Analysis. Parameters. Characteristics and Circuits with PIN Photodiodes for Multielement Photodetectors

Ivan S. Kolev and Tsanko V. Karadzhov

***Abstract* – A photodiode is a photodetector which is characterized with an internal photoeffect and a PN junction without internal amplification of the photocurrent. It has the fastest response of all types of photodetectors. Photodiodes are mainly made of silicon – Si and germanium – Ge. They are usually divided into three types – photodiodes with PN junction, PIN photodiodes and avalanche photodiodes. A detailed classification of the photodiodes is shown in Application. 1.**

Keywords – Photodiode, Photodetector, Photocurrent, Dark current.

I. OPERATION MODES

Photodiodes operate in two main modes – photodiode and photogalvanic. At photodiode mode (Fig. 1), the photodiode is energized with inverse voltage from an external source. The reverse current through it depends upon the illuminance. At photogalvanic mode (Fig. 2), the photodiode generates photoelectromotive force at illuminance without availability of an external source.

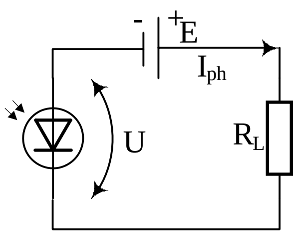

Fig. 1

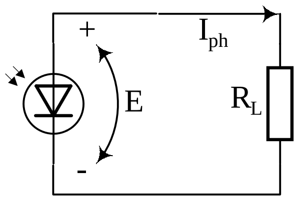

Fig. 2

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In PIN photodiodes there is a layer with intrinsic conduction (i-layer) among the layers with different conduction. Therefore they have higher sensitivity, smaller barrier capacity and possess good frequency characteristics (limit frequency over 1GHz).

When operating in photodiode mode, it can be written down about the voltage upon the photodiode:

$$U = I_{ph}.R_L - E \qquad (1)$$

where I_{ph} – photocurrent;
U – inverse voltage on the photodiode;
R_L – load resistance.

The current through the photodiode is:

$$I = I_D\left(e^{\frac{U}{m.\varphi_T}} - 1\right) - I_{ph} \qquad (2)$$

where I_D – dark current;
M – coefficient (1÷1.5), showing the deviation from the ideal volt-ampere characteristic of the PN junction; φ_T – temperature potential.

$$\varphi_T = \frac{k.T}{q} \qquad (3)$$

where k – Boltzmann's constant;
T – temperature, °K;
q – electron charge

At photogalvanic mode (Fig. 2), the photoelectromotive tension is:

$$E_{ph} = m.\varphi_T \ln\left(1 + \frac{I_{ph}}{I_D}\right) \qquad (4)$$

where:I_{ph} – photocurrent generator;
I_D – dark current generator;

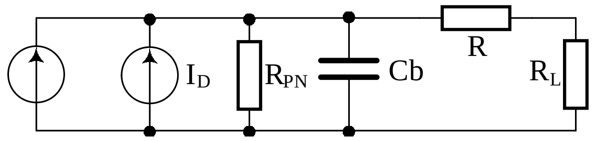

Fig. 3

An equivalent photodiode circuit is presented in Fig. 3
R_{PN} – non-linear incremental resistance of the PN junction;
Cb – barrier capacity;
R – base and junctions low-ohmic series resistance.

The incremental resistance of the photodiode depends on the applied inverse voltage and the illuminance and its value is $10^6 \div 10^9$ Ω. The diode capacity also depends on the applied inverse voltage.

The maximum limit frequency of the photodiode at $R \ll R_{PN}$ is:

$$f_{MAX} = \frac{1}{2\pi RCb\left(1+\frac{R}{R_{PN}}\right)} \approx \frac{1}{2\pi RCb} \quad (5)$$

There are three main types of photodiodes in accordance with the wavelength λ: (850÷940) nm – Si-photodiode, 1300 nm – Ge photodiode, 1550 nm – InGaAs photodiode.

II. FREQUENCY CHARACTERISTICS OF THE PHOTODIODES

The law, in accordance with which the output photodiode current is changed at switching on and switching off, is expressed through the following transition functions:

$$h_1(t) = K\left(1-e^{-\frac{t}{\tau}}\right) \quad (6)$$

$$h_1(t) = K\left(e^{-\frac{t}{\tau}}\right) \quad (7)$$

where τ is the time constant of the photodiode.

III. TIPES OF PHOTODIODES

A. PIN photodiodes with optical tails

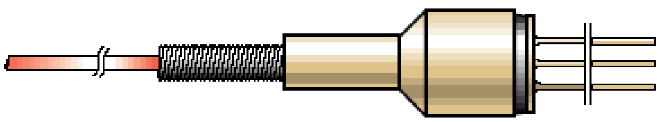

Fig. 4

The structure of such a photodiode is shown in Fig.4. It contains (20÷30) cm of optical fiber connected to the photodiode through an optical coupling. It finds application in optical communications by means of optical fibers and cables.

B. PIN photodiodes with a digital output

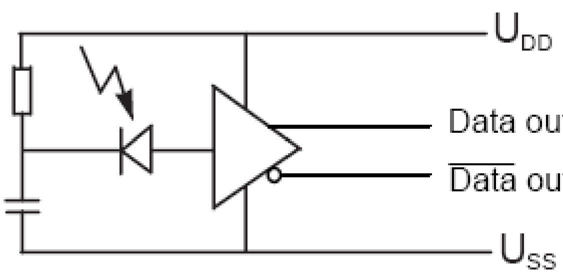

Fig. 5

They are used as photodetectors in optical lines or infrared channels for digital information transmission (Fig. 5).

B. PIN photodiodes with an analogue output

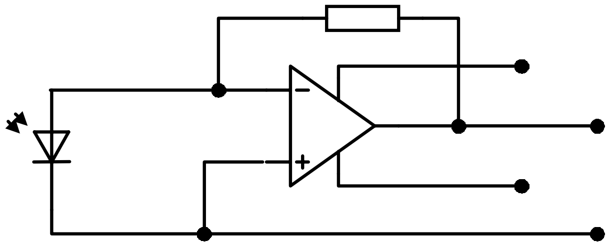

Fig. 6

They have a built-in operational amplifier with a feedback resistor in the diode case (Fig.6).

IV. CHARACTERISTICS OF THE PIN PHOTODIODES

The characteristics of a silicon PIN photodiode made by Telefunken are shown as an example.

- Lux-ampere (light) characteristic – it shows the dependence of the photocurrent upon the illuminance at constant supply voltage $I_{ph}=f(E_V)$ - Fig. 7;

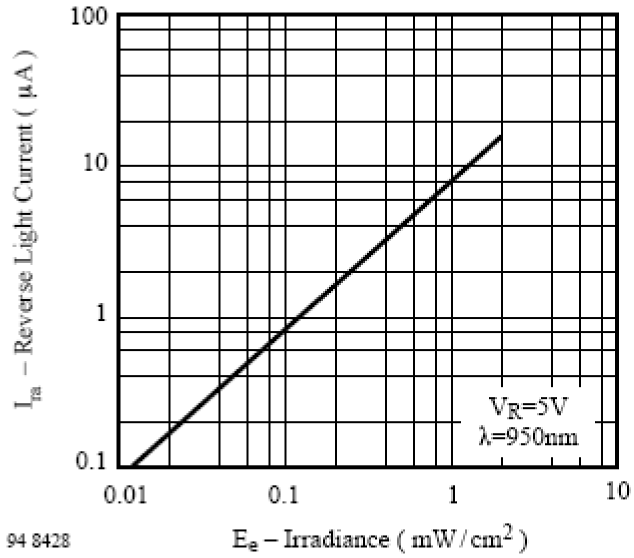

Fig. 7

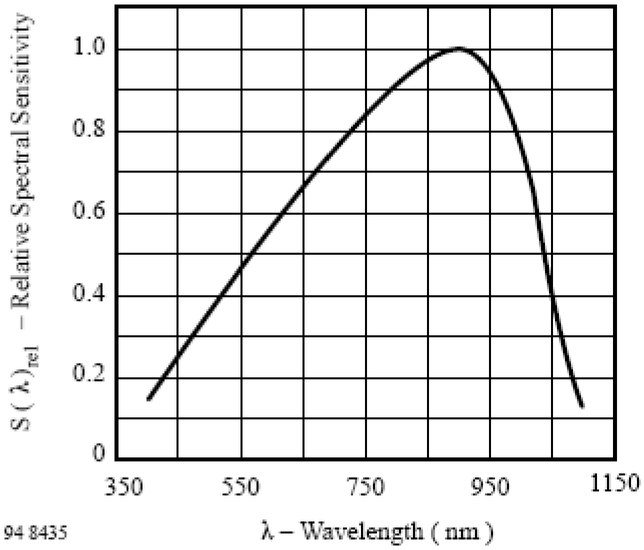

Fig. 8

- Spectral characteristic – it expresses the dependence of the photocurrent upon the wavelength at constant voltage and constant power of the irradiating luminous flux $I_{ph}=f(\lambda)$, Fig.8;
- Volt-ampere characteristic – it is a dependence of the photocurrent upon the applied voltage at a constant luminous flux $I_R=f(U_R)$ - Fig. 9;

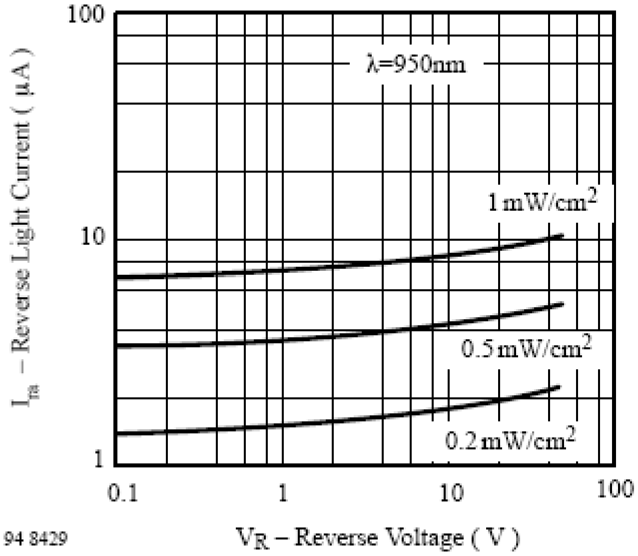

Fig. 9

- Dependence of the photoelectromotive voltage upon the illuminance $E_{ph}=f(E_V)$;
- Thermodependence of the photocurrent $I_{ph}=f(T)$;
- Thermodependence of the dark current $I_D=f(T)$;
- Thermodependence of the photoelectromotive voltage $E_{ph}=f(T)$;
- Dependence of the capacity upon the applied voltage.

V. MAIN PARAMETERS OF THE PHOTODIODES

Operating inverse voltage U_R, V	Voltage, at which the photodiode does not change its nominal parameters if it has operated long enough.
Dark resistance R_D, Ω	Photodiode resistance in the absence of the light falling upon it
Dark current I_D, A	Current flowing through the photodiode at a specific voltage and luminous flux absence
Light resistance R_{ph}, Ω	Resistance of the photodiode when irradiating it by luminoius flux in the range of its spectral sensitivity
Photocurrent I_{ph}, A	Current flowing through the photodiode at a specified voltage and luminous flux radiation upon the photodiode
Common current I, A	Photodiode current consisting of the photocurrent and the dark current
Integral sensitivity S, A/lm	Relationship between the photocurrent variation and the lunminous flux change
Spectral sensitivity S_λ	Dependence of the photodiode sensitivity upon the wavelength
Current impulse sensitivity S_{imp}, A/W	Relation of the photocurrent amplitude to the impulse power amplitude of the radiating luminous flux
Noise current I_{nois}, A	Mean square value of the photodiode dark current variation
Noise voltage U_{nois}, A	Mean square value of the photodiode dark voltage variation
Sensitivity threshold D, lm	Mean square value of the modulated fixed spectrum luminous flux acting upon the diode at which the mean square value of the photocurrent (voltage) is equal to the mean square value of the noise current (voltage)
Rise time t_r, s	Minimum time interval necessary for transition from (0.1÷0.9) of the fixed photocurrent or voltage value upon the photodiode
Decay time t_d, s	Minimum time interval necessary for transition from (0.9÷0.1) of the fixed photocurrent or voltage value to the photodiode
Limit frequency f_0, Hz	Frequency of the sinusoidal luminous flux, at which the photodiode sensitivity falls to level 0.707 of the sensitivity of constant luminous flux
Photodiode capacity C, F	Capacity of the photodiode PN junction

VI. CONCLUSION

The results of this paper will be used for lectures and seminars with students in the programmes of “Optoelectronics” и “Optoelectronics and Optical Communications”.

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Application 1