# ast GaInAsSb p–i–n photodiode for the spectral interval 23 μm

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ss of less than 0.01 dB/km is expected[1] in optical-fiber communication lines based on fibers operating in the spectral range 2-4 is loss is an order of magnitude lower than quartz fibers in the range 1.3-1.6 μm. The which has been achieved in the fabrication fibers[2] and a report of the first commercial ctures of a fluoride fiber[3] are stimulating in the development of the basic elements sources and photodetectors) of a third gen- for infrared optical-fiber communications in pectral range.

e development of efficient injection lasers on GaInAsSb solid solutions for the wavelength al 2-2.4 μm has been reported in recent years 4-6). Among these lasers are some which can erate continuously at room temperature.[7] have also been some studies of photodetectors d on multicomponent III-V solid solutions for this elength interval.[8,9]

e have previously reported[5] the fabrication study of the first uncooled photodiodes with a tant quantum efficiency ~0.6 in the range 1.4- m and a response time $\tau \approx 0.5$ ns as well as nche photodiodes[10] based on GaInAsSb/GaAlAsSb solutions.

In the present letter we are reporting the re- ts of the fabrication and study of ultrafast p–i–n todiodes based on GaInAsSb.

The structures were grown by liquid-phase itaxy on a p-type GaSb substrate with a carrier ncentrations $p = 2 \cdot 10^{17}$ cm$^{-3}$. A layer of the InAsSb solid solution 2 μm thick, with a band gap $\approx 0.53$ eV, not deliberately doped, was covered a wide-gap layer of $n^+$-GaAlAsSb with concentra- n $n = 10^{18}$ cm$^{-3}$ ($E_g = 1.2$ eV) and a thickness 3 μm.

The carreir concentration in the GaInAsSb rrow-gap active layer was $p^0 = 4.8 \cdot 10^{14}$ cm$^{-3}$, ording to measurements of the voltage depen- ce of the capacitance. This concentration, we ght note, is an order of magnitude lower than that ported in Refs. 8 and 10. The intrinsic concen- tion in the GaInAsSb solid solution with $E = 0.53$ is $n_i = 4 \cdot 10^{13}$ cm$^{-3}$.

The photodiodes were fabricated by photolithog- phy in the form of mesa diodes with a mesa ameter of 90 μm. The contacts were formed by positing a Au:Zn alloy on the p-GaSb substrate d a Au:Te alloy on the wide-gap window, with bsequent deposition of a layer of Ag. The struc- re of the p–i–n diode is shown schematically in g. 1a.

We studied the current–voltage and capaci- nce–voltage characteristics of the diodes, the sen- itivity spectrum, and the speed of the p–i–n diodes by the method of pulsed scanning electron microscopy.

The plot of the capacitance versus the voltage was characteristic of p–i–n diodes. The minimum capacitance in the depletion regime was C = 0.4 pF at a bias voltage V = 2 V. The width of the space-charge region was 2 μm, which corresponded to the thickness of the GaInAsSb narrow-gap layer. This low capacitance was achieved by virtue to the low carrier concentration in this layer. The dark cur- rent at a voltage of 0.5 V was 8-10 μA and was as- sociated with the generation–recombination current in the space-charge layer.

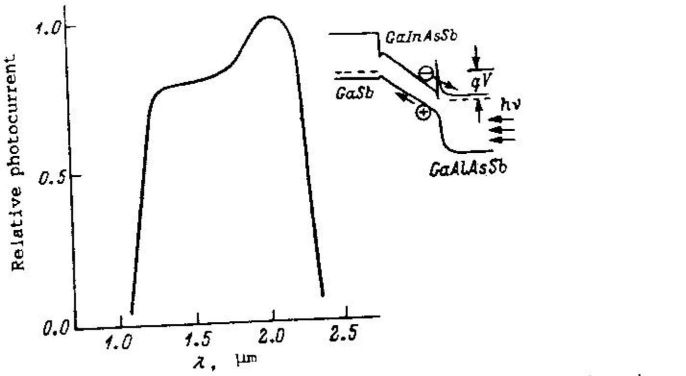


FIG. 1. Photosensitivity spectrum of a GaInAsSb/GaAlAsSb p–i–n photodiode at T = 300 K. The inset is a schematic band diagram of the p–i–n structure with a reverse bias.

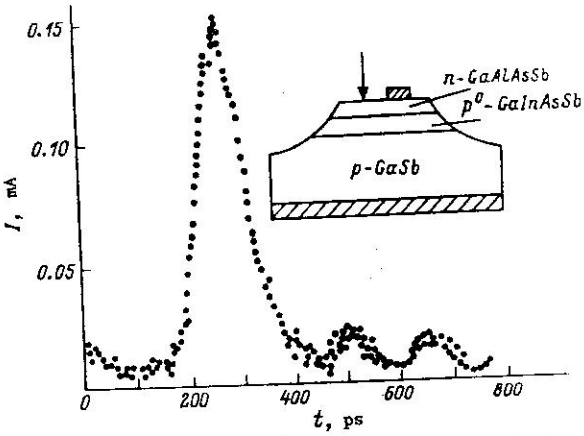


FIG. 2. Kinetics of the current induced by the electron probe with pulsed excitation of p–i–n structure. The inset shows the GaInAsSb/GaAlAsSb structure in the p–i–n photodiode.

  

Spectra of the photoresponse were recorded on an SPM-2 monochromator with a LiF prism.

Figure 1 shows the photosensitivity spectrum of a GaInAsSb/GaAlAsSb p—i—n diode at room temperature. The magnitude of the photocurrent is essentially independent of the applied voltage. The monochromatic sensitivity at the wavelength $\lambda$ = 2-2.2 μm was ~1.0 A/W. The size of the sensitive area of the p—i—n diode was $6\cdot10^{-5}$ $cm^2$. The apparent reason for the decay of the photoresponse in the short-wavelength part of the spectrum is the additional absorption in the heavily doped $N^+$-GaAlAsSb covering layer, 3 μm thick.

We studied the speed of the p—i—n diodes by the method of pulsed scanning microscopy. The experimental apparatus included an RÉM-100U scanning electron microscope with a picosecond electron-beam modulator, an S1-91/3 sampling oscilloscope controlled by an MERA-60 computer, a microwave sample holder, and an in-vacuum system for bringing out the signals for recording.[11] The minimum pulse length was 25-35 ps, depending on the beam current.

The test diodes were mounted in a gap in a 50-Ω stripline, from which the output signals was fed through a coaxial-stripline adapter section to the input of the sampling oscilloscope. These measurements were carried out at an accelerating voltage of 45 kV. Calculations[12] using the electron—hole-pair generation function showed that no more than 20% of the current carriers were excited in the quasineutral regions of the diodes adjacent to the space-charge regions. The peak value of the beam current in the pulse was $5\cdot10^{-8}$ A which corresponds to an irradiation power ~1 mW in a local region about 2 μm in size on the diode. The pulse repetition rate was in the range 30-100 KHz.

Figure 2 shows results of a kinetic study of the photoresponse in local regions of an InGaAsSb/GaAlAsSb diode structure during the application of a reverse bias voltage V = 4 V. The pulse rise time ($\tau_r$ = 50 ps) is determined by a convolution of three time scales: the length of the exciting pulse, the RC component (the capacitance in this diode construction was C = 0.4 pF), and the rise time of the transient characteristic of the oscilloscope ( ~30 ps), The decay time is limited by — in addition to the factors just cited — the carrier transit time in the active regin of the p—i—n diode. Taking the approach of Ref. 13, we can estimate the transit time to be $t_{tr}$ = 45-50 ps, which corresponds to a carrier drift velocity $v_{dr}$ = $(5\text{-}6)\cdot10^6$ cm/s in fields E ~ $2\cdot10^4$ V/cm (the carriers are presumably holes). The drift velocity has not been measured previously in GaInAsSb solid solutions. The photosensitivity and the speed were uniform within 5% over the area of the structures.

In these p—i—n photodiodes we did not observe any long-term showing of the transient response in the region of the decay of the photoresponse pulse, which is an important problem in the fabrication of fast InGaAs/InP p—i—n and avalanche photodiodes.[14] The reason lies in the particular features of the type-II heterostructure in the p-GaSb—$p^0$-GaInAsSb—n-GaAlAsSb structure which was used. It can be seen from the schematic band diagram in the inset in Fig. 1 that during the application of a blocking voltage the conditions for a pile-up of holes at the heterojunction are not satisfied in a structure of this type.

This study has resulted in the fabrication of the first p—i—n photodiode with a very high speed ($\tau$ = 50 ps) on the basis of GaInAsSb narrow-gap solid solutions for the spectral region 2-2.4 μm. The speed is comparable to the better results which have been obtained to date for the well-developed GaInAs/InP p—i—n diodes at a wavelength of 1.3 μm (Ref. 15, for example). Such p—i—n photodiodes hold promise for use in the reception modules of infrared optical-fiber communications at high data transmission rates, on the order of several gigabits/s. They may also find use for recording fast processes in scientific research.


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