CHOICE OF A WAVELENGTH OF LIDAR SYSTEM OPERATION IN AN EYE-SAFE SPECTRAL REGION

G.G. Matvienko, O.V. Kharchenko, and T.A. Yarchuk

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk
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The role of atmospheric gases in the absorption of optical radiation has been analyzed in the range 1.5–2.1 μm. *Transparency microwindows optimum for laser sensing have been chosen. The* Tm^-, Ho^-, *and* Nd^- *ion lasers with frequencies shifted in cells with stimulated Raman scattering are shown to be promising.*

The need to meet the requirements imposed by the International Standards of Public Health Service for lidars used for monitoring of our environment calls for the use of laser sources with a wavelength longer than 1.4 μm falling within an eye-safe spectral region. Modern lasers allow the radiation in the above–indicated range to be obtained with the use of new working media [for example, Er,Yb:YAG; Er,Yb:Glass; Er:CAS (lasing region 1.5–1.6 μm); Tm,Ho, Cr:YAG; Tm,Ho:YLF; Tm,Ho:$GdVO_4$; Tm,Ho:CAS (1.9–2.1 μm); GaInAsSb (1.8–2.5 μm)], cells with stimulated Raman scattering (SRS), parametric generators, and others.[2,3]

However, as is well known,[4,5] this spectral range is rich in the absorption lines of widespread atmospheric gases (H_2O, CO_2, CH_4, CO, O_2, and so on). For this reason, the problem arises of justified choice of lidar wavelength to ensure its minimum atmospheric gas absorption.

In this paper, absorption-free spectral regions in the 1.5–2.1 μm spectral range are analyzed for systems of laser sensing of the atmospheric parameters. We study the transmission spectra of a gaseous atmosphere to choose transmitting lidar systems and other laser devices operating in the atmosphere with minimum losses.

The transmission spectra of the atmosphere were estimated for near-ground path of length 1 km. Spectroscopic data were borrowed from the GEISA Atlas,[6] and meteorological parameters were for McClatchey's model for the mid-latitudes in summer.[7]

According to the data from the Atlas[6] compiling information on 37 gas, absorption bands of the following gaseous components: H_2O, CO_2, CH_4, O_2, CO, N_2O, HCl, HBr, HI, and OH, fall within the investigated range. In Fig. 1, the position and total intensity of absorption bands for gases listed above are shown. It should be noted that the H_2O, CO_2, and OH lines occur practically everywhere over the spectral range under study; therefore only the most intense absorption bands are shown in Fig. 1.

As is seen from Fig. 1, water vapor and carbon dioxide are basic absorbing components. Vibration-rotation bands of water vapor are grouped together and form very strong absorption band centred at λ = 1.87 μm. For the mid-latitudes in summer this band absorbs almost completely the radiation in the spectral region 1.77–1.94 μm at an average humidity of 14 g/m^3. Intense lines of water vapor also occur in the region 1.50–1.53 μm, in which the wing of the strong spectral band centred at 1.38 μm falls. Carbon dioxide has a series of bands grouping together in integral absorption bands centred at 1.6 and 2.0 μm, which hamper the choice of the transparency microwindows in the regions 1.57–1.61, 1.95–2.03, and 2.05–2.07 μm. Thus, in the spectral region 1.5–2.1 μm it is expedient to choose the following spectral regions: 1.53–1.57, 1.61–1.77, 2.03–2.05, and 2.07–2.10 μm as promising for laser sensing.

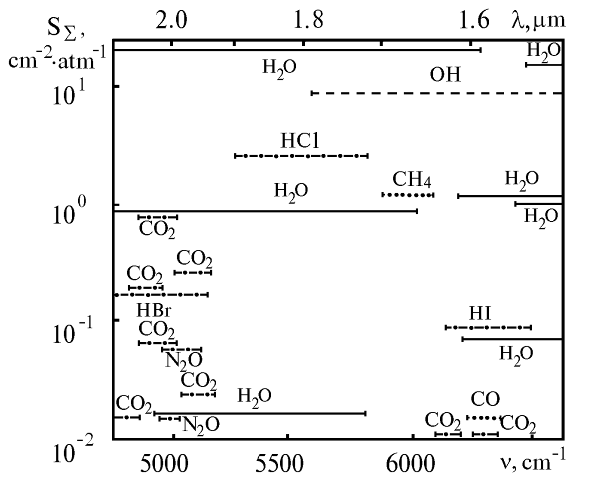

FIG. 1. Position and total intensity of absorption bands of atmospheric gases in the spectral region 1.5–2.1 μm.

Occurrence of the methane absorption band with the total intensity being equal to 1.27 cm^{-2}/atm^{-1} constrains the choice of the atmospheric transparency microwindows in the spectral region 1.64–1.70 μm.

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The OH spectrum is complex in structure and extremely rich in absorption lines, but all of them are weak (from 10^{-27} to 10^{-64} cm/mol) with exception of lines of fundamental overtone centred at 1.5 μm. The total intensity of this band is 8.97 $cm^{-2}atm^{-1}$, but the OH absorption contributes insignificantly to the extinction of laser radiation because of small OH concentration in the lower atmosphere.

Hydrogen chloride has an absorption band in the region 1.72–1.90 μm with total intensity being equal to 2.65 $cm^{-2}atm^{-1}$. Individual lines of this band are 0.03–0.05 μm apart, which allows us to choose the transparency microwindows.

Hydrogen bromide and hydrogen iodide spectra have analogous structures. Their absorption bands fall within the spectral regions 1.94–2.12 μm and 1.53–1.62 μm, respectively. However, the absorption spectra of these gases impose no essential restrictions on the choice of the transparency microwindows, because of their weak line intensities and small concentration of these gases in the atmosphere.

Weak absorption bands of nitrous oxide and carbon oxide also fall within the investigated range. Our calculations have shown that contribution of these gases to the laser radiation absorption is ~ 0.03% for model values of concentration $n_{N_2O} = 0.5$ and $n_{CO} = 1$ ppm.

The total intensity of the oxygen absorption band is very small ($2.8 \cdot 10^{-9}$ $cm^{-2}atm^{-1}$) in the region 1.56–1.59 μm. Thus, contribution from oxygen to the absorption of laser radiation within the considered range is insignificant despite its high concentration (209 000 ppm) in the atmosphere.

Let us consider the selected spectral regions in more detail. The spectral region 1.53–1.57 μm with the most intense lines is shown in Fig. 2*a*. The Er, Yb:YAG, Er,Yb: Glass, and Er: GAS laser radiation as well as the radiation of the SRS cells filled with H_2, D_2, or CH_4 gases excited by Nd:YAG laser radiation are within this spectral interval.[2,3] As is seen from Fig. 2*a*, only isolated narrow absorption lines occur in the given region, and their possible effect can be easily excluded by tuning the lasing frequency.

In Figs. 2*b* and *c* the transmission spectra of the atmosphere are shown for the region of lasing of the Tm^-, Ho^-, and Cr^- ion lasers. As is seen from the figures, isolated absorption lines of H_2O and CO_2 (intense lines are among them) occur in the selected regions. However, it is always feasible to choose the transparency microwindows which are practically free of absorption by atmospheric gases.

Our calculations justify that available laser sources are promising for sensing in an eye-safe spectral range and can be used to specify lasing wavelength in the selected spectral region. It should be noted that only widespread atmospheric gases have been analyzed in this study. Other industrial and technological gases should be considered specially.

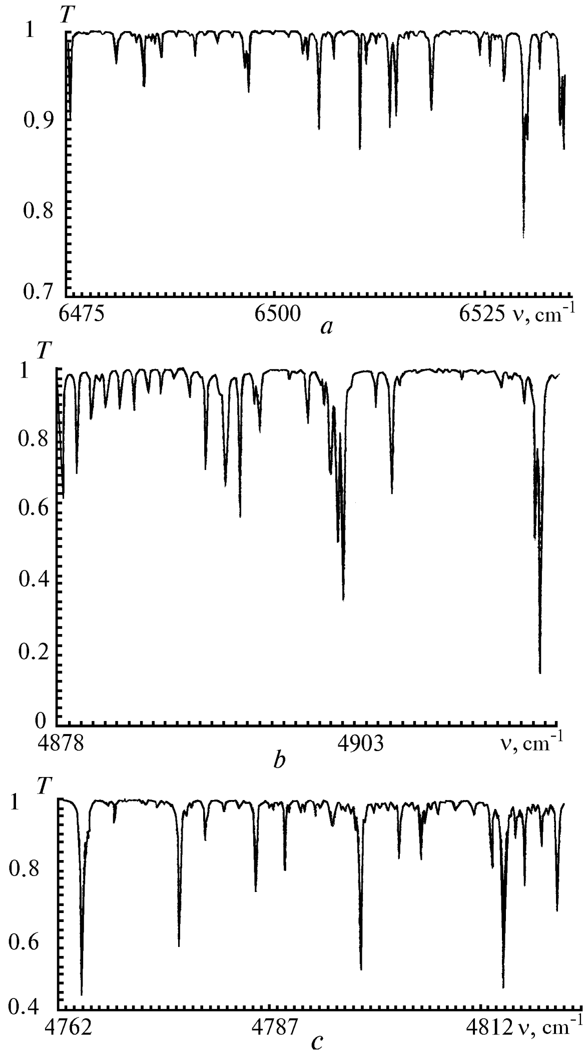

FIG. 2. Transmission spectra of the atmosphere in transparency windows within the spectral regions 1.53–1.57*(a),* 2.03–2.5*(b), and* 2.07–2.1 μm *(c).*

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