# Short-wavelength injectorless quantum cascade laser based on intracavity second-harmonic generation

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**Student Paper**

**Abstract** We present room temperature operation at record-short 2.7 µm wavelength of an injectorless quantum cascade laser based on intracavity second-harmonic generation, with about 10 µW output power and only 1.5 kA/cm² threshold current density.

## Introduction

AlGaInAs-based quantum cascade lasers (QCL) grown on InP substrates have recently reached reliable high-power continuous-wave (cw) operation in the spectral range between 3.7 and 12 µm at room temperature [1]. One of their main applications is gas sensing, where recent developments have strongly increased the demand on such unipolar laser sources [2]. Since their production is compatible with standard telecommunication laser fabrication lines, they are the first choice in terms of manufacturing costs. However, a further reduction of the laser wavelength towards 2.5 µm, where a lot of absorption lines of important gases are located, is limited by carrier scattering into indirect valleys of the well [3]. To overcome this obstacle we use the giant nonlinearity of intersubband states for second-harmonic (SH) frequency doubling [4]. The monolithic integration of a mid-infrared QCL with a multi-quantum-well nonlinear (NL) optical media offers the unique possibility to generate near and mid-infrared laser light at the same time and will be presented.

## Experimental

The presented laser devices consist of a 1.5 µm thick (60 periods) AlGaInAs-based active region, which acts as an injectorless mid-infrared ($\omega$) QCL source, followed by 55 periods of a two well AlInAs/GaInAs NL-section, which is needed for SH-generation ($2\omega$) as shown in Fig 1 (left). The MBE grown wafer was then patterned into lasers with different longitudinal NL filling factors $F$ (= $L_{\mathrm{NL}}/L_{\mathrm{Laser}}$). The period length of the grating corresponds to a 50% duty cycle and it is designed to compensate the inherent wavevector mismatch of the pump and SH beam by Quasi-phase-matching (QPM) [5]. Afterwards, the sample has been cleaned and a 4µm thick *n*-InP cladding and 50 nm *n*-GaInAs top-contact layer was grown by MOVPE. At last, the wafers were fabricated to deep-etched ridge waveguide lasers with different resonator lengths for characterization. Additionally a SiN/Ti/Au high-reflectivity (HR) coating was applied on the back facet and a SiN antireflection coating (AR) on the front facet. The device is sketched in Fig.1.

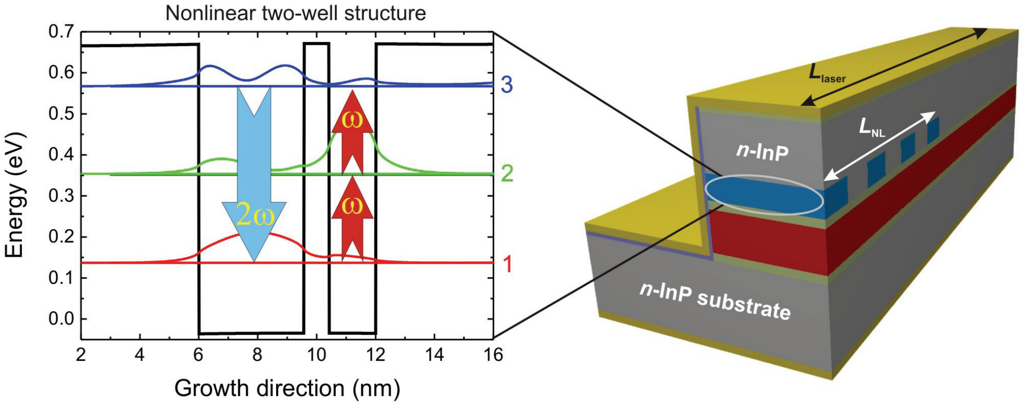

*Figure 1: The sketch of the longitudinal section of the SH-QCL (right picture) illustrates that the active region of the injectorless QCL (red) and the GaInAs cladding layers (green) range over the total device length, whereas the patterned NL section (blue) is only located near the front facet. The schematic conduction band structure of one period of this $Ga_{0.35}InAs/Al_{0.55}InAs$-based section is shown in the left picture.*

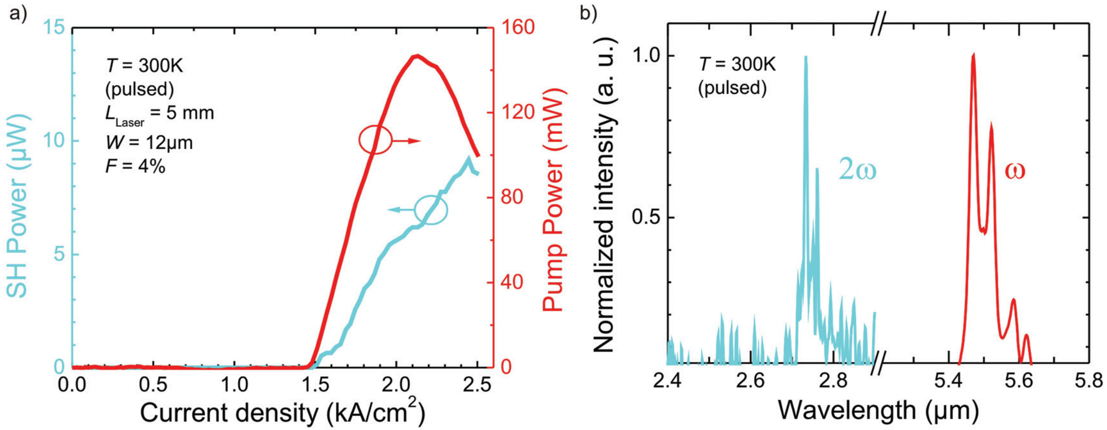

*Figure 2: P-J characteristics of the SH generated light and the corresponding pump power are illustrated (a). The room-temperature emission spectrum is shown in (b). The device length is 5 mm with 12 µm stripe width and a 4% filling factor F. A HR and AR coating was evaporated on the back and front facet, respectively.*

## Results and Discussion

Fig 2. shows the *P-J* characterisation and the emission spectra of the fabricated devices. It is obvious that the patterned NL section offers on the one hand the SH-generation due to the large second-order susceptibility $\chi^{(2)}$ and on the other hand the wavevector mismatch of the pump- and SH-wave is compensated due to the "on-off" structuring of the NL part. Since the NL-section is only localized at the front facet (Fig. 1), the high resonant losses for the pump beam are reduced so that room temperature operation is possible. The achieved SH output at 2.7 µm is the shortest reported wavelength of a QCL device operating at room temperature and indicates the expected high performance of injectorless QCLs [6]. This result is very promising to achieve a device covering the near- and mid-infrared wavelength range, which is an essential benefit for applications like gas sensing. Further improvement is the optimization of the growth of the structure, since the NL-section and the pump source must operate at the designed resonance for maximum conversion. As shown in Fig. 2 a) the rise of the SH power does not coincidences with the pump power, which indicates that pump and NL-section are not perfectly matched and get only at higher current densities into more resonance due to the stark-shift of the pump. Therefore even a further performance improvement with optimized growth and design seems to be reachable and first attempts will be presented.

## Conclusions

In conclusion we have demonstrated room temperature operation of an InP-based QCL at record short 2.7 µm wavelength by intracavity second-harmonic generation using the well-developed AlInAs/GaInAs material system. Together with the mid-infrared QCL pump source this design could lead to a compact broadband source for the coverage of the whole 2-8µm wavelength range, which would ideally meet the requirements for applications like gas sensing.

## References

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