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Spatio-temporal processes in the position−sensitive detector with moving current−voltage characteristic

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The paper considers the features of transient phenomena during output signal generation in a position−sensitive detector (PSD) with a moving current−voltage (I−V) characteristic. The dependence of the linear and exponential parts of the movement trajectory of the I−V characteristic on the magnitude of voltage distributed over the resistive divider is studied. It is shown that optimizing the operating modes of the investigated PSDs in order to obtain maximum operation speed and maintain the specified resolution of the sensor requires maintaining a balance between the minimum of the applied voltage and the slope of the I−V characteristic in the aperture region.

Keywords: position−sensing detector, moving current−voltage characteristic, operation speed.

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It is known that, among the position−sensitive detectors (PSD) based on various operating principles [1–3], PSD with moving volt−ampere (I−V) characteristic realizes the highest resolution [4]. The method of signal formation in those detectors differs fundamentally from that in lateral and segmental PSDs. The detector output signal corresponding to the optical signal median position in PSD with moving I−V characteristic is formed as a potential accumulated during photocurrent charging of the total capacitance of the detector $p{-}n$ junctions.

The structure and operating principle of PSD with moving I−V characteristic are described in detail in a number of papers [4,5]. However, dynamic processes of the device output voltage formation, as well as their dependence on magnitudes of the optical signal and voltage applied to the resistive divider, stay out of attention. This paper considers the effect of these factors on the rate of the output signal formation depending on the voltage applied to the device resistive layer.

The detector with moving I−V characteristic is based on a matrix of back−to−back photodiodes with one end connected to the resistive divider and the other one connected to the low−resistance signal bus. As a result, the device I−V characteristic may be described by a hyperbolic tangent having positive and negative branches separated by inflection point u_0 corresponding to the zero point of photocurrent flowing through the device. Pairs of the back−to−back $p{-}n$ junctions connected to the resistive divider are under voltage E linearly distributed along the detector operating area (from 0 to $+E$). This voltage is connected with the device spatial frame of reference via the one−to−one relationship between the spatial position of each point along the detector photosensitive region and relevant linearly distributed voltage:

$$x = \frac{uL}{E}, \qquad (1)$$

where x is the device linear coordinate, u is the voltage distributed along the resistive voltage divider, L is the length of the detector operating area, E is the voltage applied to the resistive divider.

When an optical signal gets on the detector, photocurrent is generated, whose direction is defined by whether the light spot is in the positive or negative zone of voltage distributed along the detector of I−V characteristic. Under the photocurrent impact, voltage is accumulated on the total photodiode capacitance and changes the device signal bus potential. Being summed with the spatially distributed voltage of the resistive divider, the signal bus potential causes variation in spatial position of the I−V characteristic inflection point u_0. This process continues until the I−V characteristic inflection point coincides with the light signal median $u_0(M)$; in this case the total photocurrent becomes zero, and variation in the spatial position of the I−V characteristic inflection point on the detector surface finishes. Therefore, the voltage formed on the capacitance corresponds to the position of the optical signal median on the scale of voltage applied to the resistive divider.

Differential equation describing the displacement of the I−V characteristic inflection point from the initial point $u_0(0)$ to that equal to the coordinate of the optical signal median looks as follows:

$$u_0(t) = \frac{1}{C}\int_0^E f(u)\,\mathrm{th}\,\frac{u - u_0'(t)}{A_u}\,du, \qquad (2)$$

where $f(u)$ is the optical signal with the median coordinate $u(M)$, projected on the detector photosensitive region. The

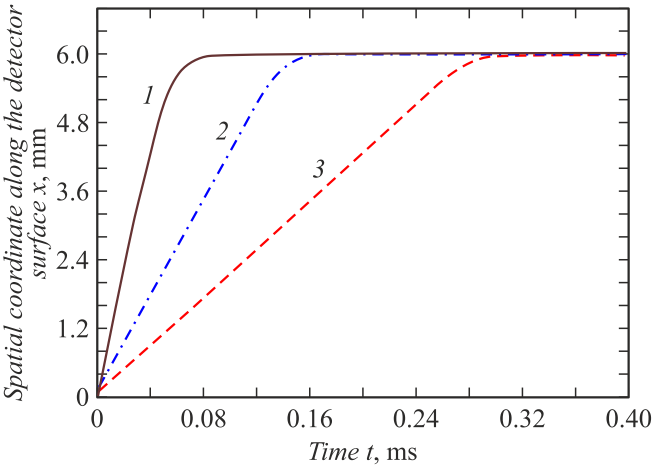

Figure 1. Calculated trajectories $x(t)$ of the I–V characteristic inflection point offset at the applied voltages of $E = 2$ (*1*), 5 (*2*) and 10 V (*3*).

$f(u)$ argument is voltage distributed along the resistive layer, $A_u = 0.26$ V is the I–V characteristic aperture width that is a constant defined by the transient region width of I–V characteristic of the back–to–back p–n junctions. The aperture width will be recalculated to the X space via the ratio between the device length L and applied voltage E expressed as $x = uL/E$.

Fig. 1 presents the equation (2) solutions corresponding to the I–V characteristic inflection point offset from initial point $x(0)$ to that equal to coordinate x_M of the optical signal median for different applied voltages E converted to the X space.

Solving the equation in the X coordinate space, we obtain the over–time trajectory of the I–V characteristic inflection point u_0 movement from its initial point $x_0 = 0$ to point $x_0 = X_M$ corresponding to the signal median position. One can see that the major part of the I–V characteristic offset trajectory is linear, which is caused by the photocurrent constancy in the photodiode reverse–bias regions. The steepness of the I–V characteristic trajectory is defined by the photocurrent magnitude and, as shown in Fig. 1, is independent of voltage E. The photocurrent independency of voltage during the I–V characteristic offset along the device axis x significantly accelerates the process of the signal coordinate formation as compared with ordinary exponential procedures of charging the capacitance. It is also clear that, at the fixed optical signal power, the lower is voltage E applied to the resistive divider, the larger is the angle of the I–V characteristic offset along the PSD photosensitive region. In addition, one can see that in the vicinity of the signal median there arises an exponential section of the aperture movement, which is caused by the optical signal entry into the I–V characteristic inflection area.

Fig. 1 shows that the lower is the distributed voltage applied to the detector, the higher is the rate of coordinate establishment. This is caused by that the applied voltage is in our case equivalent to the distance for which the I–V characteristic inflection point is to be displaced.

The size of the exponential part of the process (the nonlinear region) slightly depends on the applied voltage, which evidences for the fact that the detector resolution remains almost invariant with decreasing voltage. This conclusion is confirmed by the behavior of derivatives d^2x/dt^2 presented in Fig. 2 which describe the form of transient processes near the optical signal median.

Based on Fig. 2, it is possible to conclude that the decrease in voltage E applied to the detector resistive divider essentially increases the rate of the coordinate reading establishment and, thereat, slightly affects durations and magnitudes of nonlinear processes in the area of the I–V characteristic aperture. This demonstrates that the voltage E decrease does not affect the PSD resolution. Detailed analysis of interrelation between E, signal power and width of aperture A_u shall be a subject of further investigation.

Results of the accomplished analysis are confirmed by oscillograms presented in Fig. 3 which illustrate transient processes of the optical signal median establishment during this signal displacement along the PSD surface from point $x_1 = 0$ to point $x_2 = 6$ mm within its length L. Based on the calculations, an experiment was performed on PSD „Multi-scan“ 10 mm long at three values of the applied voltage: $E = 2$, 5 and 10 V. For the purpose of normalizing the result of the coordinate reading formation, the oscillograms were measured at different gain factors k for different E: $k = 1.75$ div/V for $E = 2$ V, $k = 0.7$ div/V for $E = 5$ V and $k = 0.35$ div/V for $E = 10$ V.

Thus, there were obtained experimental trajectories $u(t)$ of the I–V characteristic inflection point offset from initial point $u_0(0)$ to the value equal to the coordinate of the optical signal medium $u(M)$ corresponding to point X_M in the coordinate space.

Notice that, prior to studying transient processes in PSD with moving I–V characteristic, the main paradigm consisted in the desire to use in work high voltages applied to the detector. This idea was based on sharpening of

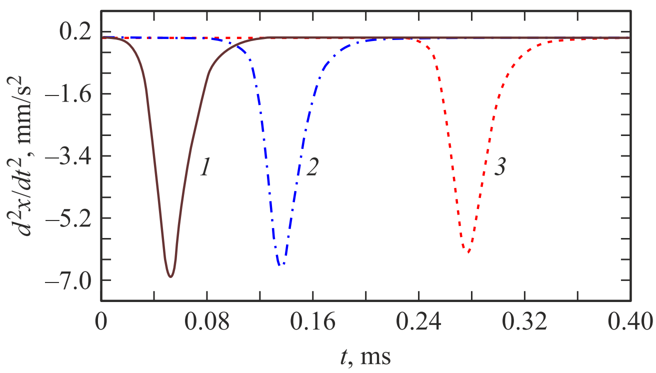

Figure 2. Sizes of nonlinear parts of trajectories of the I–V characteristic offset at applied voltages of $E = 2$ (*1*), 5 (*2*) and 10 V (*3*).

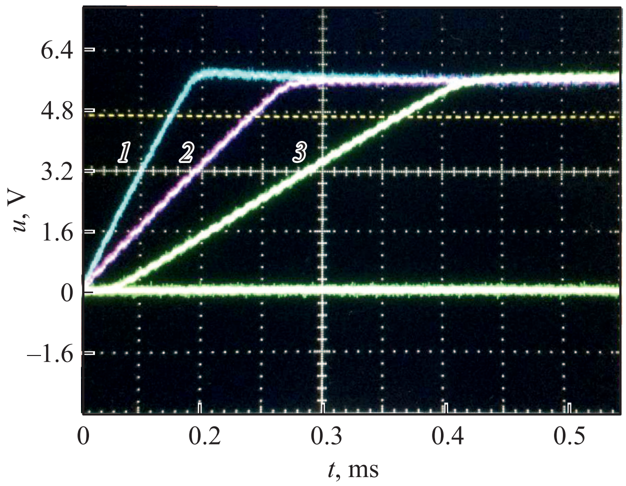

Figure 3. Experimental trajectories of the I–V characteristic inflection point at applied voltages of $E = 2$ (*1*), 5 (*2*) and 10 V (*3*).

I–V characteristic transient section with increasing voltage applied to the detector, which provided for an increase in the device resolution. However, the analysis performed in this work showed that the lower is the applied voltage, the higher is the rate of the coordinate reading formation. Thus, the paper shows that optimizing the operating modes of the studied PSDs in order to obtain maximum operation speed and maintain the specified resolution of the detector requires maintaining a balance between the minimum of the applied voltage and slope of the I–V characteristic in the aperture region.

Conflict of interests

The authors declare that they have no conflict of interests.

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