# Optimized MBE growth technique for GaSb-based edge emitters at 2.7 µm

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## GENERAL

Mid-infrared semiconductor lasers are key components for tunable diode laser absorption spectroscopy applications [1]. As wavelengths above 2.3 µm are barely accessible with the InP technology [2], the GaSb material system is used for the wavelength range from 2 to over 3 µm. Only recently electrically pumped VCSELs were realized at 2.3 µm, operating cw at room temperature [3]. In the process to further increase the emission wavelength and performance of these devices, edge emitters based on GaSb were fabricated. These devices show excellent cw threshold current density values of 91 A/cm² for 2.7 µm devices at room temperature ($L\rightarrow\infty$).

## SAMPLE DESIGN

The edge emitters were grown on an *n*-type GaSb-substrate. The growth starts with a 2 µm thick cladding layer of $Al_{0.50}Ga_{0.50}As_{0.04}Sb_{0.96}$ with a Te doping of $2\cdot10^{18}$ cm$^{-3}$ followed by a 400 nm undoped $Al_{0.10}Ga_{0.90}As_{0.01}Sb_{0.99}$ waveguide layer. Next, two 20 nm wide $Ga_{0.57}In_{0.43}As_{0.14}Sb_{0.86}$ quantum wells (QWs) are sandwiched between 8 nm GaSb barriers. The *p*-side is equivalent to the *n*-side but with a Si doping of $5\cdot10^{17}$ cm$^{-3}$ in the cladding and is followed by a highly *p*-doped GaSb contact layer. The simulated band diagram of the structure under laser operation is shown in fig 1 a. All samples were grown on a Varian Gen-II-MBE system with solid sources and valved cracker cells for Arsenic and Antimony.

## BLUE SHIFT DUE TO ANNEALING

It is well known that the GaInAsSb material used in the QWs shows a strong miscibility gap which gets more pronounced at high Indium fractions that are needed for long wavelength lasers. This leads to growth problems and a blue shift of the emission wavelength when the material is exposed to elevated temperatures after growth as needed, for instance, for the growth of upper waveguide and cladding layers [4]. Photoluminescence (PL) test samples were fabricated and annealed at different temperatures. As can be seen in fig. 1 b, the blue shift increases and the PL response gets weaker with rising annealing temperatures. The effect of the blueshift can be compensated by adding more Indium to the QW-material. However, this moves the composition even deeper into the miscibility gap. We therefore have minimized the blueshift by introducing a cold overgrowth of the *p*-side waveguide and cladding layers that follow after the active region. In contrast to other edge emitter designs in this material system using $Al_{0.90}$GaAsSb for the cladding and 20-40% Al for the waveguide and barriers [5,6], here the cladding layer contains a low Al fraction of only 50%. The waveguide layers contain 10% Al, and the barriers consist of sheer GaSb. These materials can be grown in sufficient quality at low growth temperatures around 430°C.

## DEVICE RESULTS

After epitaxy, ridge waveguide edge emitters were processed, cleaved and mounted epi-side up. The measurements were made on a temperature controlled heat sink. The devices show cw laser emission at 2.72 µm at temperatures up to 40°C. The power over current characteristic is shown in fig. 2 a. The maximum output power at 15°C reaches over 30 mW (limited by the current source) for a 1.2 mm long device with a 30 µm stripe width. The threshold current density is plotted over the inverse length in fig 2 b and reveals a $J_{th,inf}$ of only 91 A/cm² (2 QWs). This is by far the lowest val-

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ue published so far for lasers at this wavelength and shows the improved potential of the cold-grown GaSb material system for high-performance mid-IR lasers.

*Acknowledgements:* This work has been supported by the European Union via NEMIS (contract no. FP6-2005-IST-5-031845) and the German Federal Ministry of Education and Research via NOSE (contract no. 13N8772).

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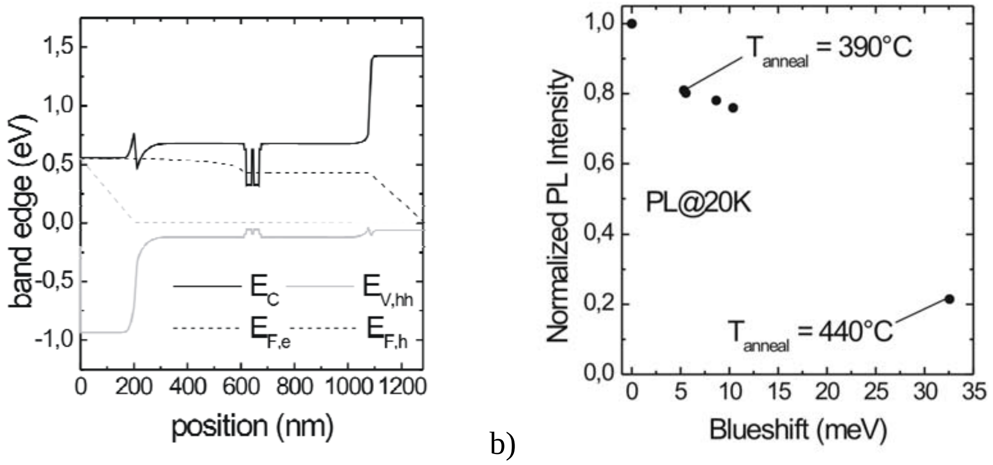
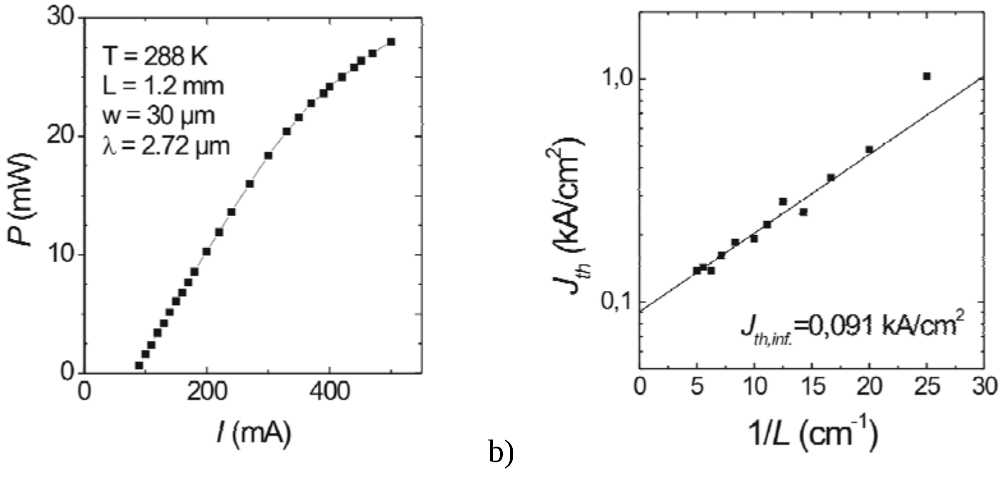
## FIGURES



a) b)

Fig. 1: a) Band diagram and Fermi level calculation of the edge emitters under lasing operation. b) Blue shift and PL intensity of PL samples annealed for 2h at different temperatures.



a) b)

Fig. 2: a) Output power versus current caracteristic of GaSb-based laser. b) Threshold current density versus inverse length.