Concept and optical design of the underwater microscope.

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Abstract. The concept of the development of a microscope to provide research in the aquatic environment is proposed in conditions where the study of living and inanimate, static or moving microscopic objects in the environment of their natural location is required. Underwater microscope uses methods and technologies, similar conventional, based on the theory of diffraction. Achievable resolution is up to 0.3-0.5 μm. The optical system of the underwater microscope should allow the study of microscopic objects in the water column (at different depths). In the case of an underwater microscope, the only way to get images is to use a digital receiver. Objective of microscope should be work in water immersion. The optical and the mechanical design of the objective for an underwater microscope must be adapted to the conditions of immersion in the water column, including to a considerable depth.

Description. In conventional microscopy, the objective and eyepiece are used as a projection system and as a surveillance system in conjunction with the human eye. However, in the case of building a microscope for underwater research, the use of objectives and eyepieces of microscopes which use in standard light microscope in most cases of microscopic studies is impossible. Indeed, if at a depth of 5-10 meters under water a person can still be in relatively comfortable conditions for himself, without special diving equipment, then below - no. The use of special diving equipment makes it almost impossible to visualize an image after a microscope with the help of a researcher's eye (even if a standard microscope could allow obtaining such an image). There is a sense of some division into "varieties" and classification for underwater microscopes. One type of underwater microscope can be a microscope designed to work at depths of 5-10 meters. In this case, the microscope can provide research, both with the participation of man (diver), and autonomously. Another type (more interesting and demanded for scientific research) can be a microscope that allows you to conduct research at considerable depths, from 100-200 meters and below. We considered some version of the construction of the optical system of the illuminator of transmitted light - much smaller in size, using the original optical system, which does not require the use of additional equipment when immersed in water. Its principal optical system is presented in Figure 1.

Figure 1. Optical system of the transmitted light illuminator.

For the detection and possible "primary" identification of objects to be further studied in detail, it is proposed to use an auxiliary searching objective, the optical calculation of which is made in such a way as to provide the possibility of "scanning" a certain water area in a wide spectral range from 200 to 2000 nm; this is a long- focus objective, built like a photographic one, but having low parameters in terms of the angular field and aperture. However, its aberration correction is performed equally well in the entire indicated spectral range by using only crystals lenses. Figure 2 shows parameters of design and graphs of aberration correction of auxiliary searching objective.

Lens: tl water
Image num aper 0.025000 Image height 8.000000 Primary wavln 0.546074

SRF	RADIUS		THICKNESS		APERTURE RADIUS		GLASS		SPECIAL
OBJ	0.000000		1.0000e+20		4.0481e+18		WATER		
AST	0.000000		150.000000		9.800000	A	WATER	P	
2	395.013500		3.300000		9.800000		SILICA		
3	-38.654000		0.660000		9.870000		AIR		
4	-30.206200		4.650000		9.850000		LIF		
5	-18.470800		1.330000		10.000000		AIR		
6	-18.561800		2.660000		9.690000		SILICA	P	
7	46.443800		2.000000		10.100000		AIR		
8	48.649400		4.650000		10.520000		CAF2		
9	-40.210200		149.947311	S	10.670000		AIR		
IMS	0.000000		0.000000		8.000000				

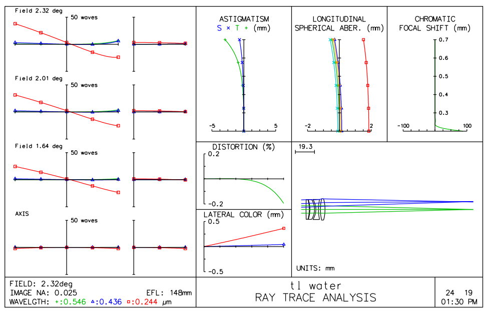
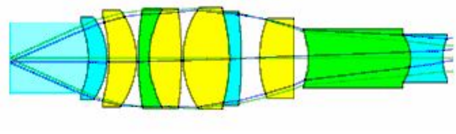
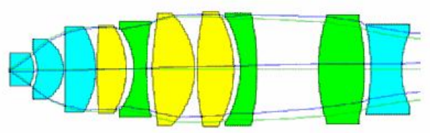
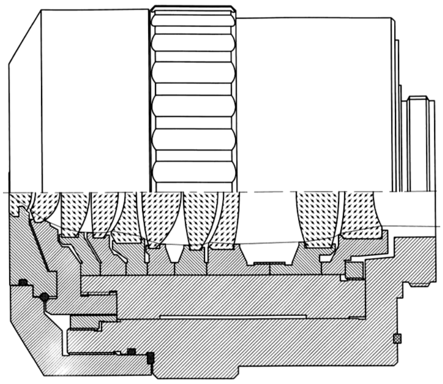


Figure 2. Parameters of design and graphs of aberration correction of auxiliary searching objective.

Table 1. Main technical parameters and basic optical layout of new "underwater" objectives.

Magnification	NA	WD (mm)	F' (mm)	R (μm)	DF (μm)	FOV on object (mm)	FOV on image (mm)	Type of correction	The principal optical layout
60^x	0.55	7	2.6	0.6	1.1	0.83	50	Plan Achromat	
40^x	1.1	0	4.13	0.3	0.28	0.4	16	SemiPlan Achromat	



The “high risk zone” is the first (frontal) lens of the objective, which, like the whole objective design, is under heavy pressure. The geometrical configuration of the front lens is not conventional - the mechanical frame is “embedded” in the part of the lens where there are no aperture rays. Such an engineering solution can prevent the lens from “squeezing” by the water column; also ensured the tightness of the inner side of this lens. At the depth of the water, a lot of pressure also affects the lenses and the frames inside the objective, but the main influence on the “stability” of the structure can be a temperature difference. Therefore, we decided to abandon the traditional methods of attaching lenses to the frames (such as fixing by “cell lip” or using glue), and use the original technology of installation and subsequent adjusting (centering) of the lenses into the frames. We propose to use 3D printing technology in the implementation of the operation of installing the lenses in the frames.

Conclusion. The above reasoning is probably the first attempt to fill in the content of the previously formulated concept of a microscope, designed for real time underwater studies of various microscopic objects, when it is necessary to achieve values of resolution less than 1 μm. Conducted theoretical and experimental studies have shown the fundamental possibility of creating such a microscope. Its main component is a projection system in the form of an objective, the numerical aperture of which is at least 0.5-0.55; the optical design of such an objective must take into account the dispersion properties of water, and its aberration correction must meet the image quality criteria adopted in microscopy. In the concept of a visualization system, perhaps the only acceptable solution is to use a digital image receiver, however, the optics should allow working with relatively wide format receivers. The illumination system used in classical microscopy can be significantly modified and simplified without obvious loss of quality parameters, such as numerical aperture and illumination contrast. With a mechanical design, it seems appropriate to use the original method, which ensures reliable fixing of the lenses in the frames. If we succeed in fulfilling all the listed conditions and innovations, we can obtain real microscopes, which are some optical information systems that harmoniously combine some components, equipment, software, elements of systems engineering, artificial intelligence, and others. Such optical information systems can provide an opportunity for the study of microscopic objects of animate and inanimate nature, which cannot be extracted from their natural habitat, namely, in the water column at various depths.