Development and research of a linearly changing narrow bandpass optical filter for hyperspectral equipment

S.A. Fomchenkov[1,2]

[1]Image Processing Systems Institute of RAS - Branch of the FSRC "Crystallography and Photonics" RAS, Molodogvardejskaya street 151, Samara, Russia, 443001
[2]Samara National Research University, Moskovskoe Shosse 34A, Samara, Russia, 443086

Abstract. This paper reports on the development and investigation of a linearly changing narrow bandpass optical filter (LCOF) fabrication process. We researched and optimized parameters of manufacturing process steps, such as vacuum sputtering, thickness controlling, phase diffractive optical element writing, plasma chemical etching and etc. Most important moment and parameters of producing influence on the final result shown in this paper. As a result of work, experimental sample of multilayer optical filter for narrow spectral selection obtained.

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 structured laser beam shaping and their splitting, optical signal distribution through processing channels, etc. [1,2]. The optical characteristics of multilayer DOE depend on many factors such as their structure, materials used and their refractive indices, the order and ratio of layer thicknesses and micro-relief.

Optical filter is one of the most common and wildly used elements in optical sets. LCOF is handy tools for any optical experiment where filters are required [3]. The filter's wavelength can be moved in filter’s wavelength range. Filter is especially useful for spectrally shaping the excitation energy from broadband sources used for fluorescence.

Micro-cavity filter or all dielectric Fabry –Perot filter is a special class of interference filters. If optical thickness of a cavity layer that surrounded by two symmetric Distributed Bragg Reflectors (DBR) is integer multiples of $\lambda/2$ then this structure is named a micro-cavity filter

Distributed Bragg Reflector (DBR) or dielectric mirror is periodic repetition of two layers with different refractive indexes (n-high, n-low) and different thicknesses (d-high, d-low) as $n \times d$ (high) = $n \times d$ (low) = $\lambda/4$ is established for each layer.

Micro-cavity filters are used as steady filters [4], adjustable filters [5,6] and chemical detectors [7]. Dielectric optical filters with Fabry – Perot structures are used in telecommunication, lasers and spectrometers in order to control and measure the exact wavelength range of visible and non-visible spectrum [8-10]. In a spectrometer, the optical filter with Fabry – Perot style is used to detect the wavelengths that are very close together [11]. The linear variable optical filter is a multi-layer Fabry-perot filter that the shape of its cavity is conical. The feasibility study of a linear variable optical filter has been carried out in a wide range (400 nm to 1000 nm) and a narrow range (from 610 nm to 680 nm and from 722 nm to 880 nm) [10-11].

Therefore, the task of optical filters manufacturing is very interest today. During the study of the manufacturing process, the purpose was to minimize the possibility of errors in manufacturing and to save the high quality of the elements. Each technological stage was investigated. In the course of experimental studies optimal modes and parameters of the processes and manipulations were selected. Therefore, as a result of an experimental study, this work demonstrated the complete technological process of LCOF producing elements on a fused quartz substrate, which includes the minimum numbers of manufacturing steps, while allowing obtaining high quality elements and structures.

2. Experimental part

In this work for high refractive index layer was chosen TiO2, for low index refractive layer was chosen SiO2. Refractive index of TiO2 for wavelength 532 nm is 2,45 and of SiO2 is 1,47. Refractive index graphs shown on figure 1.

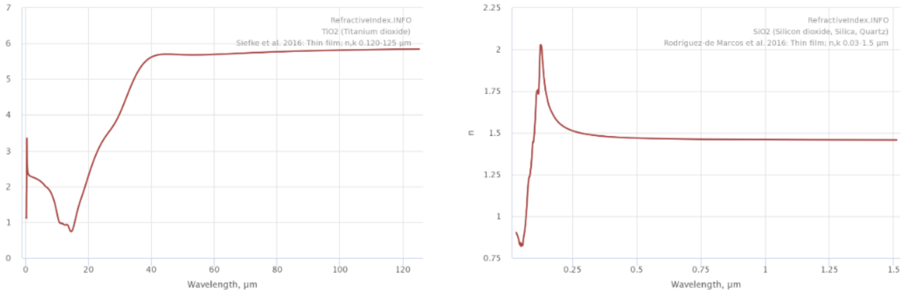

Figure 1. Refractive index of TiO2 and SiO2 thin films.

LCOF can be fabricated in a resist layer by just one lithography process. The profile of resist structure is subsequently transferred into defective layer of optical filter by plasma etching. Complete LCOF fabrication involves deposition of a lower dielectric mirror using a stack of dielectrics on the substrate, tapered layer formation and deposition of the top dielectric mirror [12].

The mail idea of this LCOF is providing of defective layer by direct laser writing and plasma chemical etching. Typically so kind of structures produced with help of slanted deposition. It means sputtering with not normal angle between sputtering source of material and substrate.

With help of direct laser writing by UV laser on circular laser writing station we can provide 256 different levels or steps inside resist volume. It gives us possibility for transfer of this structure to transparent dielectric layer by plasma chemical etching.

For manufacturing process were used common equipment: magnetron sputtering system CarolineD12A (ESTO-Vacuum, Inc.), circular laser writing system “CLWS-200S” and plasma chemical etching, providing by setup Caroline PE-15 (ESTO-Vacuum, Inc.). Outside view of lab equipment used in research shown on figure 2.

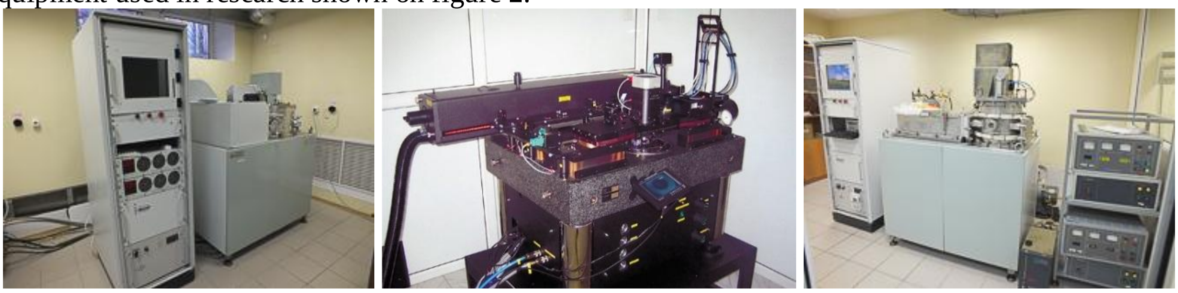

Figure 2. Lab equipment used in manufacturing process of LCOF.

On first step we deposit multilayer mirror on quartz substrate. On second step we deposit defective layer. It is material which has higher refractive index from two materials of multilayers structure. Next we coat surface by special photoresist mask. Next we make direct writing of phase structure in resist layer with help of circular laser writing station and remove of unexposed parts. Then with help of plasma etching system we transfer phase mask from resist layer to defective layer of filter. And on last step we deposit top mirror.

We used a technological process with main steps like vacuum sputtering, lithography and chemical etching. In details, manufacturing process consists of the following steps (shown on figure 3).

1) Quartz substrate used for base of future element. Roughness of surface is less than 10 nm. Oxide thin films sandwich structure (TiO2/SiO2) sputtering on the quartz substrate by using magnetron sputtering system CarolineD12A (ESTO-Vacuum, Inc.) Choice of material for layer depends on future parameters of element. All thin film deposition occurs at vacuum of 10-3 Pa and power 300-700 W.

2) Then thick oxide thin film (SiO2) sputtering for producing of future multi steps stcructure.

3) Next, resist coating providing by special circular rotating system. We provide 3 layers of resist. Total resist thickness is around 5-6 mkm, checked by profilometer P-16 (KLA- Tencor, Inc.).

4) Exposure of resist doing by circular laser writing station “CLWS-200S”. Planar structure is controlling by project written in binary machine file. Planar resolution is 1 mkm. Then removing of unexposed resist occurs by NaOH solution. Then we made cleaning and heating of substrate with structure for increasing of adhesive properties.

5) Through phase structure of resist we transfer it to oxide layer with help plasma chemical etching, providing by setup Caroline PE-15 (ESTO-Vacuum, Inc.). Etching process occurs at vacuum of 10-3 Pa and source power 450 W.

6) Second multilayers mirror deposition. Oxide thin films sandwich structure (TiO2/SiO2) sputtering. Final result.

There are a lot of small steps which are also important and influence on the final result and quality of producing elements, but they are not shown in this schematic.

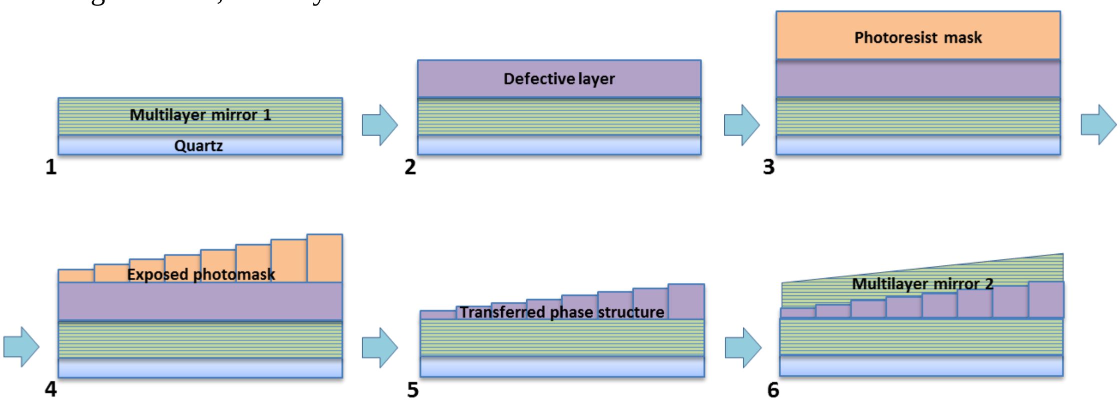

Figure 3. Linearly changing narrow bandpass optical filter fabrication process.

The main advantage of LCOF over linear variable filters is that it can be made on a small surface area. This advantage allows the use of a similar filter in optical circuits, where space and mass are important, for example for portable hyperspectrometers [13].

3. Conclusion

Technological process of the multi steps optical filter manufacturing on a fused quartz substrate, which includes available common producing steps demonstrated. Produced filter has high quality and allows using it as optical filters for narrow selection in different devices.

Thus, we find and demonstrate solution included in technological process of filter producing on a fused quartz substrate. It could be used in optical setups and hyperspectral equipment.

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5. References

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