Ultraspectral UV polychromator for SRS-isotopic sensor

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Abstract. We have developed a spectral module for the selection of narrow characteristic spectral lines of isotopes in the ultraviolet Raman spectral channel. To allow resolving closely spaced isotope lines in the continuous input radiation spectrum, extremely high resolution $\lambda/\Delta\lambda = 1000$ is implemented. The total inverse linear dispersion at the output of the double polychromator ($d\lambda / dl = 0.048 \text{ nm} / \text{mm}$) allows us to confidently separate the methane lines $283.31, 284.42 \text{ nm}$

1. Introduction

For spectral devices in general, and also for Raman sensors, which measure weak signals in particular, effective control with background highlights in the device itself is necessary while simultaneously suppressing Rayleigh scattering of airborne laser radiation by air molecules. The most radical means of dealing with diffused light is the use of double and even triple monochromators. Among the variety of spectrographs with a concave lattice, only a few have received the most widespread use, in particular, the Paschen – Runge scheme. In devices built according to this scheme, the entrance slit, the concave grating and the exit slit or photoreceiver are fixed at the Rowland circle, which is the dispersion line, and mechanically unrelated to each other. With the transition to the UV region in prisms and diffraction gratings, as is well known, the angular and linear dispersion increases substantially.

The complexity of developing a spectral module, designed to isolate narrow characteristic spectral IV lines from the continuous spectrum of input radiation, is due to the extremely high (ultra-spectral) resolution $\lambda/\Delta\lambda = 1000$. To resolve closely spaced IV isotopes, the following options are considered [1]:

1. Scheme of Cherni-Turner with many (2-3) diffractive elements in the mode of addition of wave fronts and dispersions
2. Cherne-Turner scheme with a diffraction grating in 3–4 diffraction order
3. Ebert’s scheme based on a combined collimating-focusing mirror
4. High-performance multichannel spectrometer with a Paschen-Runge monochromator based on the Rowland circle and concave hologram gratings
5. High-performance spectrometer on Echelle type gratings.

2. Experiment

To obtain the minimum level of scattered radiation, a double polychromator can be constructed according to various schemes: with a horizontal plane of symmetry, or in a horizontal-vertical scheme.
As was said, the scattered light depends on the number of optical parts in the device: the smaller, the better. It is impossible to quantify the level of scattered radiation at the design stage, since scattered radiation depends on the quality of the optics and the culture of its production.

We will conduct a preliminary assessment of the polychromator scheme, as a key element of the spectral module (fig. 1). We will carry out the calculation of the polychromator in the range of the UV spectrum, where the absorption cross sections in the Raman are maximum, 250 - 300 nm [1].

We believe that the polychromator is composed of two wide-angle stigmatic hologram gratings of the 2nd type and three slots: input, intermediate and output. Each grating is made with \( N = 3600 \) lines, radius \( R = 500 \) mm and has a resolving power of 450,000 for wavelengths of about 280 nm and a spectral reflectance of 60%.

3. Results

The use of hologram optical elements in the spectral module will not only reduce the noise characteristics in comparison with rifled gratings with noticeable light scattering, but also allow you to work with a wide aperture, because unlike rifled ones they are free from spherical aberration and astigmatism. The angles of incidence \( \psi \) and diffraction \( \phi \) are related by the known relation

\[
\sin \psi + \sin \phi = k \cdot \lambda \cdot N,
\]

where \( k = 1, 2, 3, \ldots \) - spectrum order; \( N \) is the number of grid lines per 1 mm. Angular dispersion \( \frac{d\phi}{d\lambda} = k \cdot \frac{\lambda}{(b \cdot \cos \phi)} \)

Linear dispersion \( \frac{d\lambda}{d\phi} = f \cdot \frac{d\phi}{d\lambda} \), where \( f \) is the focal length.

The limiting resolution \( \frac{\lambda}{\Delta\lambda} = \frac{Nb}{\lambda} = \frac{h}{\lambda} \), here \( b \) is the lattice period, \( h \) is the width of the shaded part of the lattice.

Thus, the resolving power is proportional to the number of lines on the entire area of the diffraction grating. As a result, the total inverse linear dispersion of a concave diffraction grating for a double polychromator is obtained equal to \( \frac{d\lambda}{d\lambda} = 0.224 \) nm / mm. Such an ultra-spectral resolution makes it possible to confidently separate the lines C12H4 (283.31; 284.42 nm), N2 (278.69 nm).

In particular, when the difference in wavelengths of 4.62 nm for CH4 and N2 molecules, the linear distance in the polychromator was 20.6 mm.

Figure 1.a. High resolution polychromator.
Figure 1. b. The scheme of high-resolution polychromator on two concave diffraction gratings in the first diffraction order with \(N = 3600 \text{ mm}^{-1}\) strokes, radius \(R = 500 \text{ mm}\).

Characteristics of mentioned polychromator are given below in Table 1.

Table 1. Characteristics of high resolution polychromator.

| High resolution polychromator | Holographic grating, concave |
|-------------------------------|-----------------------------|
| Dispersive elements, type     | 3 pcs                       |
| Number of dispersion elements |                             |
| Number of strokes             | 3600 mm\(^{-1}\)            |
| Radius of curvature           | 500 mm                      |
| Diffraction order             | 1                           |
| Spectral range                | 264-294 nm                  |
| Reflectivity (280 nm)         | 0.6                         |
| Spectral resolution           | >>1000                      |
| Dimensions                    | 820x370x185 mm              |

4. Conclusion

Studies have shown the possibilities of application of Scheme of Cherni-Turner as a sufficient accuracy method for detection lines of isotopes in the ultraviolet Raman spectral channel. Further, we have used the hologram optical elements, which are expand the aperture. In addition, the resolving power was received enough to separate the lines C12H4 (283.31; 284.42 nm), N2 (278.69 nm). The authors propose to continue their research to develop the technology for the selection closely spaced isotope lines in the continuous input radiation spectrum.

Acknowledgments

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