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Constructional features of a LISD-2M laser velocimeter and rangefinder

Yu.V.Abazadze, N.A.Litsarev, V.L.Pochtarev, V.A.Pashkov, A.Yu.Khachiev, A.A.Kazakov, Yu.P.Koval', V.A.Simakov, V.N.Neustrueva, G.S.Egorova, I.D.Zalevskii, A.A.Borodkin, S.M.Sapozhnikov

***Abstract*. The constructional features of a velocimeter – rangefinder based on pulsed AlGaAs/GaAs heterolasers are considered. The characteristics of the measuring instrument as well as of its individual elements (laser array and photodetector) are presented.**

Keywords: *laser velocimeter, laser emitter array, silicon avalanche photodiode*

The main instruments employed at present for measuring the speed of automobiles on the roads are radars operating in the microwave region [1], which use the Doppler effect for measuring speed. These instruments are quite simple in construction, but have a significant drawback in that they have a broad radiation diagram. In the best samples of the instruments used for this purpose, the radiation frequency lies in the centimetre range and the beam divergence is about 10°.

In actual practice, this means that the beam covers several traffic lanes at a distance of 100 m, and the reflected signal is received from several objects simultaneously in the case of a heavy traffic. Under these conditions, the measuring system is based on singling out the object moving at the highest speed. However, the identification of a specific vehicle in the moving traffic is rather subjective.

A radical solution of this problem is the use of laser velocimeters. The optical system can provide the required laser beam divergence such that the diameter of the laser spot at a distance of 300 – 400 m does not exceed the transverse dimensions of an automobile. In this case, the entire radiation from the optical targeting unit of the instrument can be guided on a single vehicle in the traffic and its speed can be measured. For an incorrect guidance, the reflected signal is obtained from several vehicles simultaneously, and the results of measurements are blocked by the system for processing the reflected signals obtained in the device.

Yu.V.Abazadze, N.A.Litsarev, V.L.Pochtarev, V.A.Pashkov, A.Yu.Khachiev, A.A.Kazakov, Yu.P.Koval', V.A.Simakov, V.N.Neustrueva, G.S.Egorova, I.D.Zalevskii, A.A.Borodkin, S.M.Sapozhnikov
M.F.Stel'makh Polyus Research & Development Institute, ul. Vvedenskogo 3, 117342 Moscow, Russia; e-mail: mail@polyus.msk.ru

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The constructional features of a laser velocimeter and rangefinder include:

(1) a complete safety for the eyes of the driver of the vehicle as well as the person using the instrument, in accordance with the requirements laid down for laser safety;

(2) the development of an emitter with a special laser radiation pattern of a given shape for ensuring a square cross section of size $0.23 \times 0.23^{\circ}$ of the beam passing through the forming optical unit;

(3) the reliability of the results of measurements, including the blocking of results of measurements in the case of an inaccurate guidance of the beam; and

(4) minimisation of the power consumption, mass and size of the instrument.

The requirement of eye safety determines the type of the emitter, namely, a pulsed semiconductor laser, as well as the maximum admissible radiation power. Calculations show that the pulse peak power at a 0.9 μm should not exceed 100 W for a pulse repetition rate of 2.2 kHz and a pulse width of 50 ± 10 ns. On the other hand, the range of such an instrument for such a peak power should be at least 400 m (for a dark colour automobile). This sets a lower limit on the sensitivity of the photodetector unit (PDU), which equals 3×10^{-9} W at the emitter wavelength. While calculating the maximum sensitivity of the PDU, the diameter of the input aperture of the instrument was assumed to be equal to 50 mm.

The above requirements determine the constructional features of the laser and the PDU, as well as the instrument as a whole. Let us analyse these features in greater detail.

The following requirements were taken into account while designing the laser: a pulse power of 25 – 30 W for a radiation diagram with a beam width of 27°, for a current not exceeding 20 A and for a lasing resource of 10^{9} radiation pulses. These requirements can be met only by a composite laser emitter representing an array of laser diodes of area 0.36×0.36 mm, consisting of fifteen emitting strips of 100-μm width. To prevent the emergence of ring modes and to reduce cavity losses, each laser diode was constructed in the form of three emitting strips of 100-μm width spaced 30 μm apart and connected in parallel. Such diodes were mounted in five rows and connected in series.

The laser diodes constituting the array were prepared on the basis of a AlGaAs/GaAs double heterostructure with separate confinements imposed on charge carriers and photons. The heterostructures were grown by MOS-hydride epitaxy during which the following layers were deposited successively from the gaseous phase on an *n*-type GaAs substrate: a Si-doped buffer layer; a wide-band *n*-emitter containing $\sim 50\,\%$ Al; an *n*-type waveguide layer ($\sim 30\,\% - 35\,\%$ Al); an active region; a *p*-type waveguide layer ($\sim 30\,\% - 35\,\%$ Al); a wide-band *p*-emitter; and a heavily doped contact layer.

The laser diodes fabricated from such a standard structure have a radiation diagram in a plane perpendicular to the $p-n$ junction, which ensures the concentration of about 50% of the entire radiation power emitted by a laser diode in a cone with an apex angle 27° (Fig. 1). Our investigations have shown that the emitters assembled from such diodes provide the required radiation power, which is close to the power at which the cavity mirrors are damaged and a catastrophic degradation of the laser diode takes place.

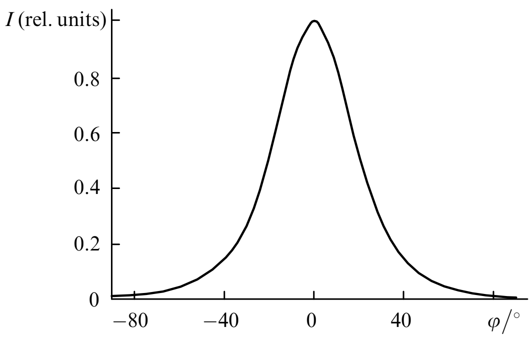

Figure 1. Divergence of radiation in a plane perpendicular to a typical $p-n$ junction.

Thus, it follows from our experiments that the standard epitaxial structure is unsuitable for the laser array intended for use in the LISD-2M laser velocimeter and rangefinder, and should be modified. The necessary modification should be aimed at a reduction of the beam divergence and at an increase in the fraction of power in a cone of angle 27°.

Calculations show that in order to ensure the required power in the required angle and to attain a high degree of reliability and stability of operation of the emitter, the ratio of aluminium in the emitter and in the waveguide should be 43/35. Testing of the structure grown by taking this requirement into account reveals a divergence of the order of 25° at the 0.5 level of radiation in a plane perpendicular to the $p-n$ junction (Fig. 2). Up to $80\,\%$ of the entire emitted power was concentrated in a cone of angle 27°. The laser array constructed by using such a structure (an ILPI-131 emitter) was fully in accord with the above-mentioned requirements. The light – current characteristic of the ILPI-131 emitter is shown in Fig. 3.

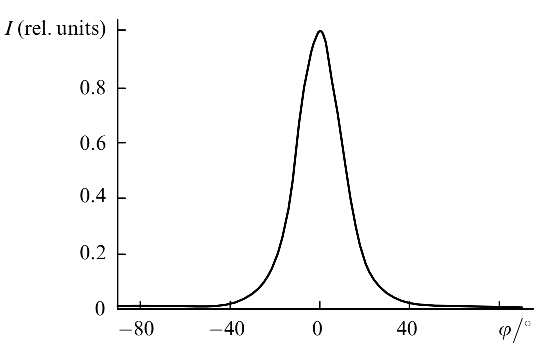

Figure 2. Divergence of radiation in a plane perpendicular to a typical $p-n$ junction in a structure developed for laser velocimeter.

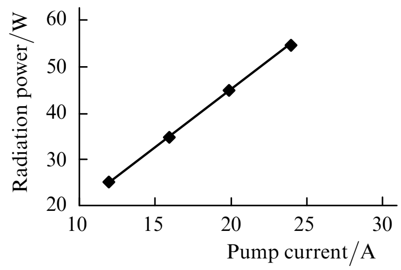

Figure 3. Light – current characteristic of the emitter ILPI-131.

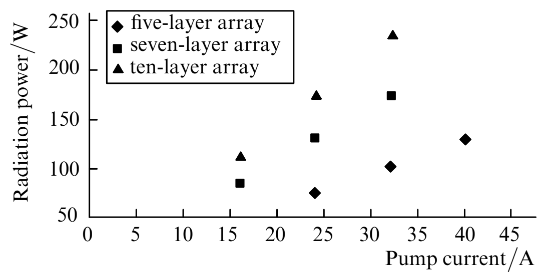

Figure 4. Light – current characteristics of composite arrays.

In the course of our investigations, composite laser emitters consisting of 7 and 10 series-connected laser diodes were assembled and tested. Fig. 4 shows the typical light – current characteristics of such emitters. Experiments show that composite emitters can be assembled in a single block with a power range 25 – 250 W and a luminous body size from 0.36×0.4 mm to 0.72×0.8 mm.

Table 1 contains the technical specification of the laser emitters. The power supplies for these emitters were prepared from modern elements to minimise the energy consumption and to decrease their size.

A silicon avalanche photodiode (APD) was used as the photodiode to ensure the required sensitivity of the PDU. Such diodes have an optimal avalanche multiplication factor M_{opt} defined by the maximum signal-to-noise ratio [2], which depends primarily on the dark current in the APD and on the current associated with the background noise in the instrument. One of the features of LISD-2M is that it has a fairly wide field of view of the detector (4 mrad) to facilitate the guiding and holding the optical axis on a vehicle. The conditions under which LISD-2M is used are diverse. Measurements can be made on a sunny day, in the evening, or in the headlights of the approaching vehicle. Consequently, the effect of the background is quite significant and should be taken into account in such measurements.

Thus, the potentialities of a silicon APD can be put to the fullest use upon a change in the background if the sensitivity of the PDU is adaptable, i.e., capable of changing automatically from the optimal to the maximum possible value. This principle was employed in the design of the PDU for LISD-2M and similar instruments. The block diagram of a PDU is shown in Fig. 5.

The PDU is constructed according to the classical diagram containing an optimal detector [avalanche photodiode (*5*)], a preamplifier (*7*), and a detection comparator (*8*). In the period when it does not receive a response pulse

Table 1. Technical parameters of laser emitters of size 60 × 40 × 10 mm with a wavelength 800 – 810 nm at 25 °C.

Laser emitter type	Output power/W	Triggering pulse repetition rate/Hz	Pulse duration/ns	Current consumption/A	Feeding voltage/V	Size of the luminous body/mm	Spectral linewidth/nm	Divergence/°		Working temperature range/°C
								at right angles to the $p-n$ junction	parallel to the $p-n$ junction	
LPI-50M-805	50	1000 – 5000	100	0.1	5 ± 1	0.4 × 0.4	3	25	10	−40 ... 60
LPI-100M-805	100	1000 – 5000	100	0.2	5 ± 1	0.4 × 0.4	3	25	10	−40 ... 60
LPI-150M-805	150	1000 – 5000	100	0.3	5 ± 1	0.4 × 0.8	3	25	10	−40 ... 60

Note: The temperature drift of the radiation wavelength did not exceed 0.3 nm/°C. The current pulse generator was triggered by a self-excited oscillator (the frequency was preset by the client) or externally (the triggering voltage pulse had an amplitude of 5 V and a duraction 10 μs).

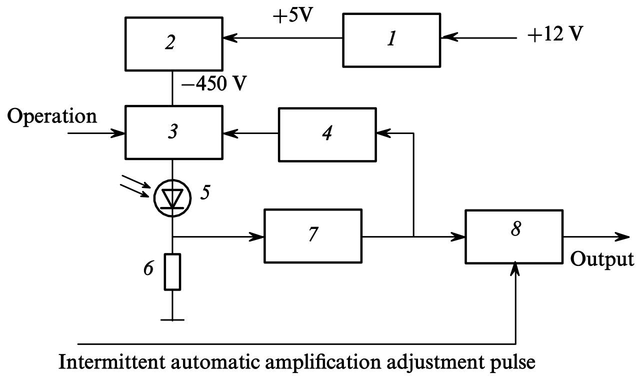

Figure 5. Block diagram of a PDU: (*1*) +5 V power supply; (*2*) −450 V power supply; (*3*) avalanche voltage adjuster; (*4*) noise detector; (*5*) photodiode; (*6*) load resistance; (*7*) preamplifier; (*8*) detection comparator.

from the moving vehicle, the PDU is in the mode of avalanche voltage adjustment according to the criterion of minimum noise pulses at the photodetector output. This adjustment takes place automatically through the avalanche voltage regulator (*3*) and the noise detector (*4*) upon a variation of the background noise, feeding voltage, or the ambient temperature. Before the emission of a light pulse, the 'operation' mode is switched on, and the adjustment is interrupted for the period of measurements.

All the feeding voltages (including the voltage −450 V) are obtained from a single +12 V voltage source.

The main technical parameters of a PDU are given below. These parameters are maintained at a wavelength 1.06 μm for an appropriate choice of the photodiode.

Wavelength/μm	0.8
Duration of the laser pulse being detected/ns	10 – 70
Threshold sensitivity/nW	⩽ 3
Dynamic range	10^5
Feed voltage/V	+12
Pulse amplitude at the PDU output/V	2.4
Temporal shift of the output pulse upon a change in the input power from 10^{-8} to 10^{-3} W/ns	⩽ 1.5
Output pulse duration/ns	⩽ 100
Working temperature range/°C	from −40 to +55
Mass/g	40
Size/mm	63 × 42 × 22

The reliability of the results of measurements using LISD-2M is provided as follows. The cycle of measurements of speed and distance from the automobile involves sending 1000 pulses with a frequency 2.22 kHz towards the vehicle, detection of the reflected signals, and processing of the obtained information. The sensitivity of the PDU to the illumination at the given instant of time is adjusted during the first 200 pulses. The remaining 800 pulses are used to determine the distance from the automobile (for each pulse reflected by it). The results are combined in two groups of 400 measurements, and the mean values of L_1 and L_2 are calculated in each group. The difference between these values over a certain time (0.18 s) is proportional to the speed of the automobile. In each measurement act, the distance is not only fixed, but also compared with the result of the previous measurement.

If the distance being measured (range L) differs from the previous result by more than 10 m, the cycle is terminated and the results of measurements are blocked. Indeed, the position of the automobile cannot change by more than 10 m during the time interval 0.5 ms between two successive radiation pulses and, hence, the detected pulse could be reflected only from another automobile. In the case when an automobile speed exceeds the permissible value, the measuring procedure becomes more complicated to make the result of measurements more reliable. The measuring cycle of 1000 pulses is supplemented with another 400 pulses which are also used for determining the mean distance (L_3), and the automobile speed is determined again over the same time interval (0.18 s) from the difference between L_2 and L_3. If the results coincide to within the admissible error, the readings of the instrument are fed to the panel showing the results of measurements.

This method of measuring the speed determines the direction of motion of the automobile (approaching or moving away) and also makes it possible to carry out sampling, i.e., determining the segment of the highway beyond which no measurements are made. This improves the reliability of the results.

The power consumption, mass, and size of the instruments were minimised by using modern elements and technologies of commercial production at the Krasnogorskii plant, where the instrument was designed and batch samples were produced.

The main technical parameters of the instrument [3] are as follows.

Range of measured speeds/km h^{-1}	0 – 350
Effective range for cars of 'Lada' type/m	400
Maximum range/m	999.9
Minimum range/m	15
Mean square error in speed measurements/km h^{-1}	2
Error in measuring distance/m	$\pm(0.2 + 0.001L)$
Measuring time/s	0.45
Laser radiation wavelength/μm	0.805
Radiation diagram width/rad	0.004 × 0.004
Radiation diagram width/°	0.23 × 0.23
Field of view of tracking device/°	6

Service life (measurement cycles)	50×10^6
Readiness time/s	0.1
Interface	RS-232
Power supply	4 storage batteries of type 316
External power supply voltage/V	12 ± 2
External power supply current/A	0.2
Size/mm	$210 \times 162 \times 92$
Mass/kg	1.4
Working temperature/°C	$-30 \ldots +50$
Laser safety class as per hygienic standards	first

Fig. 6 shows the photograph of LISD-2M.

LISD-2M is certified by the Gosstandart of the Russian Federation and included in the State Register of Measuring Instruments. Batch samples of LISD-2M are being used by the traffic police in Moscow.

Figure 6. LISD-2M laser velocimeter and rangefinder.

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