Modelling and manufacture of an interference filter for narrow spectral selection

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Abstract. We made and investigated narrow spectral selection filter. The influence of the multilayer structure properties and parameters on the spectral characteristics of the optical filter was investigated. The possibility of applying such a filter for selecting a narrow range of wavelengths that can find various applications in the field of information transfer and medical devices was shown.

Keywords: interference filter, narrow spectral selection, multilayer structures, magnetron sputtering.

1. Introduction

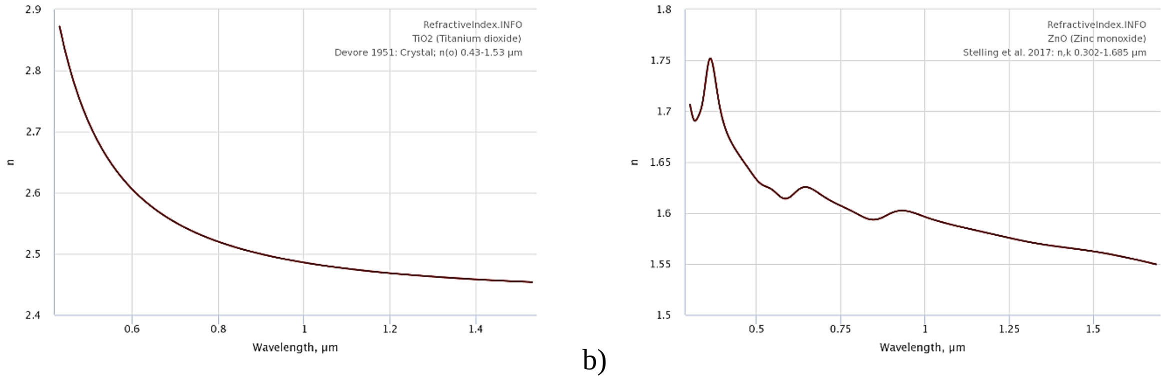
In recent years, the development of diffractive optical elements (DOE) have attracted the researchers due to the prospects of their use in optical signal and image processing systems, including in computational optics. In addition to the traditional use of DOE as spectral selectors, a significant number of DOE types have been developed so far, allowing many other functions such as multiplication and beam formation, optical signal distribution through processing channels [1-3], wave front formation, etc [4,5]. As a rule, the optical characteristics of such multilayer elements depend on many factors such as their structure, materials used and their refractive indices, the order and ratio of layer thicknesses and micro-relief, internal or surface [6-8]. The basis of such elements are optically transparent in the visible or infrared range, dielectric alternating films deposited on an optical quality substrate, for example, quartz.

Various methods for the deposition of films can be used to create such structures: vacuum thermal deposition [9], electron-beam sputtering, and many others. But the creation of optical elements requires high quality and accuracy of the results [10]. Therefore, the most preferred method is magnetron sputtering. This method allows the film to be sprayed at a high speed, with a low pressure of the working gas in the chamber, which allows obtaining very pure structures. In this paper, we investigated the possibility of obtaining such structures using a magnetron sputtering installation "Caroline D12A", modernized for the purpose of sputtering dielectric targets.

2. Modelling of multilayers structure

One of the most important part of multilayers structure's manufacture is choosing of material for it.

First of all based on such parameters like refractive index, surface roughness and light transmission, quartz substrate of 25 mm diameters was chosen like base of multilayers element. Then for "sandwich structure" based on their refractive indexes and possibilities of deposition TiO2 (n=2.7 at 532 nm) and ZnO (n=1.6 at 532 nm) were chosen. Refractive indexes depends on wavelength shown on figure 1. Refractive index of quartz substrate is 1.5.



a) b)

Figure 1. Refractive index a) TiO2, b) ZnO.

As a result of modelling based on the achieving of an objective purpose (selection of exact wavelength of 532 nm with maximal efficiency) we got next results. Efficiency depends on wavelength shown of figure 2. Parameters of five layers structure also shown on figure 2. High of each ZnO layer is 66 nm, high of each TiO2 layer is 50 nm.

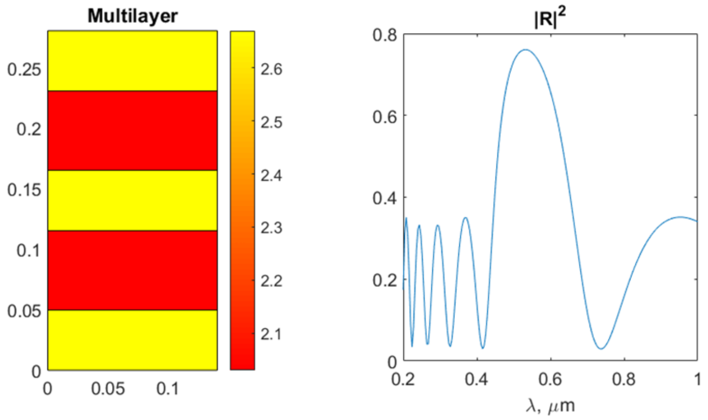


Figure 2. Results of modelling (left – structure, right – efficiency).

3. Experimental part

The installation of magnetron sputtering "Caroline D12A" is designed for the deposition of conductive films, so it has a DC source. This embodiment does not permit the dispersion of dielectric films since charge accumulation occurs on the dielectric target, which contradicts the principle of magnetron sputtering. And the power supply to the magnetron results in the start-up and quick stopping of the spraying in a very short time. To solve this problem, the power supply was replaced by a high-frequency generator with an operating frequency of 13.56 MHz and a maximum output power of 1 kW. The biggest challenge during the modernization of Caroline D12 A was the development and optimization of the matching device between the generator and the magnetron. As a result of the work done, the optimal ranges and ratios of the components of the matching device, namely a tuneable coil and a tuneable capacitor, were selected. This allowed us to achieve an optimal alignment with allowance for unrecoverable losses (10%).

In the course of the work, the optimal parameters for the deposition of a ZnO and TiO2 thin films on a quartz substrate were obtained. The power supplied from the signal generator P = 500 W, an argon flow rate Q (Ar) = 2.0 l/h, Q (O2) = 0.7 l/h, the residual pressure in the chamber p = 5 × 10-4 Pa, substrate heating temperature was t = 120 oC, the drum rotation speed V = 11 RPM. The distance from the target to the substrate was about 20 cm. Consequently, the deposition rate was 10 nm/min. Thickness was checked by Profiler "KLA Tencor P-16+". As a result, high-quality thin films was obtained on quartz substrate. The scratch test indicated that the adhesion of the film to the substrate was high. The optical and physical properties of the thin film was measured with the help of "Ellipsometer M2000DI". For optical applications, the layers should be homogenous over the entire surface of the substrate. To study these properties, the surface of the film was examined using a Zygo NewView 7300 white light interferometer. The area of the investigated surface was 351 μm x 263 μm. On the basis of surface studies using profiler, ellipsometer and interferometer, it can be observed that the height of the surface does not differ more than 1 nm per 1 mm, which indicates a high uniformity of the film.

4. Conclusion

In this work, the modernization of the magnetron sputtering unit was carried out. The deposition of multilayer structure was demonstrated by using the optimized parameters of the matching device and the deposition modes. The height of the deposited layer helped determine the deposition rate at a given mode. The layers were smooth and homogeneous which makes it possible to use it for fabrication of multilayer diffractive optical elements.

5. Acknowledgments

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6. References

[1] Danilov, O.B. Controllable diffractive optical elements with a vanadium dioxide film / O.B. Danilov, A.I. Sidorov // Journal of Technical Physics. – 1999. – Vol. 69(11). – P. 91-96.

[2] Bykov, D.A. Diffraction of an optical beam on a Bragg grating with a defect layer / D.A. Bykov, L.L. Dokolovich // Computer Optics. – 2014. – Vol. 38(4). – P. 590-597.

[3] Butt, M.A. Modeling of multylayer dielectric filters based on TiO2 / SiO2 and TiO2 / MgF2 for fluorescence microscopy imaging / M.A. Butt, S.A. Fomchenkov, A. Ullah, M. Habib, R.Z. Ali // Computer Optics. – 2016. – Vol. 40(5). – P. 674-678. DOI: 10.18287/2412-6179-2016-40-5-674-678.

[4] Bezus, E.A. Scattering in elements of plasmon optics suppressed by two-layer dielectric structures / E.A. Bezus, L.L. Doskolovich, N.L. Kazanskiy, V.A. Soifer // Technical Physics Letters. – 2011. – Vol. 37(12). – P. 1091-1095.

[5] Volkov, A.V. A method for the diffractive microrelief formation using the layered photoresist growth / A.V. Volkov, N.L. Kazanskiy, O.Ju. Moiseyev, V.A. Soifer // Optics and Lasers in Engineering. – 1998. – Vol. 29(4-5). – P. 281-288.

[6] Butt, M.A. Thermal effect on the optical and morphological properties of TiO2 thin films obtained by annealing a Ti metal layer / M.A. Butt, S.A. Fomchenkov // Journal of the Korean Physical Society. – 2017. – Vol. 70(2). – P. 169-172.

[7] Paranin, V.D. Tunable diffraction grating with transparent indium-tin oxide electrodes on a lithium niobate x-cut crystal / V.D. Paranin, S.V. Karpeev, K.N. Tukmakov, B.O. Volodkin Computer Optics. – 2016. – Vol. 40(5). – P. 685-688. DOI: 10.18287/2412-6179-2016-40-5-685-688.

[8] Bezus, E.A. Scattering suppression in plasmonic optics using a simple two-layer dielectric structure / E.A. Bezus, L.L. Doskolovich, N.L. Kazanskiy // Applied Physics Letters. – 2011. – Vol. 98(22). – P. 221108. DOI: 10.1063/1.3597620.

[9] Verma, P. Design, simulation, and fabrication of silicon-on-insulator mems vibratory decoupled gyroscope / P. Verma, V.S. Pavelyev, B.O. Volodkin, K.N. Tukmakov, A.S. Reshetnikov, T.V. Andreeva, S.A. Fomchenkov, S.N. Khonina // Computer Optics. – 2016. – Vol. 40(5). – P. 668-673. DOI: 10.18287/2412-6179-2016-40-5-664-668-673.

[10] Kazanskiy, N.L. Interaction of dielectric substrates in the course of tribometric assessment of the surface cleanliness / N.L. Kazanskiy, S.V. Karpeev, V.A. Kolpakov // Optical Memory and Neural Networks (Information Optics). – 2008. – Vol. 17(1). – P. 37-42.