# GaInAsSb/GaSb ($\lambda$=1.8÷2.3 μm) immersion lens photodiodes

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Optical sensing, that is, chemical composition determination through the use of spectroscopic/transmission measurements is becoming more and more attractive due to fascinating improvement of the performance of light emitting diodes (LEDs) and photodiodes (PDs). The latter are of particular importance since photovoltaic operation mode leads to a minimum noise that is beyond the capabilities of photoresistors, thermopiles and bolometers.

The episide-down bonded (or back-side illuminated (BSI)) PDs are appropriate for many applications since they can be "immersed", that is, optically coupled with the lens that provides the increase of the D* value by factor of $(A_{opt}/A_{p\text{-}n})^{1/2}$, where $A_{opt}$ – is the lens area and $A_{p\text{-}n}$ – is the p-n junction area. In addition to evident advantages of the immersion lens configuration such as narrow far field pattern and increased transparency for the incoming radiation the BSI PDs allows use of a radiation transmitted through the active zone and reflected back by a mirror contact. The above reflection increases quantum efficiency in thin layer devices (that is, with low dark current) when absorption is not strong enough to make useful all radiation at a single pass through the active layer. However to the best of our knowledge all previous BSI GaSb-like PDs did not contain broad mirror contact and there have been no attempts to couple these PDs with immersion lenses.

Here we present characterization of the BSI InGaAsSb/GaSb heterostructure photodiodes, fabricated in an episide-down manner and optically coupled (immersed) with large area lenses.

The diodes were grown onto a n-GaSb (100) (Te, $n = 5\cdot10^{17}$ cm$^{-3}$) substrate at 470$^{o}$C by the LPE method and consisted of a 2-3 μm thick n-InGaAsSb undoped layer, a 0.5÷1 μm thick p-InGaAsSb layer and finally a 2-3 μm thick heavily Ge-doped p$^{+}$- GaSb ($p = 0.5\div1\times10^{18}$ см$^{-3}$) "contact" layer. The diodes had either $In_{0.09}Ga_{0.91}As_{0.08}Sb_{0.92}$ ("shortwave" PD) or $In_{0.15}Ga_{0.85}As_{0.13}Sb_{0.87}$ ("longwave" PD) active layers with interpolated values of $E_g$=650 and 570 meV respectively.

Heterostructure wafers were treated by a multistage wet photolithography process that enabled us to prepare 150÷200 μm thick flip-chip devices with a ~300 μm and a ~210 μm wide circular mesa and gold anode respectively. The 3.5 mm wide silicon lens was attached to the substrate side of the chip by a chalcogenide glass with high refractive index (n=2.4). The lens was partly shadowed by a holder and thus optical area was a 3.3 wide mm circle.

Both types of the PDs exhibited narrow spectral response and same shortwave cut-off due to GaSb substrate transmission cut-off as shown in Fig.1. The current sensitivity was practically independent on a temperature (see Fig.2) while current at saturation rapidly grew in the 20÷185$^{o}$C range (see Fig.3). The latter dependence is most likely reflects that current consisted of diffusion and generation-recombination components. In view of sensitivity "stability" the D* variation with temperature was associated mostly with the zero bias resistance ($R_o$) change.

The achieved $D^*_\lambda$ values are the highest parameters published for room temperature operation which together with data on high temperature operation of GaInAsSb/GaSb PDs will stimulate applications of these devices.

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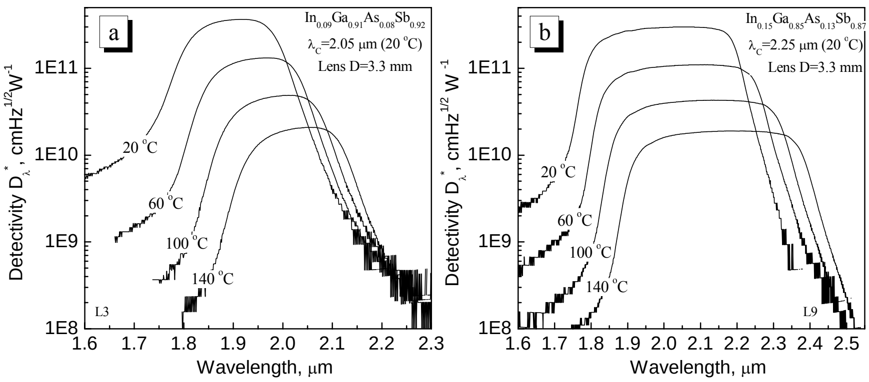


**Fig. 1** Spectra of the $D^*_\lambda$ for the "shortwave" (**a**) and "longwave" (**b**) immersion lens PDs at 20, 60, 100 and 140$^o$C.

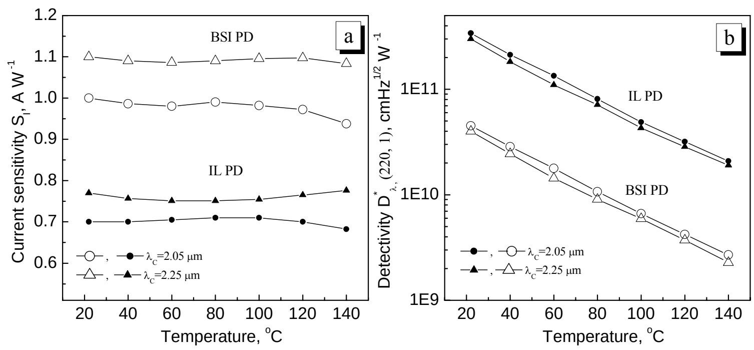


**Fig. 2** Temperature dependence of sensitivity ($S_I$) (**a**) and detectivity at maximum ($D^*_{\lambda max}$) (**b**) for BSI (open triangles and circles) and immersion lens (IL PD) (filled triangles and circles) photodiodes.

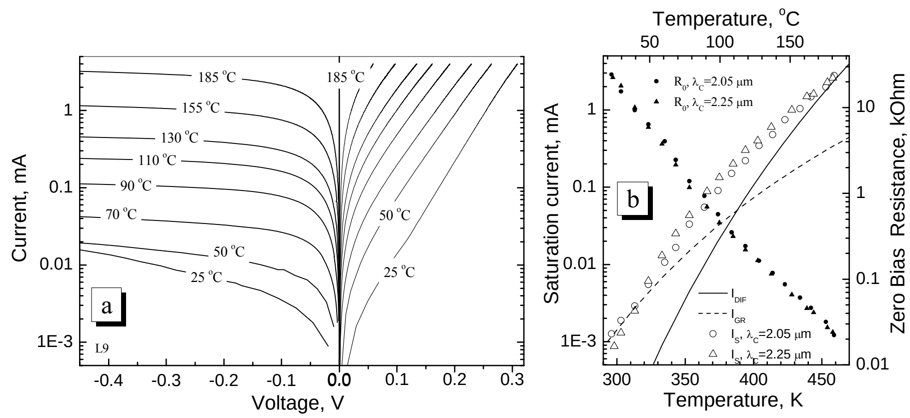


**Fig. 3** I-V characteristics of the uncoated "longwave" photodiode at several temperatures in the 25÷185$^o$C range (**a**) and temperature dependence of the zero bias resistance, saturation current for "longwave" (triangles) and "shortwave" (circles) photodiodes together with simulated values of the diffusion (solid line) and generation-recombination (dashed line) currents (**b**).