Vertically emitting InAs LEDs and lasers with mirror anode

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There has been remarkable progress in the performance of the mid-IR LEDs that can be used for optical methane and carbon dioxide detection in the 3.3-4.3 μm spectral band. Unfortunately the emission spectrum of the above diodes is strongly effected by the temperature change and thus narrow bandpass filtering is often required to attain desirable peak position stability.

On the other hand creation of a microcavity whose planes are parallel to the p-n junction and cavity length is close to the emission wavelength ($L \sim \lambda$) enable to achieve narrow linewidth with temperature insensitive wavelength position and with subsequent increase of the output power. The corresponding resonant cavity LEDs (RC LEDs) and vertical cavity lasers (VCSELs) are well known for the near infrared spectral region while mid-IR RC LEDs are still exotic.

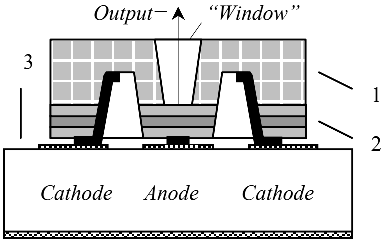

Fig 1. Schematic of the «flip-chip» LED mounted onto Si submount : 1 - *n-InAs substrate, 2- InAs/InAsSbP double heterostructure, 3 – Si submount with Pb+Sn bonding areas*

The report will describe resonant cavity features of room and above room temperature electroluminescence and coherent emission at 77 K escaping perpendicular to the p-n junction from the flip-chip InAsSbP/InAs double heterostructure (DH) diodes with broad nonalloyed gold anode.

InAsSbP/InAs DHs with n-InAs active layer grown onto heavily doped n^+- InAs(Sn) substrates or/and InGaAsSb/InAsSbP buffers were processed by a two-side wet photolithography into constructions with mesa diameter D_m= 300 and 430 μm. Some devices contained window adjoining the n-InAsSbP cladding with total structures thickness of about 7.5 μm in the active part of the LED as shown in Fig.1 , other devices were thinned down to 45 μm.

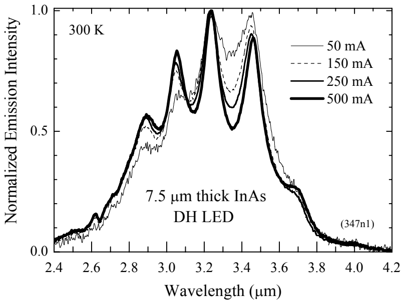

Fig. 2 Room temperature emission spectra of a 7.5-μm thick resonant cavity LED at pumping currents of 50-500 mA.

Due to the nonalloyed character of the bottom anode contact and mirror like surface at the air/semiconductor interface we have been able to measure Fabry-Perot modes in a spontaneous regime in many of our LEDs (see Fig. 2, 3) with $\Delta\lambda=\lambda^2/2nL$ (n=3.52) mode spacing at 300 K. The resonant quality factor (fiancée) Q estimated from the mode linewidth and predicted reflectivity of R_1=0.9 (for the anode) and R_2 =0.3 (for the air/semiconductor interface) was as high as 24 and 80 for the 7.5-μm and 45-μm thick LEDs correspondingly. In addition to standard RC LED behavior such as an increase of the spectral brightness of the modes, the decrease of the mode linewidth/far field pattern FWHM at the pumping current increase, these LEDs exhibited fine tuning of the mode structure towards short wavelengths with a rate close to that of the tunable diode lasers made from nominally similar materials [1].

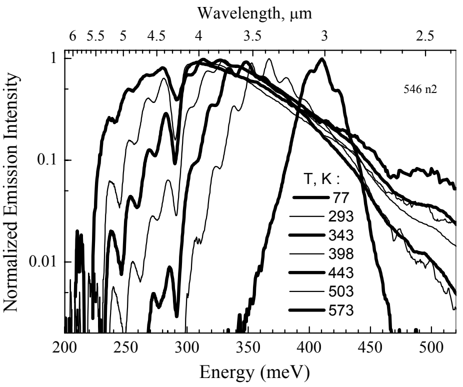

Fig.3 Emission spectra of the forward biased (“positive luminescence”) 7.5- um thick LED at 77, 293, 343, 398, 443, 503 and 573 K

Peak position of the 7.5-µm thick LED spectra with kT/2 correction corresponds to the known InAs energy gap temperature dependence: $E_g = 415 - 0.276 \cdot T^2/(T+83)$ while the short wavelength shoulder slope reflect electron distribution: I~exp(- hν/kT). It is seen that the InAs diode can well be used for the high temperature (200-300°C) CO_2 gas detection since the absorption spectrum of the latter overlaps with the LED emission as manifested in Fig.3 as a dip at 4.3 µm.

The I-U characteristic at elevated temperatures (200-300^{0}C) lacked “ideal” saturation character, however, we believe that the slight increase of the reverse current at $U>U_{saturation}$ was caused by the current crowding effect [2], that is typical for narrow gap devices with strong dependence of the material resistance on the impurity doping levels. This is supported by the observation of the negative luminescence power increase that accompanied the increase of the reverse current beyond the “saturation” point. The existence of current crowding effect will be also confirmed by analysis of spectral and L-I features of the forward bias luminescence.

The negative luminescence power at elevated temperatures exceeds the positive one by factor 3-4 showing advantage of the extraction activation of the p-n junction/LED. (see Fig. 4). Possible reason for the superiority of the negative luminescence mode is the suppression of the Auger nonradiative processes at the carrier concentration decrease.

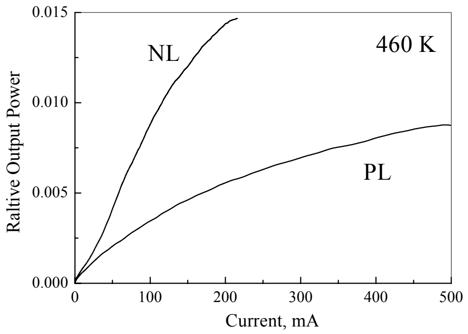

Fig.4 InAs LED output at forward (PL) and reverse (NL) bias vs current at 190°C

Cooled devices (77 K) lased perpendicular to the p-n junction at λ=2.95 µm at thresholds as small as 300 A/cm^2 with one dominant stable mode in the whole 1-2 A pumping current range with blue shift of the line position typical for the InAsSbP/InAs system. Data on far field pattern, temperature dependence, output power and 2-D radiation distribution across the outcoupling surface would be also discussed.

References

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