MIR PhotoVoltaic detectors based on type II p-InAs/AlSb/InAsSb/AlSb/p-GaSb heterostructure with deep quantum wells at the interface

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Applications of MIR Photodetectors

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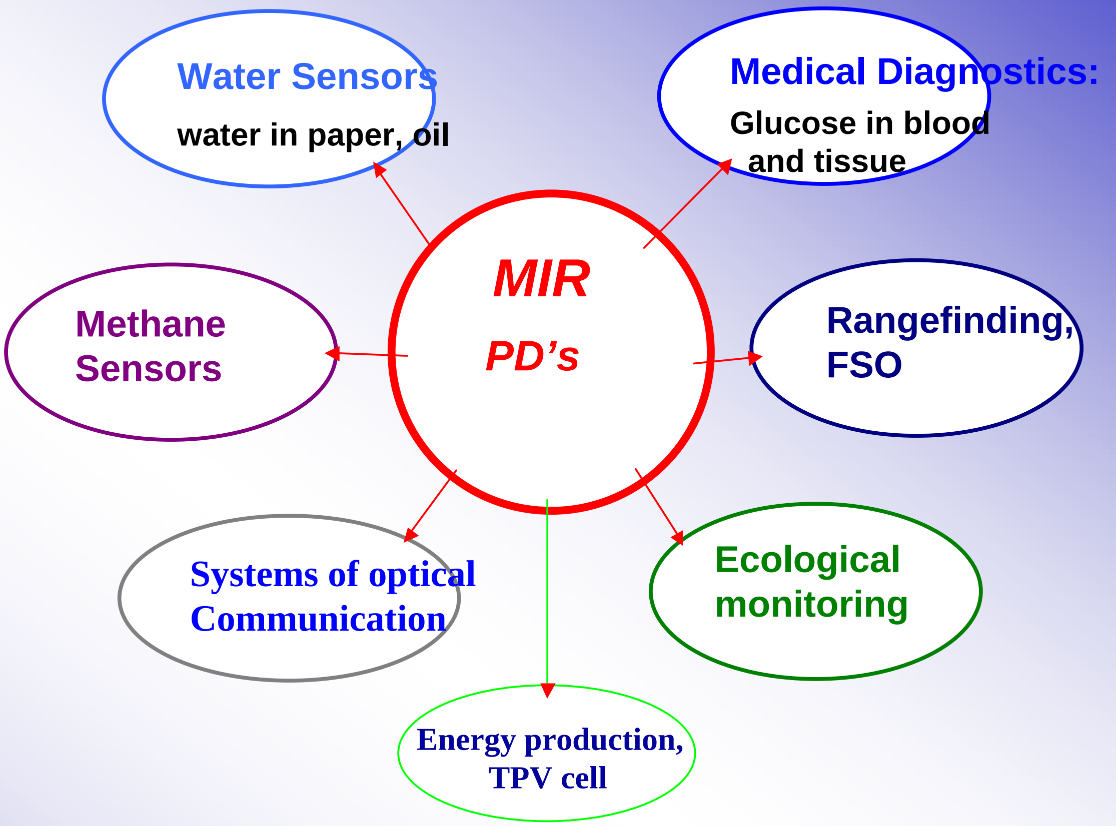
GHeterodyne spectroscopy and free space communications using quantum cascade lasers
Gases analyzers
Medical diagnostics
Ecological monitoring



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Samples growing and characterisation

The structures were grown in an AIXTRON 200 machine with RF heated graphite susceptor in a horizontal reactor by low-pressure MOVPE.

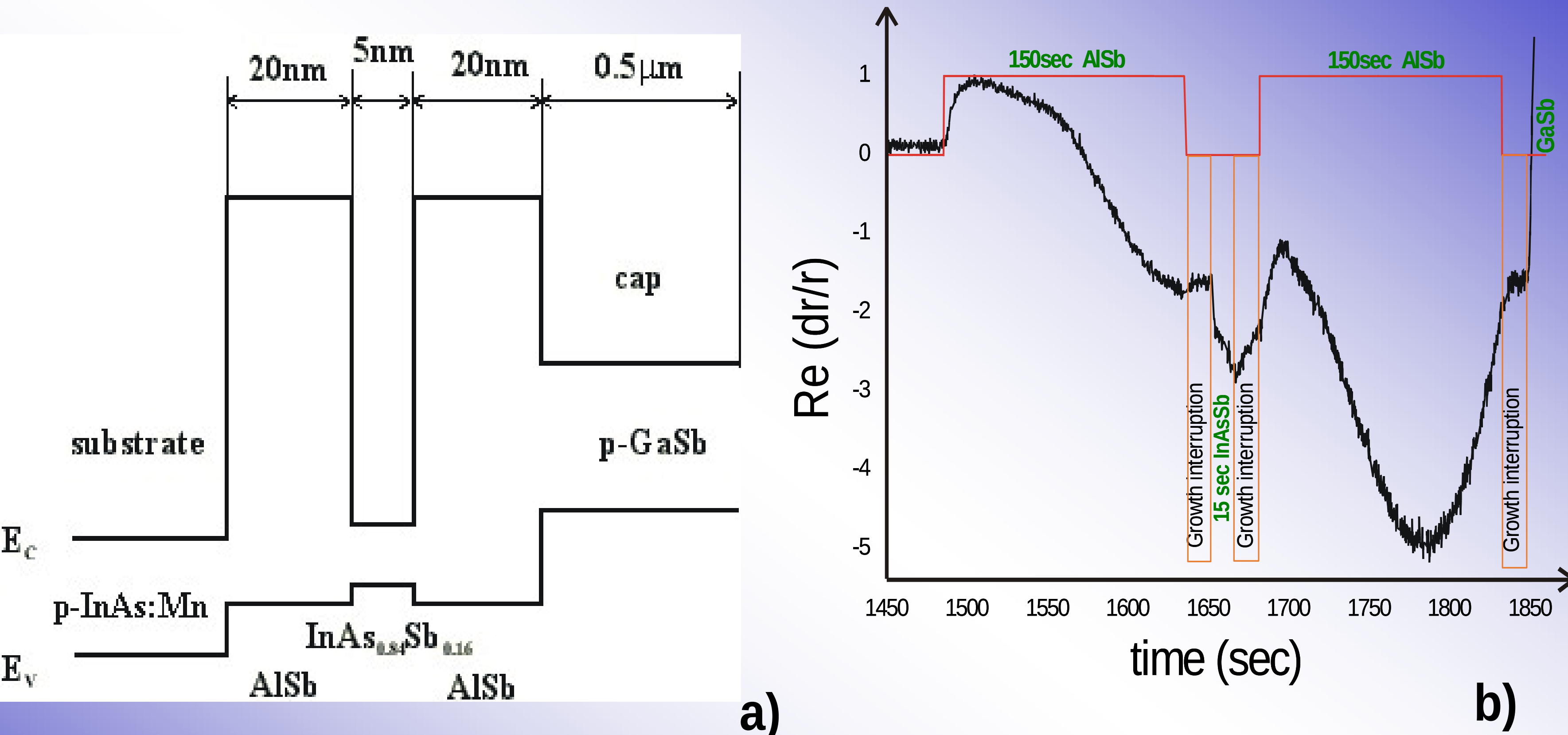
Precursors: Tris(tertiarybutyl)aluminium (TtBAl), triethylgallium (TEGa), trimethylindium (TMIn), tertiarybutylarsine ($tBAsH_2$) and triethylantimony (TESb)

The epitaxial structure was grown on p-InAs:Mn substrate and consisted of a single (or triple) 20 nm-AlSb/5 nm-$InAs_{0.84}Sb_{0.16}$/20 nm-AlSb quantum well based on undoped materials followed by undoped 0.5 μm-thick p-GaSb cap layer.

Before the growth, substrates were heated to 640°C for 5 minutes, then the growing was carried out at temperature T=560°C in Pd-diffused H_2 athmospere.

A schematic band energy diagram is shown in Fig.1a

Scheme of the asymmetric structures.



Band offsets at the InAsSb/AlSb interface were ΔE_C=1.35 eV and ΔE_V=0.15 eV.
In-situ measurements using reflectance anisotropy spectroscopy (EpiRAS 200TT - LayTec) in the time resolved mode at 3.7 eV were performed during the growth (Fig.1b).

The samples under study were as round mesa-diodes with 300 μm in diameter prepared by standard photolithography procedure and wet etching. EL spectra, I-V characteristics and spectra of photocurrent response were studied at temperatures 77 K and 300 K.

Positive and Negative Electroluminescence in InAs/AlSb/InAsSb/AlSb/GaSb SQW structures.

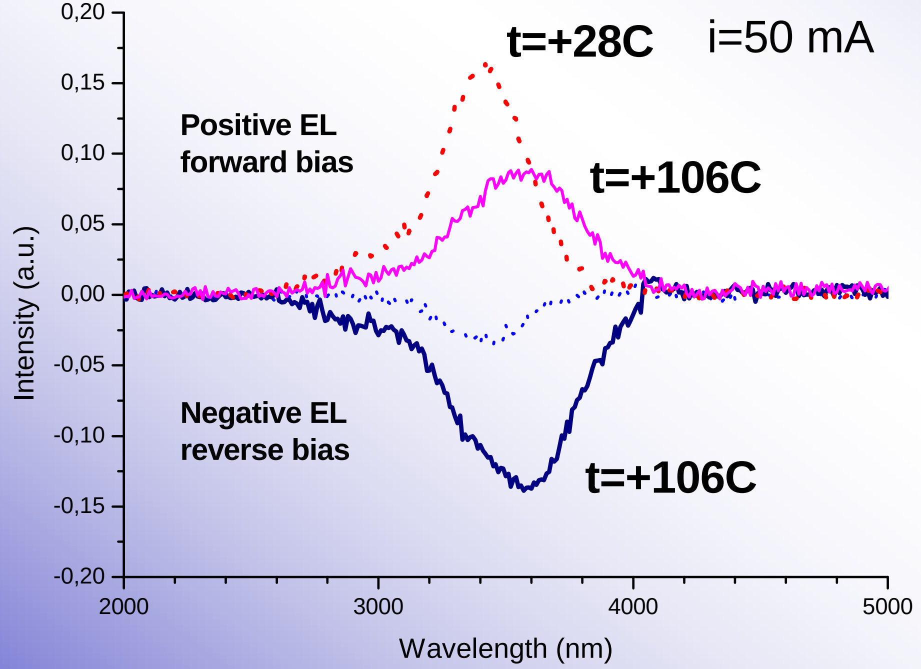


Fig 2. EL spectra of InAs/AlSb/InAsSb/AlSb/GaSb SQW measured under both bias directions at i=50 mA

Intense EL, both positive and negative, from the heterostructures with a singe QW at the interface was observed in the photon energy range of 300-400 meV at temperature range t=28-106 ^{0}C. By applying forward bias to the structure (+ at p-InAs substrate) one pronounced emission band hν=0.350 eV was observed in EL spectrum at T=300 K.

At reverse bias (- at p-InAs substrate) NEL has been found out. Increase of the NEL emission intensity with temperature can be explained by the radiative recombination of the carriers transferred across the AlSb/InAsSb/AlSb quantum well due to resonance injection responsible for the suppression of Auger-recombination process at high temperature.

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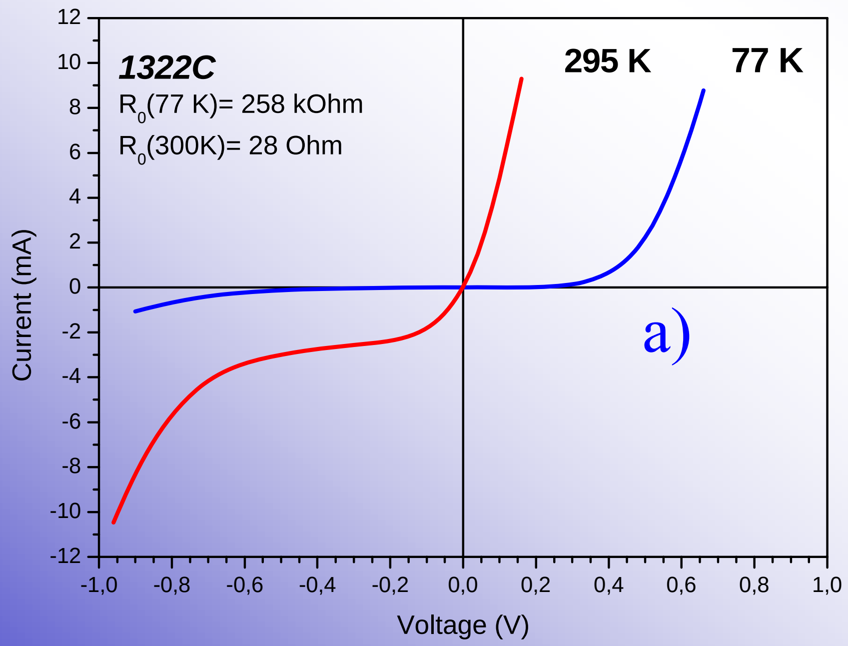
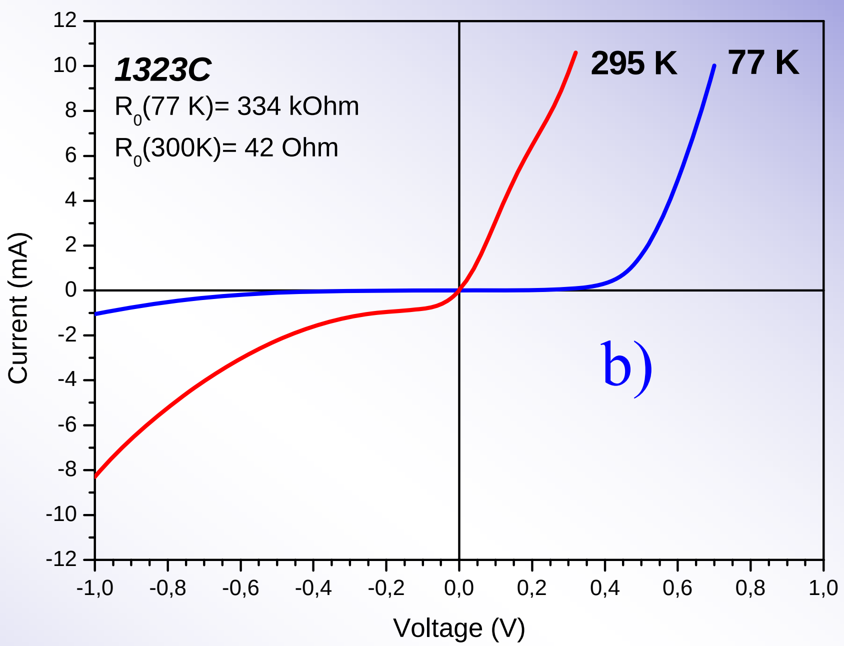
The dark current of InAs/AlSb/InAsSb/AlSb/GaSb SQW structures a) and 3QW structures b)

These results, especially high-intensive radiative recombination, which is evidence of high internal quantum efficiency, allow us to attempt testing the structures under study as PD's. Current-voltage characteristics and spectra of photoresponse were studied at 77 and 300 K. Experimental results have shown rectifying I-V characteristics at low bias.





R_0=28 Ohm (295K), 258 kOhm и R_0×A=120 Ohm × cm^2 (77K) – a).

R_0=42 Ohm (295K), 334 kOhm и R_0×A=155 Ohm × cm^2 (77K) – b).

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Negative differential resistance (NDR) in InAs/AlSb/InAsSb/AlSb/GaSb SQW structures

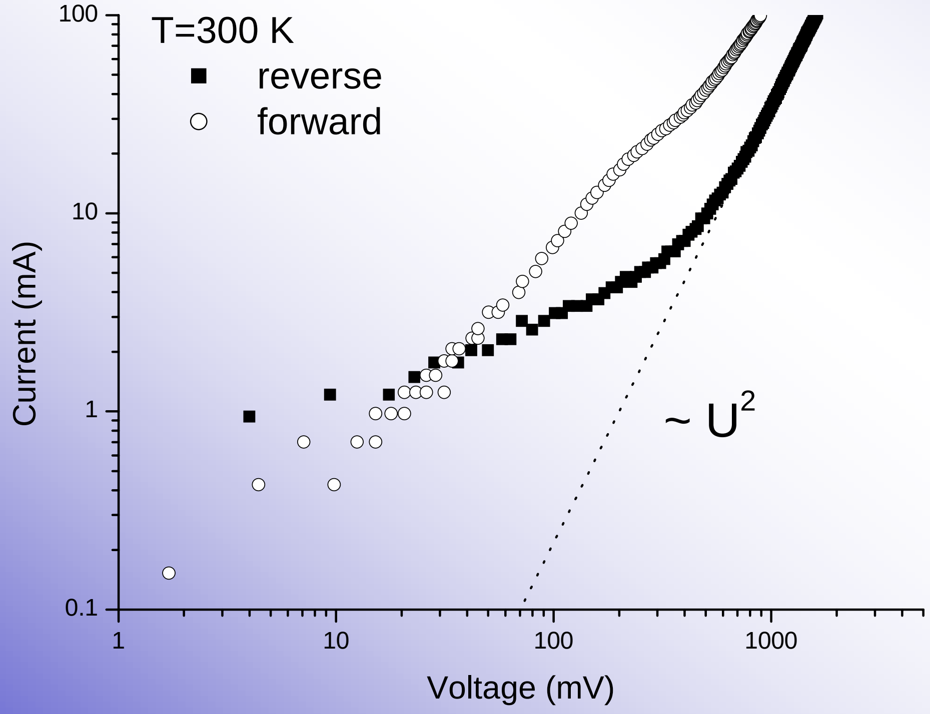
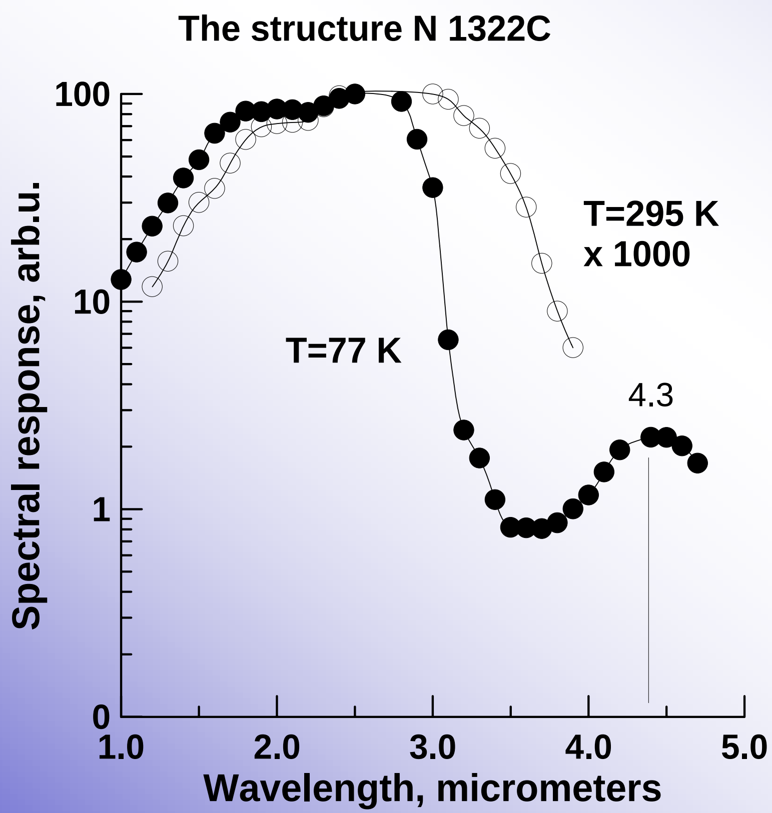
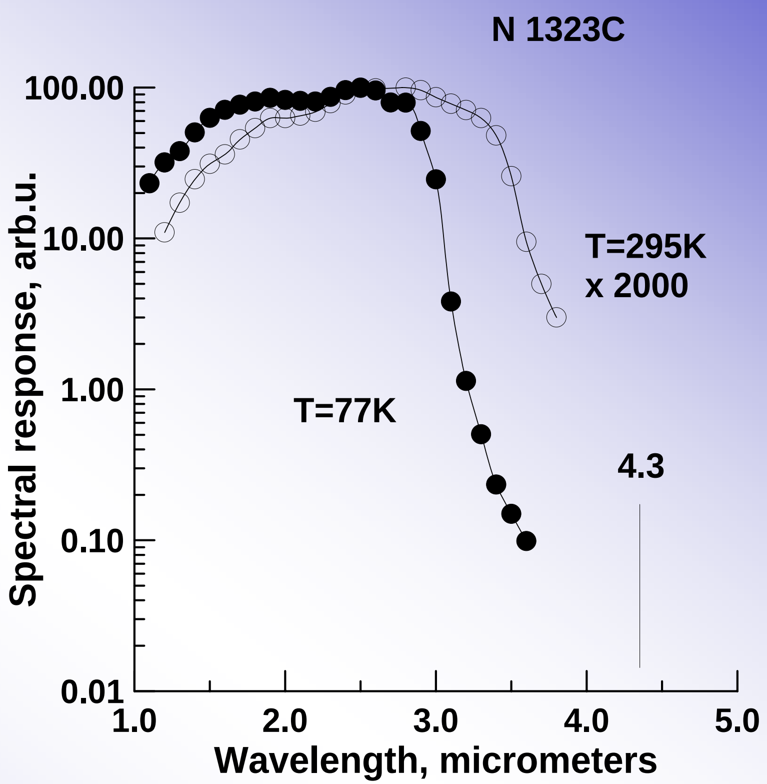


Fig.5: Room temperature I-V characteristics of InAs/AlSb/InAsSb/AlSb/GaSb SQW heterostructure at high injection conditions.

Increasing the applied bias to higher values (U=1-3 V) a NDR was observed in forward curve of I-V at RT. As it was shown this effect can be associated with resonant-tunneling transitions of carriers through the states in the quantum well (occupied electron level E_1=370 meV) and/or the deep donor states in the AlSb barrier near the InAs/AlSb interface.

Spectral response distribution of InAs/AlSb/InAsSb/AlSb/GaSb SQW structures and 3QW structures





$\Delta\lambda$ =1.7-3.0 μm S_λ= 0.9-1.4 A/W, η =0.6-0.7, T=77K

NEP= 6×10^{-14} $W/Hz^{1/2}$ D*=3.5×10^{11} $cm^2\times Hz^{1/2}\times W^{-1}$.

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Summary

1. **Asymmetric type II p-InAs/AlSb/InAsSb/AlSb/p-GaSb heterostructures with deep quantum wells at the interface were grown by LP-MOVPE. Electroluminescent, current-voltage characteristics and photoelectrical properties were studied. Intensive PEL and NEL was observed at T=300-400 K in the spectral range 0.30-0.42 eV.**
2. **Current-voltage characteristics were rectifying. At high reverse bias a NDR was observed which due to resonant tunneling through the narrow-gap QWs.**
3. **Photoresponse for the samples with QW's at the interface were obtained in the spectral range 1.7-3.0 µm at 77 K in a PV mode. Sensitivity S_λ=0.9-1.4 A/W, quantum efficiency η=0.6-0.7 and detectivity D*=3.5×10^{11} cmHz$^{1/2}$W^{-1} were obtained. These parameters are comparable with ones for InAs-based commercial photodiodes as well as for reported double-barrier InGaAs(GaAs)/GaAlAs QW photodiodes grown by MBE.**
4. **At T=77 K a weak additional peak was observed at around of 4.3 µm. We suppose the weak longwavelength peak can be associated with tunneling transitions of electrons from level E_1=370 meV in QW involving deep donor level, E_D=0.41 eV in AlSb.**

ACKNOWLEDGEMENTS

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