SOME PROBLEMS OF SELECTION OF THE NARROW SPECTRAL INTERVALS FOR PURPOSES OF LASER SOUNDING OF THE ATMOSPHERE

S.N. Volkov, B.V. Kaul', V.A. Shapranov, and D.I. Shelefontyuk

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk
Received March 23, 1995

This paper deals with some problems of the use of light guides for selection of the narrow spectral intervals in laser sounding of the atmosphere. The problems of linking spectral devices with lidar receiver have been considered. Constructional features of the spectral devices applied in the Raman channel of the Siberian lidar station have been described.

Application of light-guide optics to laser sounding has motivated a new view on the classical use of instruments intended for the selection of narrow spectral intervals in the optical range. Sometimes, for example, in the sounding of aerosol, it is necessary to select a single spectral interval, in which case interference filters are successfully used. Monochromators are often used for simultaneous selection of several spectral intervals, and the Fabry-Perot interferometer is used for the selection of individual spectral lines. A successful example of application of the light-guide technology in lidar sounding can be found in Ref. 1.

The problems connected with the use of light guides are reduced, first, to the optimal link of a lidar antenna with a spectral device through a light guide and second, to constructional features of the spectral device caused by light-guide optics that allow good use of the light flux in the Raman channel.[2] Linking of the light guide with a lidar receiver and spectral device is reduced to the fulfillment of the following conditions:

$$d \geq \varphi \cdot F \;, \tag{1}$$

$$L/2\,F \lesssim \sqrt{n_1^2 - n_2^2} \;, \tag{2}$$

$$\Delta W = d/f \;, \tag{3}$$

$$A/2\,f \gtrsim \sqrt{n_1^2 - n_2^2} \;, \tag{4}$$

where d is the light-guide diameter; φ if the total angular divergence of a laser beam; F and L are the focal length and the diameter of a receiving antenna, respectively; f and A are the focal length and the working diameter (aperture) of a monochromator objective, respectively; ΔW is the angular width of a spectral line; and, n_1 and n_2 are the refractive indices of light-guide core and cover, respectively.

The fulfillment of condition (1) makes feasible complete interception of the singly scattered radiation incident on the antenna. Condition (2) meets the requirement for light-guide operation at incidence angles smaller than the critical angles, since its right-hand side contains the light-guide numerical aperture[3] being equal to the sine of the critical incidence angle. Condition (3) determines the desired angular width of the slit instrumental function.[4] Condition (4) makes feasible complete interception of radiation coming from the light guide by the monochromator objective.

The most characteristic values of the light-guide aperture are in the range 0.2–1.2 mm, and the most characteristic relative apertures are within 2.5–3 mm. It should be taken into account that when the radiation is transmitted through the light guide, angular divergence of the beam increases up to the light-guide numerical aperture due to local inhomogeneities and bends of the light guide.

Joint fulfillment of conditions (1)–(4) is provided in the Raman channel of the Siberian lidar station as follows (Fig. 1). The receiving mirror diameter is equal to 2.2 m, and its focal length is 10 m; thus, its relative aperture is 1:5. The angular laser beam divergence is 1', so the image size in the focal plane is equal to 3 mm. An input pupil of the light guide consists of seven fiber cores 1 mm in diameter aligned in a bundle 3 mm in diameter. At the output, quartz fibers of the light guide are arranged in a strip and form an output slit of a double monochromator 1 mm wide and 7 mm long. The relative aperture of the monochromator is 1:3, and the spectral range of an input slit is 0.1 nm.

Let us consider some constructional features of the double monochromator with light-guide decoupling.

The double monochromator is destined for selection of the following spectral intervals: pure rotation Raman scattering (RS) spectrum of nitrogen, elastic scattering at base lasing line, Raman scattering line of water vapor, and the unsuppressed background of the base lasing line.

0235-6880/95/10 833-03 $02.00

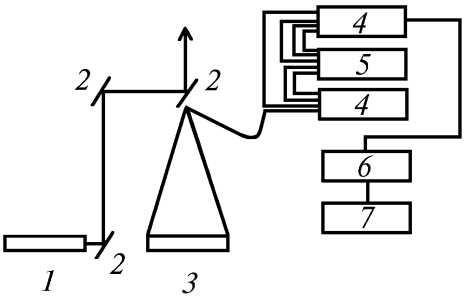

FIG. 1. Raman channel of the Siberian lidar station: 1) laser, 2) deflecting mirrors, 3) mirror, 4) double monochromator blocks, 5) photomultiplier, 6) photoelectron counter, and 7) computer.

The monochromator consists of two identical blocks, each embodying the autocollimation principle, with a diffraction grating having 1200 lines per mm, operating in the first diffraction order, and providing reciprocal linear dispersion of 12 Å/mm. The autocollimation principle of construction of the monochromator makes it feasible to minimize the effect of aberrations and astigmatism in the image plane. Four spectral intervals of the rotation Raman spectrum of nitrogen, symmetrical about the base line of elastic scattering, and the Raman line of water vapor are selected at the output of the first block by light guides arranged in a 1×7 mm strip. The spectral width of the selected intervals is 1.2 nm. The light-guide outputs of the elastic scattering line and Raman line of water vapor are connected with a photomultiplier, and the outputs of four other light guides form input slits of the second block of the monochromator. Two spectral intervals of the rotation spectrum and the background line of elastic scattering are selected at the output of the second monochromator and are directed to the photomultiplier through the light guides.

Thus, light-guide decoupling makes it feasible to simplify the monochromator construction, to exclude a massive common base, and, what is most important, to translate the optical axes in the double monochromator so that the output lines after the first monochromator be at the input plane of the second monochromator in any given sequence. In our case, the input light guides are arranged in the second block of the monochromator so that two input spectral intervals be summed in pairs to form a single output interval with the background suppression by four orders of magnitude. It is practically impossible to solve this problem without light-guide decoupling.

When we take into account that the unsuppressed background, being four orders of magnitude of the base lasing line, is formed by the secondary maxima caused by diffraction on a grating and is manifested in the image plane as line whose height is equal to the length of the input slit,[5] it becomes feasible to realize a dual-beam monochromator that makes the double monochromator construction simpler. Such monochromator, constructed on the basis of autocollimation principle, is tested now at the Siberian lidar station. The monochromator consists of one block with diffraction grating having 600 lines per mm and operating in higher diffraction order. The input and output image planes in this monochromator are separated along the vertical direction symmetrically about the monochromator axis (Fig. 2). The input slit and the image plane of the first stage of the spectral selection are located closer to the monochromator axis, and the input and output image planes of the second stage are located symmetrically at its ends. The selected spectral intervals after the first spectral stage are brought in the input plane of the second stage of the monochromator. Thus, the total suppression of the base line background is eight orders of magnitude.

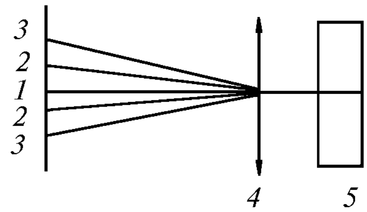

FIG. 2. Dual-beam monochromator: 1) optical axis of the dual-beam monochromator, 2) the first stage of spectral selection, 3) the second stage of spectral selection, 4) lens, and 5) diffraction grating.

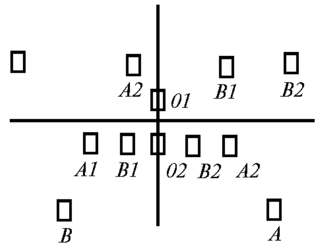

FIG. 3. Arrangement of slits in the image plane of the dual-beam monochromator: input and output slits of the first stage of spectral selection (01 and 02); selected spectral intervals of the rotation Raman spectrum of nitrogen (A1, B1, A2, and B2); output slits of the second stage of spectral selection (A and B).

The arrangement of slits in the image plane of the dual-beam monochromator is shown in Fig. 3. Four symmetrical intervals of the rotation Raman spectrum of nitrogen are selected after the first stage of the spectral selection. The spectral width of the selected intervals is 0.69 nm. The mutual arrangement of the spectral intervals in the input plane of the second stage of the spectral selection is such that they are summed to a single interval at the output of the second stage. Then, the output slit A corresponds to the input intervals $A1$ and $A2$, and the spectral intervals $B1$ and

$B2$ are summed to the output spectral interval B. The spectral width of the output spectral intervals is 0.35 nm.

The light guides introduce additional losses in the optical scheme of the lidar. The principal losses are due to the inhomogeneities of the light-guide ends. The mean transmittance of the quartz light guides is approximately 70–80% in the visible spectral range. However, the gain is obvious when it is necessary to decrease the effect of vibrations, to stabilize the transmittance of the optical train of the lidar, and to decrease its dimensions and mass.

ACKNOWLEDGMENT

The work was supported in part by Russian Fund of Fundamental Research Grant No. 93-05-9376.

REFERENCES

1. Yu.F. Arshinov, S.M. Bobrovnikov, D.I. Shelefontyuk, et al., in: *Abstracts of Reports at the First Interrepublic Symposium on Atmospheric and Oceanic Optics*, Tomsk (1994), Part 2, pp. 26–27.
2. S.N. Volkov, B.V. Kaul', V.A. Shapranov, and D.I. Shelefontyuk, Atmos. Oceanic Opt. **5**, No. 6, 384–385 (1992).
3. B.A. Krasyuk and G.I. Korneev, *Optical Communication Systems and Light-Guide Sensors* (Radio i Svyaz', Moscow, 1985), 192 pp.
4. K.I. Tarasov, *Spectral Devices* (Mashinostroenie, Leningrad, 1974), 368 pp.
5.V.I. Malyshev, *Introduction into Experimental Spectroscopy* (Nauka, Moscow, 1979), 480 pp.