Spectrally tunable illumination system based on acousto-optic diffraction of light

A S Machikhin1,2, A B Kozlov1,3, D D Khokhlov1,2, V E Pozhar1,4, V I Batshev1,4
1 Laboratory of acousto-optic spectrometry, Scientific and Technological Center of Unique Instrumentation of Russian Academy of Sciences, 15 Butlerova, Moscow, 117342, Russian Federation
2 Department of Electrical Engineering and Introscopy, Institute of Automatics and Computer Engineering, National Research University “Moscow Power Engineering University”, 14, Krasnokazarmennaya street, Moscow, 111250, Russian Federation
3 POLYUS Research Institute of M.F. Stelmakh Joint Stock Company, Building 1, 3 Vvedenskogo St., Moscow, 117342, Russian Federation
4 Department of optic-electronic devices, Bauman Moscow State Technical University, 5, 2-ya Baumanskaya street, Moscow, 105005, Russian Federation

E-mail: machikhin@ntcup.ru

Abstract. Spectrally tunable illumination is widely used for spectral imaging, spectroscopy, spectral-domain optical coherence tomography and other applications. Most of swept-wavelength light sources are based on mechanical change of narrow-band filters or on a supercontinuum laser coupled with a tunable filter. Such commercially available sources suffer either from a limited number of spectral channels or from a spatial noise caused by parasitic interferences. Here, we describe an alternative solution, which is free from the mentioned disadvantages and provides speckle-free uniform illumination. It is based on acousto-optic (AO) diffraction of a wide-band light. AO tunable filters (AOTFs) are fully software-controlled solid-state devices and do not require mechanical scanning. The selected wavelength of light is determined by the period of the volume phase grating induced in the crystal by an ultrasound wave, i.e. by the frequency of the electric signal applied to the piezo-transducer that excites ultrasound wave. Due to high spectral resolution, small entrance pupil diameter and small angular aperture of AOTFs, its utilisation together with wide-band light sources is problematic even with a specific optical coupling to optimize the light-energy and aberration parameters of the filtered light. In this paper, we show that efficiency of this approach may be radically improved by acoustic frequency modulation.

1. Introduction
In spectroscopy, there are two techniques of spectral tuning: by means of the illumination arm or the detection arm, i.e. with the spectral element location before and behind the inspected object. Though the second scheme is used more often, the first one is sometimes preferable, for example, in order to limit the radiation flow upon the object. Nowadays, spectrally tunable illumination is widely used for spectral imaging, spectroscopy, spectral-domain optical coherence tomography and other applications1-3.

1 To whom any correspondence should be addressed.
Modern spectral tunable illumination systems can be divided into two classes: laser sources and combination of wideband source with a tunable filter. Despite the outstanding characteristics like high spectral brightness, high spectral resolution, and high speed of sweeping, lasers are not suitable for many applications because of speckle structure. Most of swept-wavelength light sources are based on mechanical change of narrow-band filters or on a supercontinuum laser coupled with a tunable filter. Such commercially available sources suffer from a limited number of spectral channels and from a spatial noise caused by parasitic interferences, correspondently.

Here, we describe an alternative solution, which is free from the mentioned disadvantages and provides speckle-free uniform illumination. It is based on acousto-optic (AO) diffraction of a wide-band light. Acousto-optical tunable filters (AOTFs) are electronically-driven solid-state devices and do not require mechanical scanning. The selected wavelength of light is determined by the period of the volume phase grating induced in the crystal by an ultrasound wave, i.e. by the frequency of the electric signal applied to the piezo transducer.

It should be noted, that effective coupling of AOTFs with wide-band light sources is a challenge due to narrow angular aperture and rather small entrance pupil diameter of the filters. Additionally to these losses, the significant decrease of the output light intensity results from narrow-band filtering. In this paper, we show that efficiency of this approach may be improved significantly by controllable broadening of the spectral bandwidth by means of acoustic frequency modulation.

2. Experimental setup
Spectrally tunable illumination system (figure 1) comprises wide-range light source, AOTF and all the necessary optical elements. The incandescent lamp or light-emitting diode can be used as an optical source. The coupling optics provide light beam shaping in respect to cross-section as well as to AOTF field-of-view. The output optics enable adjusting to the studied sample or to the working optical system.

![Figure 1. Spectrally tunable illumination system.](image)

1 – wideband source, 2 – coupling optics, 3 – AOTF, 4 – output optics, 5 – spectral tunable radiation.

The specific feature of the AOTF (figure 2, a) is two different operation techniques: single-frequency (classical) and transmission window broadening modes. In the first modes, the single-frequency signal is supplied to AO crystal cell, thus producing homogeneous grating in crystal. Therefore, the bandwidth written in optical frequency units (\(\nu = 1/\lambda_0\)) is determined by the acoustic grating width \(\Delta \nu \sim 1/D\). In the second mode, the frequency is changed rapidly, so the grating becomes inhomogeneous across the light beam, and therefore different parts of grating diffract different spectral components. In this way, the transmission window of AOTF is broaden (see figure 3 below). For modulation, we applied sawtooth-like periodical frequency variation (figure 2, b) to keep the window motionless. Varying the limits of acoustic frequency sweeping \((f_{\text{min}}, f_{\text{max}})\) we can control AOTF bandwidth and spectral location.
3. Results
The basic characteristics of spectrally tunable illumination system are following:
- spectral range: 450-850 nm
- bandwidth: from 60 cm$^{-1}$ up to 500 cm$^{-1}$
- spectral tuning: computer-controlled addressing (less 1 ms)
- AOTF: non-collinear wide-angle TeO$_2$

The developed illumination system provides fast random spectral access over the spectrum with a function of bandwidth control.

4. References
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