\pi\nu l + 4\pi + \Phi(\nu) = 2\pi m$, where $\nu = 1/\lambda$ and m is the interference order. To determine the absolute phase, it is necessary to know the values l_0 (the interferometer base at zero voltage) and m. The value of l_0 can be found from the voltage across the piezoelectric cell when the mirrors of the reflective interferometer are in contact; however, this procedure requires ideal planarity of mirrors, which cannot be obtained in our case. The values of l_0 and m were found from short-wavelength measurements ($\lambda \approx$ (0.6–0.7) μm), corresponding to the transitions far from the GaAs absorption edge, where $\Phi = \pi$; in this case, the operating interference order was determined from the known value of m in this short-wavelength spectral region. In the measurements reported here, $m = 33$ and $l_0 = 16.0$ μm.

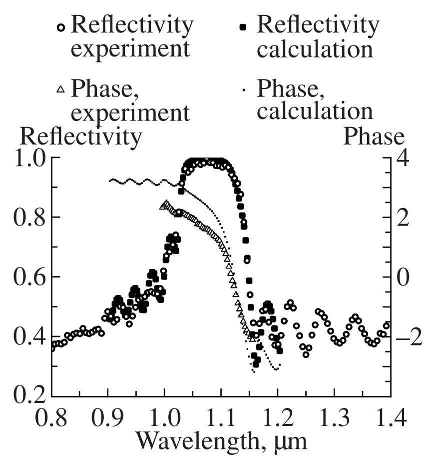

Fig. 3. Comparison of the calculated amplitude and phase characteristics with the measured ones for a completely semiconductor laser mirror of the all-in-one type. The discrepancy between the theory and experiment is related to the interdiffusion processes in the nanostructures.

A laser mirror of specific design, intended for simultaneous compensation of the group-delay dispersion and operation as a saturating absorber was an object of study. Layers of the Gires–Tournois interferometer type with negative group-delay dispersion and a saturating absorber based on two $GaAs/In_{0.25}Ga_{0.75}As/GaAs$ quantum wells were used in the mirror design. Thus, a combined (so-called "all in one" [10]) element has been designed. The mirror was MBE-grown; it proved to be able to implement the self-locking mode for a $Nd^{3+}KGd(WO_4)_2$ laser. The spectral dependences of the reflectivity and phase were calculated for this combined mirror. The refractive and extinction indices were taken from [11]; the dispersions of both values were also taken into account. The absorption by quantum wells was calculated as in [12]; the refractive index of the quantum-well material was taken to be 3.55.

The measured spectral dependences of the phase (triangles) and reflectivity (circles) of the mirror studied (Fig. 3) exhibit some deviations from the calculation results. Taking into account the quadratic chirp in the refractive index n and the layer thickness h, we find that, even near the substrate, the values of n and h differ significantly from those assumed in the initial design: $n(AlAs) = 3.02$, $n(GaAs) = 3.343$, $h(AlAs) = 0.185$, and $h(GaAs) = 0.0656$. This fact is reflected in the calculated curves in Fig. 3. A possible cause of this deviation is the interdiffusion contribution.

Thus, a new method has been proposed for measuring the phase characteristics of laser mirrors providing the ultrashort-pulse mode in compact lasers. This technique was checked and tested on a combined, completely semiconductor mirror. Comparison of the calculated and measured characteristics indicates a significant contribution of interdiffusion in the layers.

ACKNOWLEDGMENTS

This study was supported by the Russian Foundation for Basic Research, project no. 06-02-16527, and the integration project of the Russian Academy of Sciences and the Belarus National Academy of Sciences, grant 3.22.

REFERENCES

1. Gires, F. and Tournois, P., *C. R. Ac. Sci, Paris*, 1964, vol. 258, p. 6112.
2. Kuhl, J. and Heppner, J., *IEEE Trans. Quantum Electron.*, 1986, vol. QE-22, p. 182.
3. Szipocs, R. and Kohazi-Kis, A., *Appl. Phys.,* 1997, vol. 65, p. 115.
4. Kartner, F.X., Matoushek, M., Schible, T., et al., *Opt. Lett.*, 1997, vol. 22, p. 831.
5. Knox, W.H., *Appl. Phys. B*, 1994, vol. 58, p. 225.
6. Naganuma, K. and Sakai, Y., *Opt. Lett.*, 1994, vol. 19, p. 487.
7. Beck, M. and Walmsley, I.A., *Opt. Lett.*, 1997, vol. 15, p. 492; Beck, M., Walmsley, I.A., and Kafka, J.D, *J. Quant. Electron,* 1991, vol. QE-27, p. 2074.
8. Troitski, Yu.V.*, Odnochastotnaya generatsiya v gasovyh laserakh* (Single-Frequency Generation in Gas Lasers), Novosibirsk: Nauka, 1975.
9. *Handbook of Optical Constants of Solids,* Palik, E.D., Ed., Orlando: Academic, 1985.
10. Kopf, D., Zhang, G., Fluck, R., et al., *Opt. Lett.*, 1996, vol. 21, p. 486.
11. Adachi, S., *Optical Constants of Crystalline and Amorphous Semiconductors: Numerical Data and Graphical Information,* Boston: Kluwer, 1999.
12. Chemla, D.S. and Miller, D.A.B., *J. Opt. Soc. Am.*, 1985, vol. 2, p. 1155.