High-aperture NUV and DUV Microscopy based on Dioptric Optics. Optical Design

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ABSTRACT. The aspects of the use of dioptric optics for DUV (deep ultraviolet) microscopy are considered. The transition to the NUV (near ultraviolet) and DUV range can significantly improve the resolving power of the microscope. Different kinds of crystals can be used as optical materials.

1. INTRODUCTION. The well-known Abbe and Rayleigh relationships relate the value of the resolving power of an objective, depending on its numerical aperture and the wavelength used. Optical design can allow creating objectives whose maximum numerical aperture in air (vacuum) reaches 0.90-0.95. This is the technological limit in the creation of such systems. In this case, the use of a shorter wavelength is the only way to further enhance the resolution of the microscope. At present, in light microscopy the visible spectral range is mainly used as the working spectral range. In this spectral range in objectives without immersion it is possible to obtain resolution values of about 270-470 nm.

Table 1. Theoretical resolution values for the numerical aperture 0.95 for some NUV and DUV wavelengths.

Wavelengths (nm)	248	222	213	193	157	121.6	106
Resolution value (nm)	159	143	137	124	100	78	68

2. WHAT OBJECTS CAN BE INVESTIGATED?

When exposed to NUV and DUV radiation on living organisms, it is absorbed. Due to its action, the chemical properties of molecules of biological polymers change. On microorganisms and cultured cells of higher animals and plants, such radiation has a harmful and mutagenic effect, since the spectrum of the lethal and mutagenic effect of ultraviolet radiation roughly coincides with the absorption spectrum of nucleic acids, and in some cases the spectrum of biological action is close to the absorption spectrum of proteins. In this case, the optical properties of many substances in the ultraviolet range of the spectrum are significantly different from those, for example, in the visible region.

The ability of many substances to selectively absorb in NUV and DUV can be used to detect and study various inclusions and impurities. In ultraviolet microscopy, it is possible to investigate non-living biological objects that are prepared by special methods. In addition, in a standard sample that includes a slide, a cover glass, there should be no glue, optical glass materials should provide high transmission of ultraviolet radiation, that is they must be made of crystal optics. The most complete consumer qualities of an ultraviolet microscope are manifested when researching objects of the mining and ore industry. The study of such samples can be carried out in the field of crystallography, petrography, and chemistry. Objects of the metallographic and semiconductor industry can be studied using NUV and DUV microscopy.

3. WHAT OPTICAL MATERIALS CAN BE USED?

It is necessary to separate the spectral ranges indicated in the table 1. In the first interval there are wavelengths within the range of 248 nm – 193 nm, conditionally call it the NUV range. In the second interval were the wavelengths within the range and 157 nm – 105 nm, conditionally call it the DUV range. The peculiar border of these spectral ranges can be air, the transmission of which ends at about 185 nm. The very popular and frequently used quartz crystal, which is used very effectively for the NUV range, at about 156 nm ceases to transmitting. Also, fluorite can be used for this range, which is a universal and well-mastered optical material. In the optic design of the NUV optics, it is of interest to share these two materials in the same optical scheme.

Due to the extremely difficult optical design of dioptric lens objectives for the DUV band, the degree of optical correction is limited to correcting monochromatic aberrations for a selected fixed wavelength. The use of fluorite is possible for all types of NUV and DUV lenses, however, at a wavelength of about 122 nm this material completely loses its transparency. Therefore, for optical systems operating at the so-called Laiman wavelength of 121.6 nm, it is better to use lithium fluoride, the transparency region of which extends to about 105 nm. For the spectral region of the wavelength range shorter than 105 nm, transparent materials are practically absent.

In the wavelength range shorter than 185 nm, where air is not transparent, it is necessary to fill the working area of the microscope with any of the gaseous substances. The best transparency has inert gases, the shortest wavelength transparency of which has helium (approximately 50.4 nm).

Table 2. Main technical parameters and basic optical layout of DUV objectives

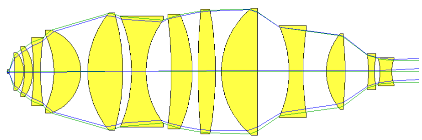
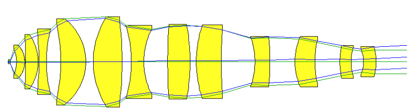
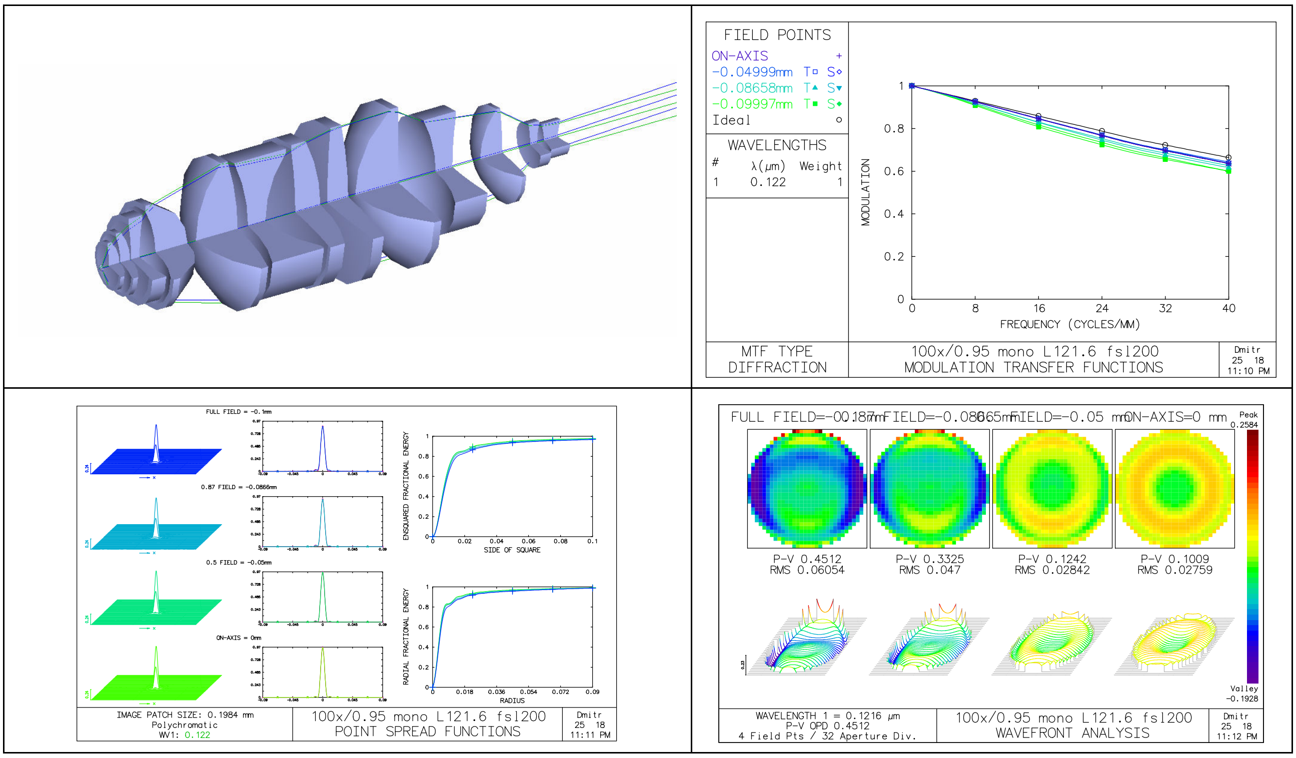
Magnification / F’	NA	“Glass”	λ (nm)	WD (mm)	R (nm)	FOV on object (mm)	FOV on image (mm)	The principal optical layout
100x / 2.0	0.95	LiF	121.6	0.52	78	0.20	20	
		LiF	106	0.40	68	0.20	20	

Table 3. The design graphs of aberrations of the 100x objective NA=0.95 for λ=121.6 nm



4. CONCLUSION. Some suggestions for building a NUV-DUV microscope are presented. The construction of a microscope in this area is a complex task that combines specific requirements for optics, mechanics and positioning devices. However, the main requirement is that the optical system provides advantages in terms of resolution and transmission. Optical design of the original objectives are presented. The principal possibility of creating dioptric systems for NUV-DUV microscopy with a high numerical aperture is shown. In the developed objectives, high numerical apertures of 0.95 for dry systems are realized. The use of the proposed objectives, as well as some practical engineering solutions, can significantly improve the quality of research on a microscope.