Comparison of different photoelectronic systems for recording of lidar return signals in atmospheric ozone sensing

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Domestic FEU–130 photomultiplier tube with also domestic amplifier-discriminator are compared with a HAMAMATSU R7207–01 photomultiplier and C3866 amplifier-discriminator as applied to the problem of ozone sensing at the Siberian Lidar Station. It is shown that use of a R7207–01 photomultiplier provides for wider capabilities in extending the altitude range, in which ozone profiles can be reconstructed, upward and downward by 30% due to higher count rate and higher quantum efficiency as compared with those of the FEU–130 photomultiplier. In addition, application of a HAMAMATSU R7207–01 photomultiplier and C3866 amplifier-discriminator extends the altitude range of ozone profile reconstruction and improves the measurement accuracy by 10–15%.

Lidar sensing of ozone at the Siberian Lidar Station has been performed since 1989 in the routine mode.[1] During this time, the lidar was modernized several times. The updated block-diagram of the ozone lidar is shown in Fig. 1. The ozone lidar includes two sources of optical radiation based on excimer XeCl and KrF lasers equipped with SRS hydrogen cells for the SRS frequency conversion of radiation and two receiving systems with large and small telescopes. The parameters of the lidar are given in the Table. Two radiation wavelengths (308 and 353 nm) are used for sensing the stratospheric ozone, and other pair of wavelengths (277 and 313 nm) is used for sensing the tropospheric ozone. Backscattered radiation, upon passing through the receiving optics, is recorded with photomultiplier tubes (PMTs) operated in the photon counting mode. In the ultraviolet (UV) spectral region, photon counting PMTs have highest sensitivity and linearity that provide for quite an acceptable signal-to-noise ratio in a wide dynamic range up to 10^5. At the same time, parameters of PMTs vary widely depending on the electronic components used, design, and technological peculiarities.

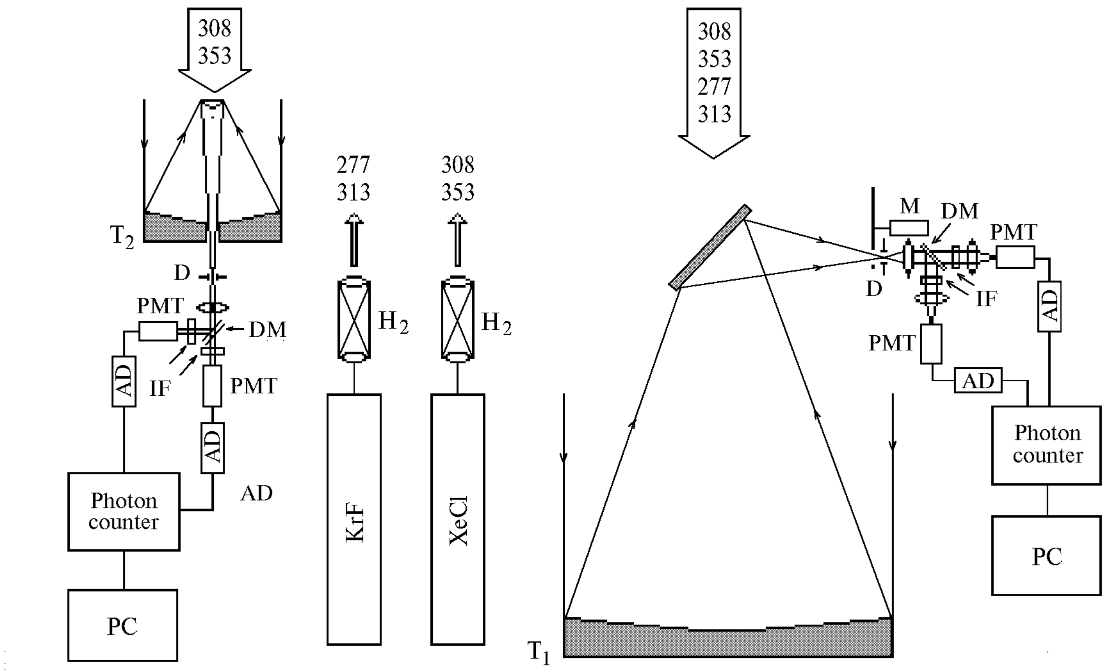

Fig. 1. Block-diagram of the ozone lidar: excimer XeCl laser (λ = 308 nm), excimer KrF laser (λ = 248 nm), H_2 cell of SRS converter, large and small receiving telescopes T_1 and T_2, field stop diaphragm D, mechanical chopper M, interference filter IF, dichroic mirror DM, amplifier-discriminator AD, and a personal computer PC.

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Table

Channel	Laser	Wavelength λ, nm	Energy per pulse E, mJ	Mean power P, W	Pulse repetition rate f, Hz	Divergence θ, mrad
Stratospheric channel	XeCl+SRS(H_2)	308, 353	$80_{(308\ nm)}$	2.5	100	0.1
Tropospheric channel	KrF+SRS(H_2)	248, 277, 313	$350_{(248\ nm)}$	7	20	0.1

Receiving telescope	Mirror diameter D, m	Focus F, m	Field of view φ, mrad	Wavelengths of received radiation, nm
Newtonian system	1	2	1	277, 313, 308, 353
Cassegrainian system	0.25	1.1	1–2	308, 353

The signal from a PMT comes to the amplifier-discriminator (AD), which produces standard transistor-transistor-logic (TTL) pulses at its output converted from emitter-coupled-logic (ECL) pulses. TTL pulses are then recorded with a photon counter. The PMT–AD chain plays the principal role in the lidar recording system that significantly affects the altitude range of ozone profile reconstruction. In this connection, when modernizing the lidar, particular attention is paid to both the development of an AD circuitry and choosing PMTs to be operated in the corresponding UV region. Criteria of making the choice are the dark count rate level, sensitivity, and the dynamic range of linear operation.

The first steps choosing acceptable domestic PMTs operating in this spectral region in the photon-counting mode has led us to the FEU–130 as the optimal PMT in the quantum efficiency of a photocathode and the signal-to-noise ratio. The matter is that FEU–130 has a semitransparent potassium-cesium-antimony photocathode sensitive in the spectral region from 300 to 650 nm with a maximum in the region of 400–420 nm. It has electrostatic focusing of electrons and box-like 12-dynode gain system with the first dynode from gallium phosphide arsenide. The resistors of the voltage divider are chosen to meet the ratios: $R1 = 5.2R$, $R2 = 1.18R$, $R3 = 0.82R$, $R4 = R5 = \ldots = R13 = R$. The value of R is taken equal to 110 kΩ. The capacitors set at three last dynodes have the following capacity: $C1 = 0.15$, $C2 = C3 = 1$ μF. Resistors and shunt capacitors are numbered from the photocathode. The AD with the input resistance of 50 Ω and the amplification factor $K_{am} \sim 50$ is used as a PMT load.

After pulse-height discrimination of pulses, a comparator converts ECL to TTL. The AD output cascade generates 15-ns pulses that could be transmitted through a 50 Ω impedance line. A FEU–130 PMT provided recording of lidar signals with the subsequent reconstruction of the ozone profiles in the altitude range from 14 to 34 km (Ref. 2). The highest altitude of ozone sensing was restricted not only by the energy of the laser source, but also by the efficiency of the photocathode of a PMT. The restriction at low altitudes is connected with the increase of the photon count rate that cannot be resolved in time with a PMT in the so-called transient operating mode.

The R7207–01 photomultiplier produced by HAMAMATSU proved to be the most efficient photomultiplier. It has a bialkali photocathode sensitive in the spectral region from 160 to 650 nm with a box-like and line-like 11-dynode system and the maximum spectral sensitivity at 420 nm. It possesses a very low dark count rate (10 pulses/s) and high temporal resolution (anode current pulse duration of 1.7 ns). As a result, the photon count rate can be almost an order of magnitude higher than that of a FEU–130. The R7207–01 has the maximum supply voltage of 1500 V, whereas for FEU–130 it is 2200 V at almost the same size.

As an amplifier for the lidar recording system, we have chosen a HAMAMATSU C3866 amplifier-discriminator.[3] It includes an amplifier of the PMT output pulses, comparator, pulse shaper, pulse stretcher, ECL/TTL pulse converter, and a multiplexer. The AD has high signal-to-noise ratio with the amplification factor $K_{am} = 125$, wide pass band up to 100 MHz when using 1:10 divider, which can be turned on both with a switch and with a control voltage pulse. The C3866 provides a 10-ns long output pulse (without a 1:10 divider); in the presence of the divider, the duration of output pulses depends on the count rate. The resolution of a pair of pulses provided by the AD is 25 ns without dividing and 10 ns with dividing. This corresponds to the frequency bands of 40 and 100 MHz.

Before installing new photodetectors into the lidar, we have determined their statistical characteristics on a test bench for domestic and foreign PMTs. Using a FS1 UV filter we cut off the visible part of the spectrum. Figure 2 shows the counting characteristics measured at the test bench under the same conditions at constant illumination and with the use of the domestic AD. The dark count characteristic of FEU–130 has a sharp increase starting from the supply voltage of 2 kV. The counting characteristic with illumination has no pronounced plateau. The supply voltage was chosen based on the maximum signal-to-noise ratio; for this PMT it proved to be 2000 V. The R7207–01 PMT has a pronounced plateau on the count characteristic. This plateau begins at the voltage of 920 V. The maximum signal-to-noise ratio for this PMT is observed at the supply voltage of 950 V; just this voltage was taken as the operating one. The count characteristics for these PMTs were obtained at the discrimination threshold at the level of 60 mV.

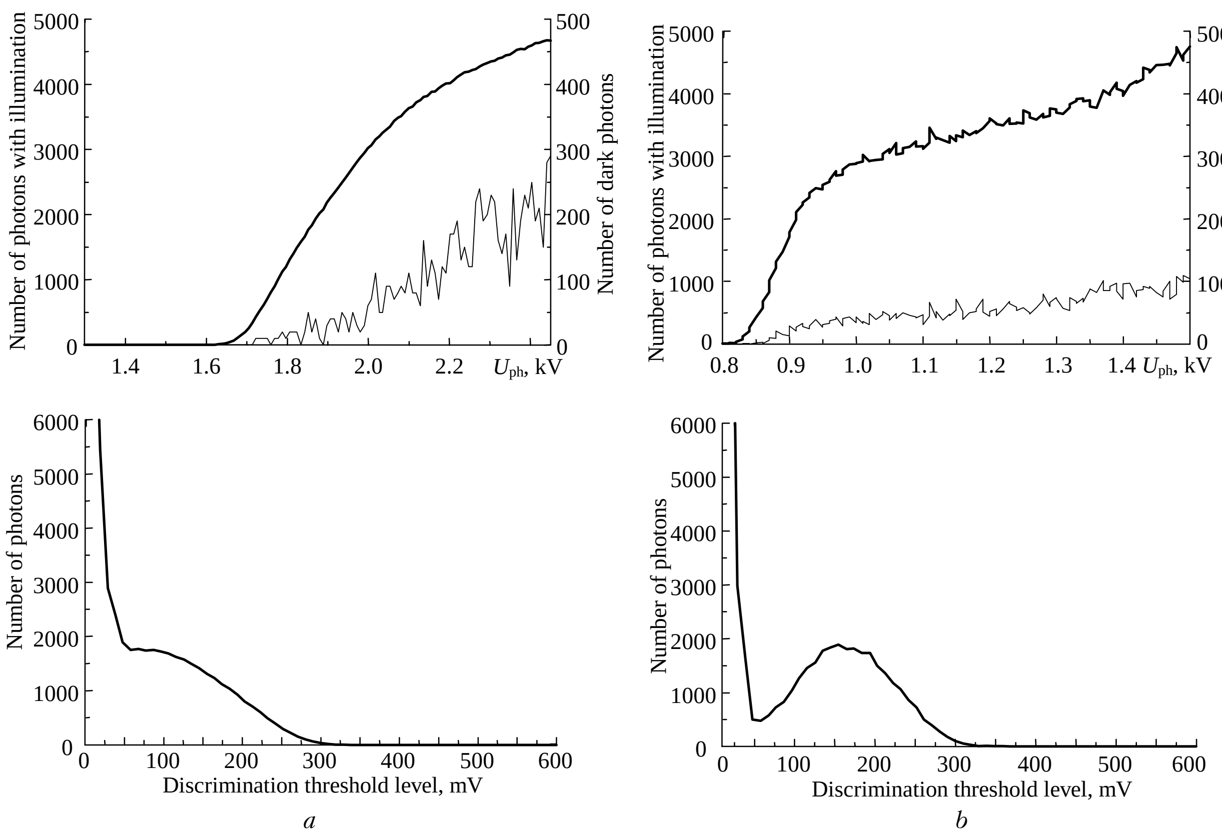

Fig. 2. Counting characteristic and amplitude distribution: FEU–130 (*a*) and HAMAMATSU R7207–01 (*b*).

After bench tests, the photodetectors were set on the lidar. The recorded signals were corrected for possible coalescence of photocurrent pulses by the equation[4]

$$M = N \exp(-N\tau/n\Delta T),$$

where N is the number of photons that come to the PMT input; M is the recorded number of single-electron pulses; n is the number of measurements; τ is the width of a single-electron pulse at the discrimination threshold level; ΔT is the time-gate length. For FEU–130 the duration of a single-electron pulse at the discrimination threshold level is 13 ns, whereas for R7207–01 it is only 1.7 ns.

Accumulated signals are shown in Fig. 3. The signals at maximum for the 353-nm channel differ by 40%, and for the 308-nm channel they differ twice.

The ozone profiles were reconstructed from the lidar data by using the differential absorption lidar (DIAL) method and highly efficient algorithms of spline-approximation.[5] The obtained profiles are shown in Fig. 4. It is seen that if the domestic photodetectors allow reconstruction of the ozone profiles in the altitude range from 14 to 34 km, the use of the HAMAMATSU products extends it from 11 to 36 km due to higher quantum efficiency and operating rate of the HAMAMATSU PMTs. The difference in the operating rate by about an order of magnitude causes the observed difference in the position of the ozone profiles, including different position of its maximum.

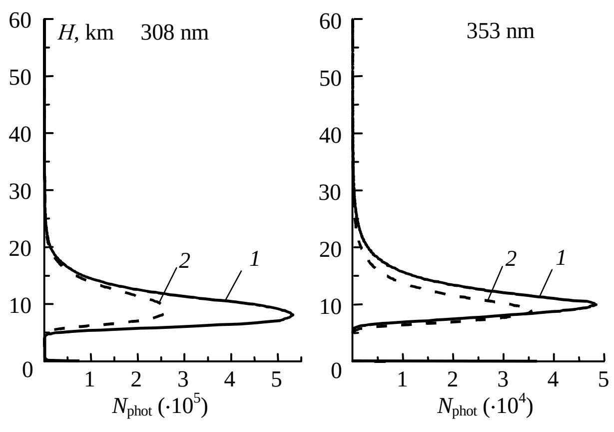

Fig. 3. Lidar signals recorded in the 308 and 353-nm channels: receiving-amplifying system with HAMAMATSU PMT and amplifiers-discriminators (*1*), receiving-amplifying system with FEU–130 and domestic amplifiers-discriminators (*2*).

Thus, modernization of the ozone lidar with new HAMAMATSU R7207–01 PMTs and C3866 amplifier–discriminators has allowed us not only to extend the altitude range of the ozone profile reconstruction in the stratosphere by almost 30%, but also to increase the accuracy of the recorded data by 10–15%.

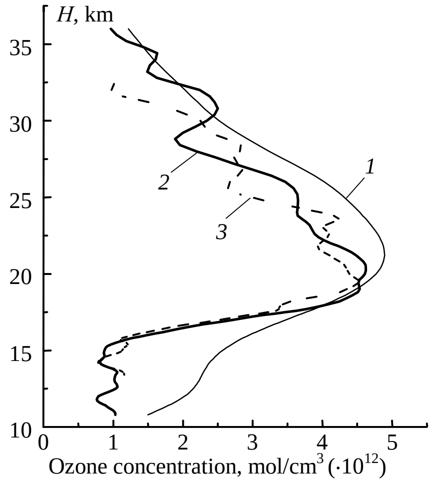

Fig. 4. Reconstructed ozone profiles: Kruger model (curve *1*), reconstructed ozone profile recorded with HAMAMATSU PMT and amplifiers-discriminators (*2*), and reconstructed ozone profile recorded with FEU–130 and domestic amplifiers-discriminators (*3*).

Acknowledgments

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