Hight-temperature luminescence of mid-IR LEDs based on an InGaAsSb/GaAlAsSb heterostructure

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BIOGRAPHY
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TECHNICAL ABSTRACT
Mid-IR LEDs are promising as radiation sources for water and carbon dioxide sensors. The characteristic absorption band of water and water vapor is near 1.9 μm; that of carbon dioxide, near 2.0 μm. Mid-IR LEDs with a narrow emission band (Δλ/λ < 0.1λmax) may form a basis for designing fast-response humidity and carbon dioxide sensors. There often arises the need to measure the water vapor and carbon dioxide concentrations at temperatures much higher than the room value. In connection with this, it is of interest to gain insight into the spectral and electrical performance of LEDs that emit in the near-IR range at high temperatures.

The object of investigation was a type-II heterostructure LPE-grown on an n-GaSb (100). Two-micrometer-thick In0.055Ga0.945AsSb quaternary solution Te-doped to n = (1–2) × 1017 cm–3 served as an active region of the structure. The active region and a 3.5-μm-thick p-GaSb overlayer (p = 7 × 1017 cm–3) produced a type-II p–n junction. As a wide-gap barrier for electrons, a 3.5-μm-thick p-Ga0.66A0.34AsSb film was used.

![Fig. 1. Distribution of the LED emission power spectral density at different temperature.](image1)

![Fig. 2. Decomposition of the spectrum into high-energy and low-energy components (HEC and LEC).](image2)

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Figure 1 shows the distribution of LED emission power spectral density $P_{\text{den}}$ at different temperatures. As expected, the emission power decreases with temperature and its maximum shifts toward longer wavelengths. In addition, the long-wavelength part of the spectrum is rather broad, the broadening being more pronounced at low temperatures. The broadening of the spectrum may be related to radiative recombination through acceptor levels, which are due to intrinsic structural defects, such as gallium vacancies and gallium substitutes for antimony [1]. The emission spectrum of the LED can be decomposed into two Gaussian components. Figure 2 shows such decomposition for temperatures of 17 and 200 °C. The total maximum of the power spectral density depends largely on the high-energy component (HEC) of the spectrum, since, with the integral powers of the components being comparable to each other (Fig.3), the FWHM of the HEC is smaller than that of the low-energy component (LEC). For example, the FWHM of the HEC at 17°C is ≈30 meV and that of the LEC, ≈71 meV. In the temperature range considered, the temperature dependences of $\nu_{\text{max}}^{\text{HEC}}$ and $\nu_{\text{max}}^{\text{LEC}}$ are linear, with $|d(\nu_{\text{max}}^{\text{HEC}})/dT| = 4.497 \times 10^{-4}$ eV/K and $|d(\nu_{\text{max}}^{\text{LEC}})/dT| = 3.732 \times 10^{-4}$ eV/K. Derivatives $|d(\nu_{\text{max}}^{\text{HEC}})/dT|$ and $|d(\nu_{\text{max}}^{\text{LEC}})/dT|$ are not equal to each other, because the activation energy of the deep acceptor levels decreases linearly with increasing temperature as $|d(\nu_{\text{max}}^{\text{HEC}}-\nu_{\text{max}}^{\text{LEC}})/dT| = 75.5$ meV/K. So the HEC and LEC shift relative to each other with increasing temperature.

In the case of optical transitions keeping the wavevector the same, the energy of the conduction-to-valence band transition must be lower than the energy of the maximum of electroluminescence by $kT/2$; that is, $E_g = \nu_{\text{max}} - 0.5kT$ [2]. Using this relationship and the linear approximation of the experimental dependence $\nu_{\text{max}} = f(T)$, one can derive an expression for the bandgap of the active region (In$_{0.055}$Ga$_{0.945}$AsSb, $n = (1-2) \times 10^{17}$ cm$^{-3}$): $E_g \approx 0.817 - 4.951 \cdot 10^{-4} \cdot T$ (eV) for 290 K $< T < 495$ K. The total emission power exponentially drops as $P \approx 0.4 \exp (2.05 \times 10^3 / T)$ with a rise in temperature primarily because of an increase in the Auger recombination rate. It should be noted that, in $n$-type semiconductors, the Auger process in which a minority hole recombines with an electron, transferring the released energy to another electron from the conduction band, is the most probable one (conduction-hole-conduction-conduction, or CHCC, process) [3].

![Fig.3](image)

**Fig.3.** Te Temperature dependence of (●) emission total integral optical power and its (◊) high-energy and (■) low-energy components.

The resistance of the LED, $R_0$, decreases exponentially with rising temperature $R_0(\text{Ohm}) = 5.52 \times 10^{-2} \exp (0.672/2kT)$. The reverse current through the diode in the given temperature interval is governed by the diffusion or generation-recombination mechanism, as $\eta = d(E_g/kT)/d\ln R_0 = 2.0$.

**Keywords:** InGaAsSb, heterostructure, mid-infrared, high-temperature, LED

**References:**