Differential properties of acousto-optical tunable filters in phase-modulation mode

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Tailoring the transmission function of acousto-optical tunable filters (AOTF) via acoustic waves control is one of the most challenging tasks, which is promising for optical spectroscopy applications. In our early work it was theoretically predicted and experimentally demonstrated that collinear AOTF with fast periodic phase manipulation exhibits differential properties, in particular capability of detection spectrum derivatives.

In the report, the form of the instrument function of such AOTF was measured with use of Ne-lamp linear spectrum. Comparison to theoretically calculated function shows rather good agreement. Also the form of window of equivalent differential filter was determined and proved to be quite similar to AOTF classical window. Advantages of using this differential detection technique are considered.

1 Introduction

Modulation of ultrasonic waves in AOTF-based spectrometers is primarily used for subtraction of additive component of photodetector signal caused by permanent light-striking. Also modulation provides increase of signal-to-noise ratio of the device due to elimination of long-period instabilities [1]. Modulation frequency for this purpose must be low enough compared with inverse time of ultrasound transition through photoelastic crystal $f_{mod} << 1/t_{tr}$ to ensure homogeneity of the ultrasound wave inside the crystal and applicability of stationary approximation of light diffraction. If the frequency is increased the sound intensity becomes inhomogeneous that leads to change of transmission function shape. This effect can be used for transmission function custom shaping of AOTF-based spectral devices [2-3].

Previously [3] we had for the first time pointed out that modulation makes it possible to detect photocurrent at different harmonics of modulation frequency and also had demonstrated that for fast frequency modulation ($f_{mod} \sim 1/t_{tr}$) instrument functions are different if different harmonics are used for detection. Therefore, it opens possibilities for variation of instrument function of AOTF spectrometers.

Also in the article [3] it was shown that phase modulation (manipulation) of acoustic wave in combination with phase-sensitive frequency-synchronized detection, results in complex-valued instrument function because in addition to amplitude detection it is measured the phase shift between modulation signal and recorded periodic photodetector signal. It means that spectrometer does not only integrates spectrum over definite intervals, but also is capable of comparing spectral power from different spectral intervals. It also was demonstrated [3] for spectrometer based on collinear AOTFs, that in case of alternating switching of ultrasonic wave phase with period being equal to ultrasound transit time ($t_{mod} = t_{tr}$), transmission functions at 1st and 2nd harmonics are real-valued sing-reversing function. And that photocurrent spectral dependence on AOTF central wavelength recorded at 1st and 2nd harmonics are quite similar to 1st and 2nd derivatives of spectrum of input optical radiation recorded with non-modulated AOTFs. This fact was tested and studied in this work.

2 Device

Spectrometer prototype (fig.1) was developed with phase modulated AOTF. It has following characteristics.

Spectral range	0.45 – 0.75 mcm.
Spectral resolution	0.6 nm at 0.65 mcm.
Aperture	∅6 mm × 2°.
Sizes	25×15×5 cm 2 kg.

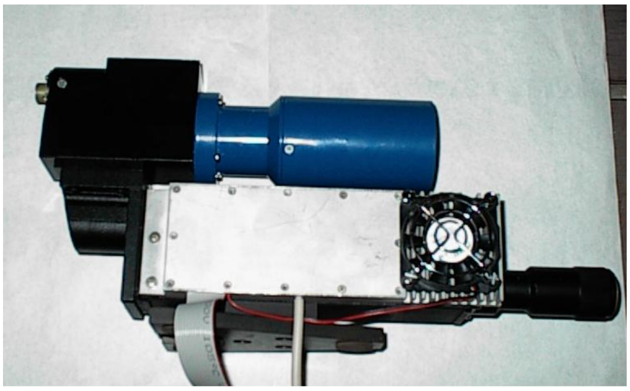

Fig.1. Modulation AOTF spectrometer for differential spectroscopy.

3 Testing

Two kinds of experiments were made with the device to answer two questions. Is spectrometer measure the derivatives or only some similar-shaped curves? Is developed theoretical model correct ?

We measured with the device several spectra lines of neon-filled gas-discharged lamp. Then 1st and 2nd derivatives were calculated from the primary spectrum. At fig.2-3 they are compared to the spectral curves detected at 1st and 2nd harmonics of modulation frequency. The plots exhibit rather good agreement in shape except some divergence at fig.2. It looks like these curves have different spectral resolution. These effect does not manifest at fig.3. This fact shall be studied later both experimentally and theoretically.

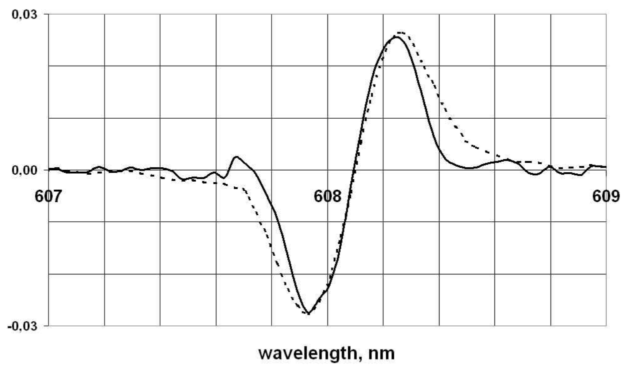

Fig.2. Experimental spectral curve (solid line) detected at 1st harmonic and 1st derivative curve (dashed) calculated from spectrum.

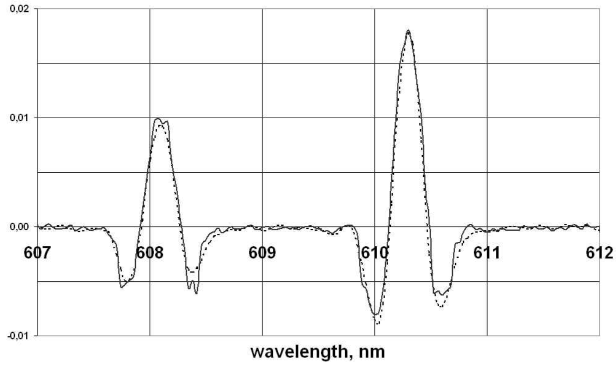

Fig.3. Experimental spectral curve (solid line) detected at 2nd harmonic and 2nd derivative curve (dashed) calculated from spectrum.

For answer second question we studied dependence of photodetector signal frequency components on phase shift value Δφ, which in fact is magnitude of modulation signal. (Authors acknowledge Dr. Sergey Boritko, who fulfilled these complex of measurements.)

At fig.4-6 there are presented experimental curves measured for different phase shift for three different detection channels: with signal integration (zero-channel), at modulation frequency (1st harmonic-channel) and at 2nd harmonic. The dependences detected are in correspondence with theoretical predictions and formula [3].

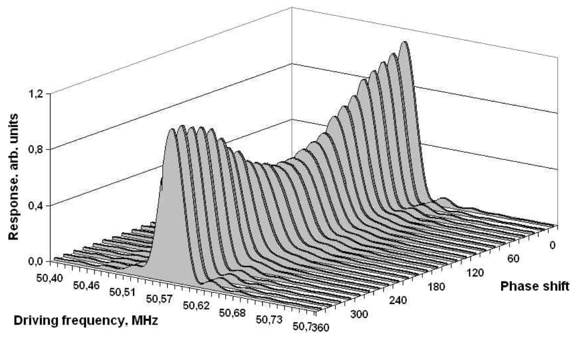

Fig.4. Experimental spectral curves detected via integration (zero-channel) for different phase shift

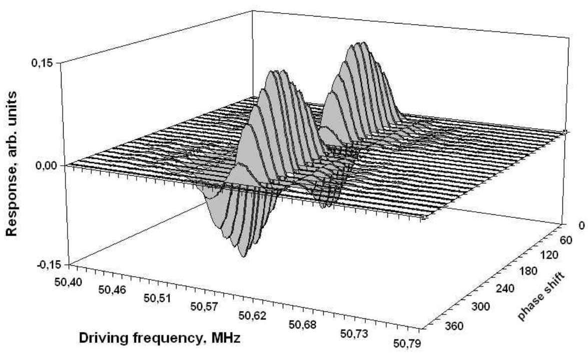

Fig.5. Experimental spectral curves detected at 1st harmonic for different phase shift.

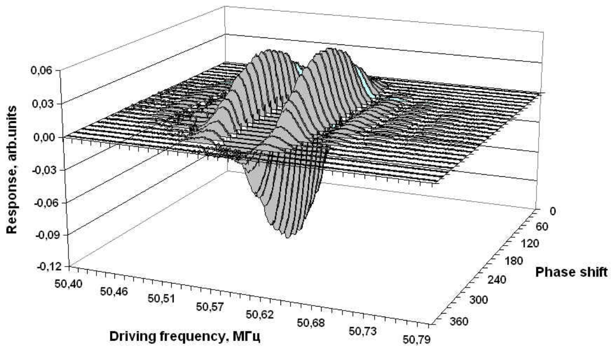

Fig.6. Experimental spectral curves detected at 2nd harmonic for different phase shift.

In particular, if phase shift equals zero then harmonic signals vanish and modulation AOTF is equivalent to classical AOTF. Also at Δφ=π only 1st harmonic signal vanishes.

4 Conclusion

Optical spectrometer based on modulation AOTF was tested. Experimental results are in quite good agreement with theoretical model.

Acknowledgments

The report was prepared in frame of works on President program of RF scientific school support (grant 5708.2008.9).

References

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