Microtechnology in computer optics

V A Danilov

1Russian Academy of Sciences, Scientific and Technological Center of Unique Instrumentation, Butlerova st. 15, Moscow, Russia, 117342

e-mail: viktordanilov@bk.ru

Abstract. The article briefly describes the development of microtechnology in the field of diffractive computer optics. The author presents the material based on the development of the laboratory of micro- and nanotechnology of Image Processing Systems Institute of the RAS. The creator and head of this laboratory was Doctor of Technics, Professor Alexey Volkov, a well-known expert in the field of electronic and vacuum technologies. The author analyzes the impact of scientific results of Professor A.V. Volkov on the development of diffractive optics.

1. Introduction

Diffraction optical elements (DOEs) have a long history. The Rayleigh-Soret diffraction gratings and Fresnel zone plates developed over 200 and 150 years ago respectively should be considered the first DOEs. The emergence of new types of DOEs is usually associated with two main factors: the methods for calculation of such elements and the manufacturing technology. Diffraction gratings are simple elements in the form of a diffraction microstructure with periodic phase relief and are intended to form a one-dimensional or two-dimensional set of flat beams with a given ratio of energy between the beams. Multi-order diffraction gratings are widely used nowadays in optical devices for image multiplication, in optical fiber connectors and free space connectors, in devices for optical communication and information processing, in coherent optical processors. The basic manufacturing technology of diffraction gratings is mechanical, using a sharp cutter. After the diffraction grating, a zone plate was invented, which began to be widely used only at the end of the 20th century because of the lack of reliable manufacturing techniques. These elements have binary amplitude or phase transmission and are used in optics communications and information processing means.

The use of computers (1970), as well as laser technology and microelectronics technology (1980) allowed to make a quantum leap in calculation and production of DOEs. It became possible to create DOEs with a complex microrelief.

The availability of computerized synthesis of binary amplitude-phase and phase spatial filters, wave-front correctors led to the creation of multi-level DOEs with unique characteristics that are not achievable within the framework of traditional optics [1, 2]. In 1981, the focusators of laser radiation were suggested and studied in our country for the first time [3]. The basic solutions of the focusing problem for various focal areas for creating various focusing DOEs were found in the works of I.N. Sisakyan, V.A. Soifer et alias and in a number of other works of domestic researchers in the first half of the 1980s [4-7]. The works appeared that performed a computational treatment of influence of technological errors of microrelief formation on the operation of focusing DOEs [8-10].
The publications reviewed above demonstrate a broad study of the theoretical issues of producing DOEs. However, the technology of producing DOE did not keep pace with the development of theoretical methods. As the microelectronics developed, various microlrelief formation methods appeared, such as photolithography and e-beam lithography. Direct transfer of these methods to the production of DOEs appeared to be not quite effective. For example, in microelectronics, it is essential to obtain a surface-supported binary microstructure and the presence of point errors of the microstructure is absolutely unacceptable and leads to inoperativeness of the product. At the same time, the thickness of the structure obtained is not very important, moreover, there is no need to make the structure thickness different over the area. The production of DOE microlreliefs, on the contrary, allows for a fairly large number of point errors in the structure, while the thickness of the relief should be controlled with a considerable accuracy ($\lambda/8$). The undoubted advantage of the technology is the possibility to change the depth of the microlrelief over the area, thus forming multi-level DOEs.

2. Methods of forming a multi-level microlrelief

The production of DOEs using traditional materials and traditional methods does not allow to reach the potential of diffractive optics. It is impossible to achieve continuous or almost continuous reliefs needed for the construction of optical elements without the excessive costs. It was the modification of microelectronics technology for DOE production [11-20] where the talent of Professor Alexey V. Volkov (August 3, 1939 - January 13, 2015) was of great value.

A key problem in making focusators [11] is to achieve high energy efficiency together with the required intensity distribution in the focal area. It should be noted that almost all the works on theoretical evaluation of efficiency of optical elements are based on the assumption of a perfect or almost perfect accuracy of microlrelief production. In reality, there are technological errors due to the drawbacks of the methods of microstructures formation: errors in the size of the zones and the microlrelief height, shift of the boundaries of the zones, etc.

During the study, the team of A.V. Volkov suggested several methods of forming a relief with a continuous profile of various heights and resolutions. For example, in [12, 19] a liquid photopolymerizable composition exposed through DOE halftone photomask was used to form the microlrelief (Fig. 1).

![Figure 1. The focusator in the segment based on a liquid photopolymerizable composition.](image)

In [13, 20] a method of layer-by-layer photoresist enhancement allowing to form a multilevel microlrelief was suggested and studied. In [21, 22] a technology of manufacturing DOEs using chalcogenide glassy semiconductors is reviewed. Figure 2 shows a microlrelief section formed according to this technology.

In [23] it was suggested to form DOE microlrelief using polyamide films. Another task related to the technology of forming a multilevel microlrelief considered by Professor A.V. Volkov is the transfer of microlrelief from a polymer mask to a substrate material (silicon, quartz, glass) [12, 13, 20, 23-25]. The process of transfer of multilevel microlrelief from a polymer composition to a solid substrate is significantly more complicated as compared to obtaining a binary structure. The main problem is that the plasma etching rate for the polymer composition and the substrate material is different, and as a result, the total thickness of the microlrelief changes [25]. This situation was solved
by using metal-based protective layers. In this case, it is necessary to perform several sequential etching operations to obtain a multilevel microrelief [14].

![Figure 2](image1.png)

**Figure 2.** Microrelief section on a chalcogenide glassy semiconductor measured on a scanning probe microscope.

### 3. Production of DOE with submicron resolution

Different approaches to errors in microelectronics and optics led to the necessity to adapt the control methods and surface cleaning methods to the task of forming DOE microreliefs. A significant number of works of Professor A.V. Volkov is dedicated to solving particular problems of technology: preparation of substrates, control of pollution and roughness, and rapid methods to control the microrelief shape [18, 26-35].

Another direction of microelectronics technology improvement reflected in the works of Professor A.V. Volkov is increasing the resolution of the microrelief of DOEs produced [15, 36] using electronic lithography technologies. One of the significant problems is that DOE microrelief shall have a certain thickness, which may be comparable with the period of DOE for some purposes. The task of obtaining such a microrelief was successfully solved (Fig. 3) [36].

![Figure 3](image2.png)

**Figure 3.** SEM image of a diffraction grating with a period of 400 nm in a resist with the height of 500 nm.

The problems of producing DOEs for the operation outside the visible range resulted in the need to adjust the microelectronics methods for the new materials: sapphire substrates, diamond films, chalcogenide glasses [36-48].

Recent works of Professor A.V. Volkov were devoted to increasing the resolution of photolithographic process by using the recording of a photomask on thin films of refractory metals [49-52]. This allowed to obtain a resolution of almost 200 nm.

![Figure 4](image3.png)

**Figure 4.** Image of a microrelief on the end of a chalcogenide fiber obtained with a scanning probe microscope.
4. Conclusion

Comprehensive adaptation of microelectronics methods to the requirements of DOE production have brought the results. The methods developed by Professor A.V. Volkov allowed to develop and produce optical devices with DOEs [53], focusors for different transverse and longitudinal areas [11, 54-61], DOE for the formation of modes [16], lighting devices [62-64] and polarization devices [65-67]. The technological routes and lines developed under the direction of A.V. Volkov still work, which made it possible to create compact and light computer vision systems and hyperspectrometers [68-72] for unmanned aerial vehicles and nanosatellites.

5. References

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