A compact acousto-optical module for hyperspectral imaging systems

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Abstract. We present an acousto-optical module, which is characterized with small monolithic design, rather good image quality and variability of instrument function. The module is compact and USB-controlled that makes easy its integration into existing imaging systems. We demonstrate the efficiency of the module for hyperspectral imaging in the ranges 450-900 nm and 900-1700 nm. The module may be the basis of hyperspectral imagers for various applications.

1. Introduction

The most promising method for spectral imaging is based on acousto-optical tunable filters (AOTF). They have a number of important advantages: fast (~ 1 ms) random spectral access, high spectral resolution (the bandwidth up to 0.1 nm), the ability to modulate the signal and synthesize the transfer functions, lack of moving elements, small mass and dimensions [1-3]. They can be the basis for implementation of fundamentally new methods for visualizing objects [4].

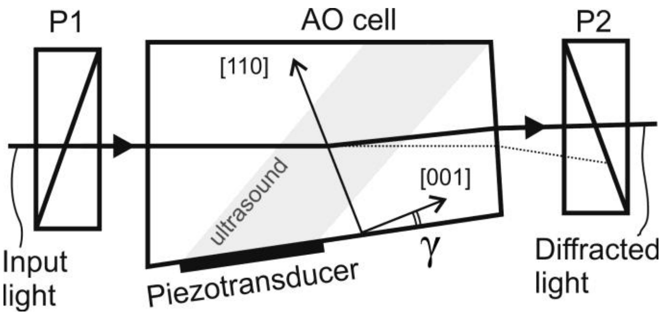
Now, acousto-optical (AO) functional elements as well as some devices based on them, for example imaging spectrometers, are commercially available. Typically, AOTF comprises an AO cell, input and output crossed polarizers and radiofrequency electronics for ultrasound wave generation. Its principle of operation is based on anisotropic Bragg light diffraction by a dynamic acoustic grating [5]. AOTF is capable to select the light waves in any narrow spectral range with the required transmission factor by tuning the frequency and the power of the ultrasound.

One of the factors limiting the application area of AOTFs is the spectral range of tuning, limited by technological factors, usually one octave, for example, 450-900 nm, 900-1800 nm, etc. To create instruments operating in a wider spectral range, several AOTFs can be used. In this paper we show the ability to create AOTFs operating in visible and near infrared (NIR) ranges (0.45 - 0.9 μm, 0.9 - 1.7 μm) with using of the same AO cell geometry. Moreover, one of the modern trends in optical instrumentation is the modular concept of the devices [6]. That is why we designed AOTF as a module which, unlike commercially available AOTFs, contains all the necessary electronic components (generator, amplifier, piezotransducer). Our module can be inserted into the device or removed from it without any affect on it.

2. Method description

The shape of AO cell defines the image distortions. Moreover, these distortions also depend on the optical design of the spectral imaging device. In the paper [7] we show that confocal telecentric scheme provides the best image quality. So, for this scheme the proposed AOTF was designed. Chromatic aberrations appearing in this scheme could be compensated by the inclination of the output AO cell facet. The calculations performed using the special ray-tracing module [7] show the possibility of such compensation in AO cell of paratellurite (TeO_2) with a cut angle $\gamma = 7°$ for wide spectral range. The residual chromatic shift in the range of 0.45 - 1.7 μm not exceed of 1% of the field of view. So, this AO cell geometry could be used in AOTF of any working spectral range within 0.45 - 1.7 μm.

To confirm it two AOTFs were manufactured (figure 1). They are completely identical except the spectral range. Their technical parameters are presented in the table 1.

a)


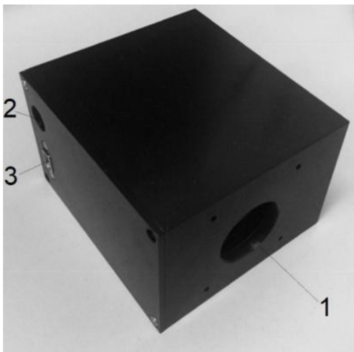
b)


Figure 1. The housing of the acousto-optic module: optical scheme (a) and appearance (b). P1, P2 – crossed polarizers; 1 - optical window, 2 - power supply socket, 3 - USB port for data exchange.

Table 1. Technical parameters of the manufactured AOTFs.

Parameter	AOTF #1	AOTF #2
Spectral Range	0.45 – 0.9 μm	0.9 - 1.7 μm
Spectral resolution	4 nm (532 nm)	56 nm (1,7 μm)
Light diameter	10 mm	
Numerical aperture	0.04	
Dimensions	75 × 82 × 52 mm^3	
Interface	UBS 2.0	

The instrument functions of the modules are shown in figure 2.

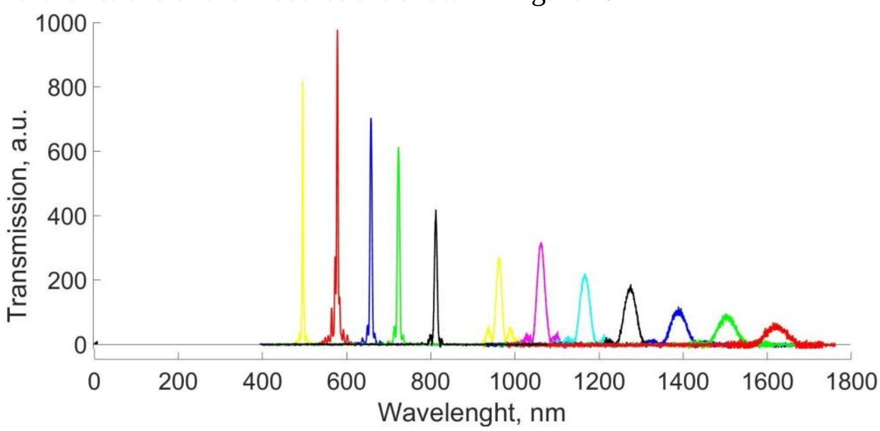


Figure 2. Transmission windows (instrument functions) of AOTF module.

A series of spectral images representing a fragment of a standard test-pattern (figure 3) demonstrates a good spectral stability and negligible distortions.

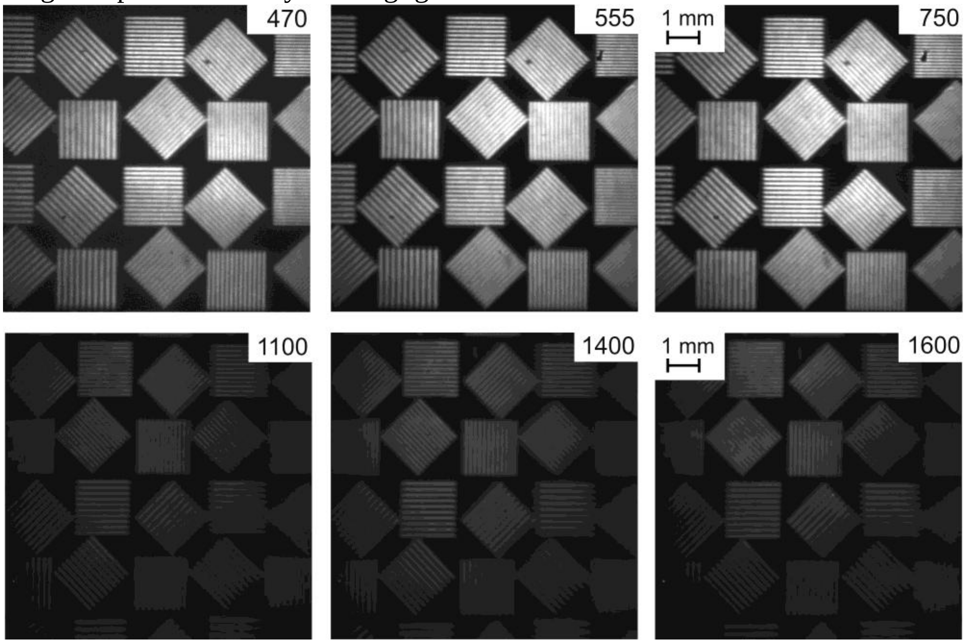


Figure 3. Spectral images of an optical test-chart recorded at different wavelength with the AOTF modules in the confocal scheme.

The developed program-controlled spectral AO filter has a potential to be the basis for hyperspectral systems and imaging spectrometers for various applications. Compact, modular design makes it easy to integrate it into various optical schemes [7]. The spectral tuning module with proper spatial spectral calibration can be used for precision spatial-spectral measurements.

3. Acknowledgment

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4. References

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