Photocurrent crowding in InAsSbP based front surface illuminated photodiodes

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BIOGRAPHY

Boris A.Matveev is a leading researcher at Ioffe Physical-Technical Institute, division - Centre of Nanoheterostructure Physics (St.Petersburg, Russia) and scientific consultant at Ioffe spin-off company - IoffeLED. He graduated from V.I.Ulyanov/Lenin/ Electrical Engineering Institute ("LETI") in 1977 and at the same year he joined Ioffe Institute.. His Ph.D. work (1987) was devoted to investigation of deformation in narrow gap III-V semiconductor heterostructures, his doctor dissertation (2010) was devoted to mid-IR-lasers, LEDs and photodiodes.

TECHNICAL ABSTRACT

Photodiodes (PDs) sensitive in a 3–5 µm wavelength range and capable of operating at room temperature are required for solving tasks of optical monitoring of the state of both environment (analysis for NO_2, CO, etc.) and human organism (CO_2 and C_2H_5OH vapor). In comparison to CdHgTe-based devices, PDs of the InAsSbP system are characterized by higher stability of the metallurgical interfaces and faster response. However, InAsSbP surface illuminated PD sales volumes are still lower than those for the CdHgTe-based devices poor efficiency of the former being one of the reasons for that. It is shown in the report that collection efficiency and detectivity in surface illuminated n-InAs/n-$InAsSb_x$/p-InAsSbP or/and graded band-gap n-InAs/n-InAsSbP/p-InAsSb(P) PDs could be considerably enhanced by a redesign of an anode shape onto a p-InAsSbP surface.

All types of our standard square shaped front surface illuminated samples (with n-InAs or n-$InAsSb_x$ active layers having $0.2 \geq x \geq 0$ and point, that is, small area contact (D≤100 µm)) exhibit pronounced negative luminescence (NL) intensity nonuniformity as a result of the inhomogeneity of the reverse current density distribution over the diode surface. Current crowding under the contact occurs because of the low resistance R_{pn} of the *p–n* junction, or more precisely, because the condition $R_{pn} < R_p + R_a$ is satisfied, where R_p and R_a are the resistances of the *p*-InAsSbP layer and the anode, respectively (see Fig.1 with schematic showing this graphically). At room temperature in PDs with InAs active layer at a reverse bias, the condition $R_{pn} > R_p + R_a$ is satisfied and the NL intensity distribution over the chip surface is homogeneous. As the temperature is raised from 25 to 80°C, R_{pn} exponentially decreases (see, e.g., the $R_0(1/T)$ dependence in [1]) and, probably, the resistivity of the *p*-InAsSbP layer increases. The expected increase in R_p for *p*-InAsSbP, found from the $1/\rho(T)$ dependence for the closest analog, *p*-InAs, is ~(10–15)%. For the above reasons, the homogeneous reverse current distribution at 25°C gives way to current crowding near the anode at 50–80°C.

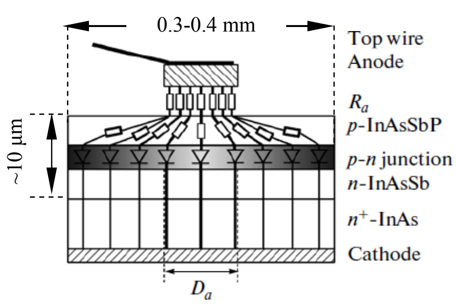

Fig 1. Schematic and equivalent PD circuit.

Figure 2 shows the dependences of the optical power efficiency for the light incident on the p-InAsSb/n-$InAsSb_{0.08}$/InAs ($\lambda_{0.1}$=4.5 µm) diode (or the efficiency of photogenerated carrier collection F) on the total current I_{tot}; the dependences were obtained at three temperatures from the NL intensity distribution over the chip surface by the formula:

$$F = \frac{\int_x \int_y L(x,y)\,dx\,dy}{L_{max}(A - S_a)}$$

where x,y are the coordinates onto a p-InAsSbP surface, L(x,y) is the radiation intensity in the 3 µm spectral range determined by spectral response of IR microscope, based on InAs matrix detector, L_{max} is the radiation intensity in the vicinity of the anode, A, S_a are the p-n junction and opaque anode areas, respectively.

It can be seen in Fig. 2 that the dependences $F(I_{tot})$ are well approximated with linear functions and the efficiency of photogenerated carrier collection at zero bias (F_0) is substantially smaller than unity even at room temperature and decreases by nearly an order of magnitude as the temperature is elevated to 80 °C. It follows from data in Fig. 2 that the efficiency of nonequilibrium carrier collection and PD sensitivity can be raised in three ways: (I) by applying a reverse bias to the PD, (II) by lowering the working temperature of the PD, and (III) by using contacts with a long perimeter and small area.

The application of reverse bias to the PD leads to an increase in dark current and noise, which adversely affects the PD parameters, with the influence exerted by these factors on the PD operation being especially pronounced at high temperatures. Lowering the working temperature of a PD requires thermoelectric coolers, which have high energy consumption and high cost. At the same time, making the perimeter longer only requires that the configuration of masks used to fabricate the upper contact be changed and the photolithographic processes be somewhat adjusted, and, therefore, it is presumably the least expensive. As shown below, the latter method made us able to increase the D* value by factor ranging from 1.6 to 3. As an example in Fig.3 we present data on main PD parameters in three InAsSbP graded band gap PDs ($\lambda_{0.1}$=5.8 μm) fabricated from a single wafer but with different types of top contacts (shown on the right). As seen from Fig.3 there is a nice 1.7 fold increase of the D* value in PD with net (big perimeter) contact.

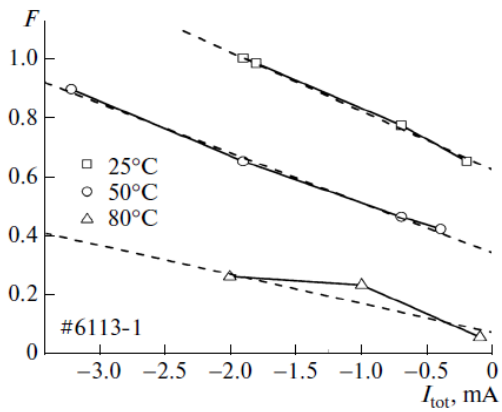

Fig. 2. Photogenerated carrier collection factor F vs the total current I_{tot} for a InAs/InAsSb$_{0.08}$/InAsSbP PD with point contact (D=100 μm) at various temperatures.

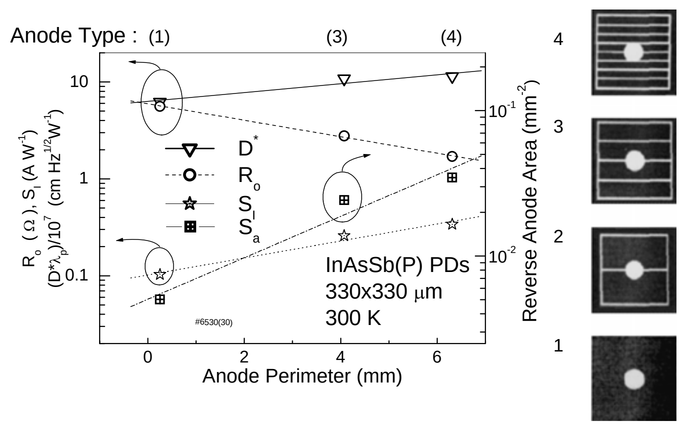

Fig.3 Plots of the zero-bias resistance (R_0), current photoresponsivity (S_I), and detectivity (at maximum of the PD response spectrum) at room temperature versus anode contact perimeter in a InAsSb(P) PDs. For comparison, the right hand scale shows the inverse anode area and the top scale indicates PD anode types (numbered as on a schematic in the right insert)

Keywords: Mid-IR photodiodes, current crowding, negative luminescence

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References

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