Nonlinear light generation in GaAs quantum-cascade lasers

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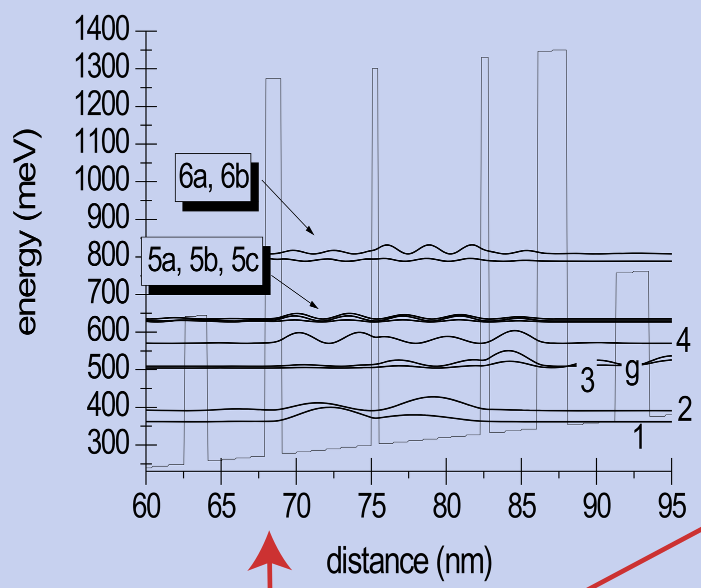
Motivation

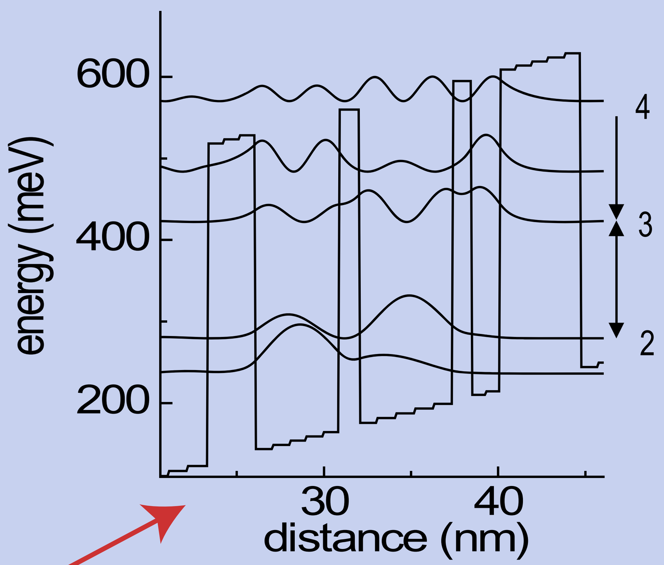
Quantum cascade lasers (QCLs) are unipolar injection lasers emitting in the mid- and far-infrared. Bandstructure engineering allows tailoring the emission wavelength and designing electronic levels that enhance intersubband nonlinearities. Nonlinear light generation in QCLs is not only an interesting field for basic research, it also extends the wavelength range of these devices. As the laser emission energies are typically well below the band gaps of the hosting materials (GaAs or InP), intracavity second-harmonic (SH) generation is feasible in these semiconductor lasers. Investigation of the nonlinear conversion efficiencies of QC active regions, and finding suitable wavegeuides that minimise the phase mismatch are necessary for efficient nonlinear light sources.

Bandstructure & Performance

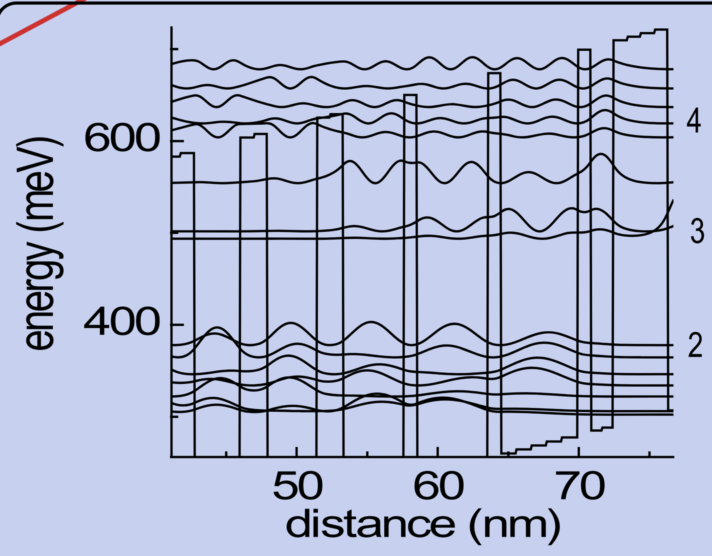
Three QC active regions: 3-well AlAs (A), bound-to-continuum (B), 3-well AlGaAs are investigated with respect to their nonlinear output. Doping is shown to have an influence on the conversion efficiency, as well as the waveguide type.

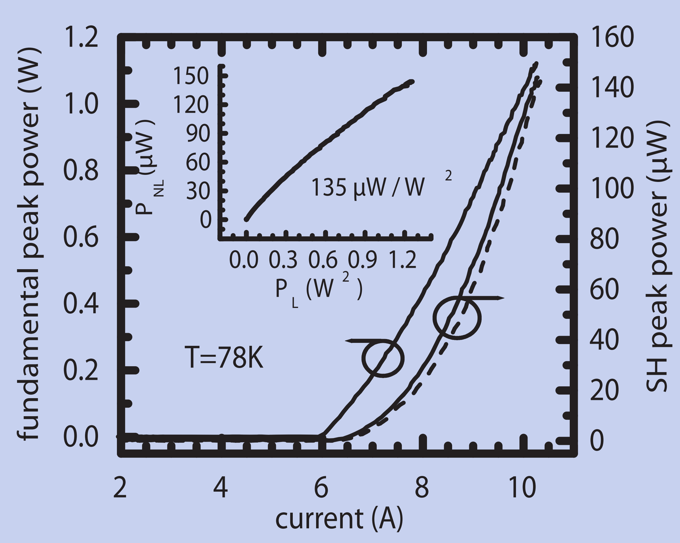
$$P(2\omega) \approx \frac{e^3 N_e E_z^2(\omega)}{\hbar^2}\left(\frac{z_{23} z_{34} z_{24}}{\Gamma_{42}}\left(\frac{n_3 - n_4}{\Gamma_{43}} + \frac{n_3 - n_2}{\Gamma_{32}}\right)\right)$$

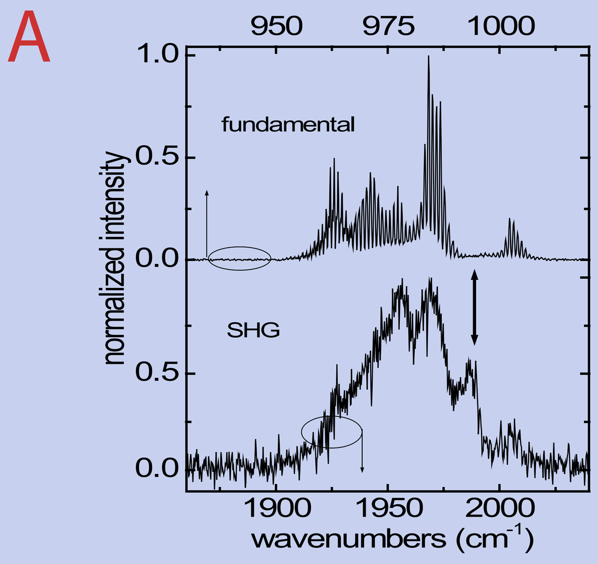


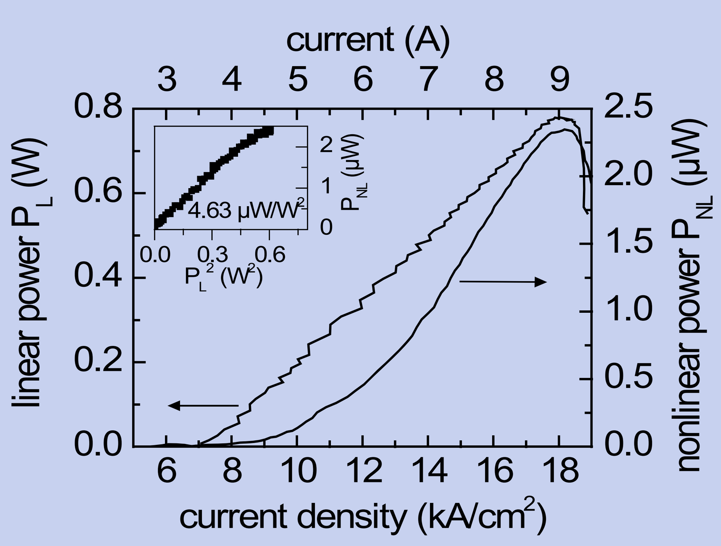


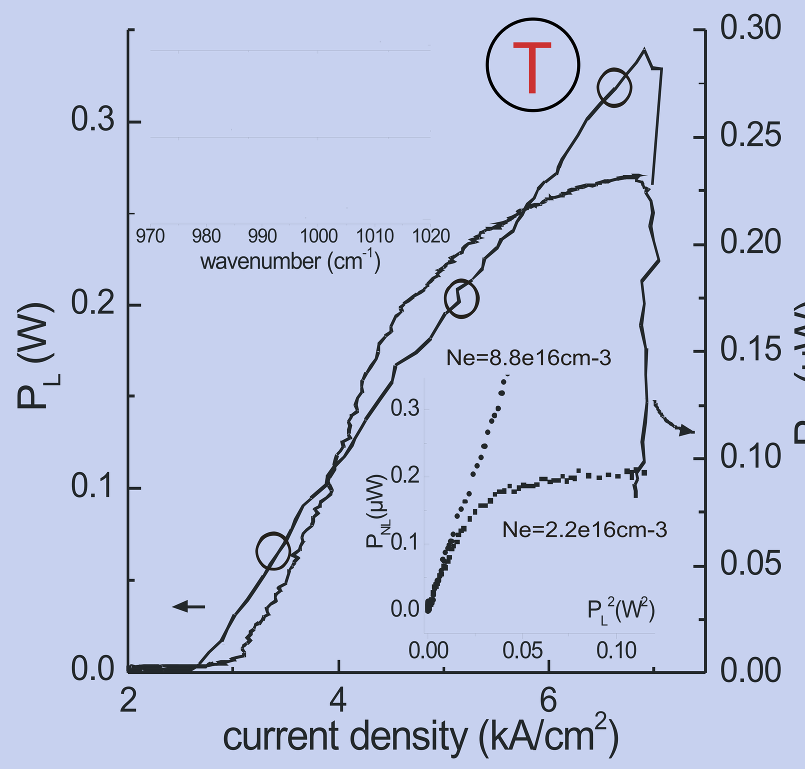
	Structure A	Structure T	Structure B
E_{32} (meV)	117	143	124
z_{32} (nm)	1.53	2.09	2.07
$E_{43(5c3)}$ (meV)	128	148	128
$z_{43(5c3)}$ (nm)	0.11	0.22	0.6





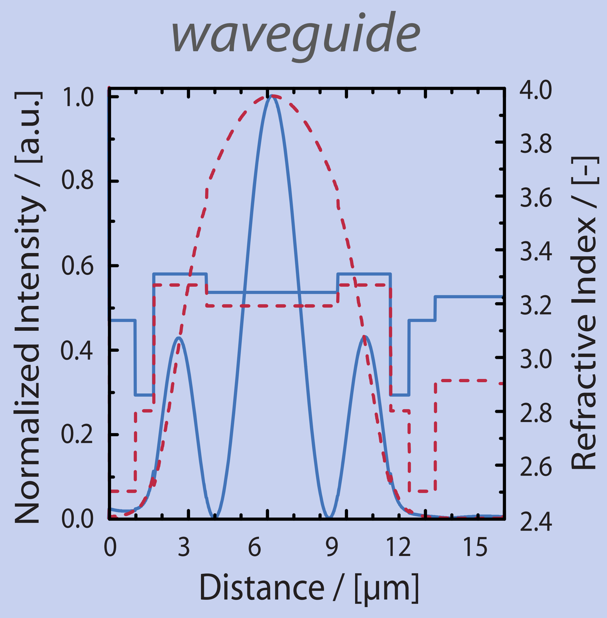




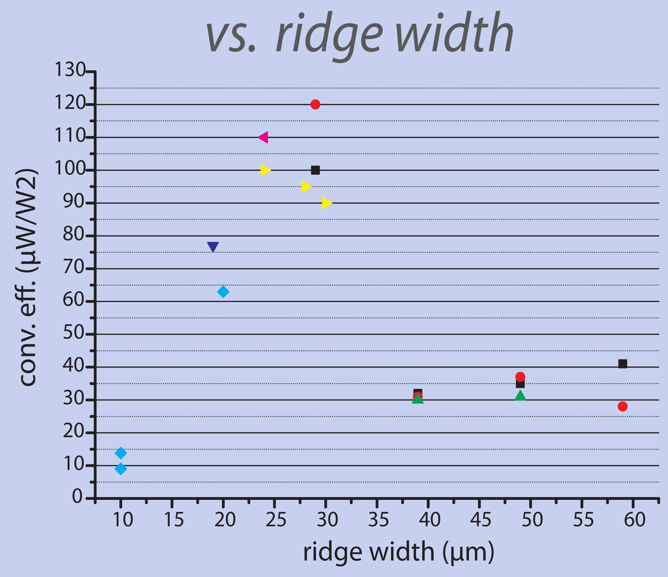


Phase-matching in Fabry-Perot devices

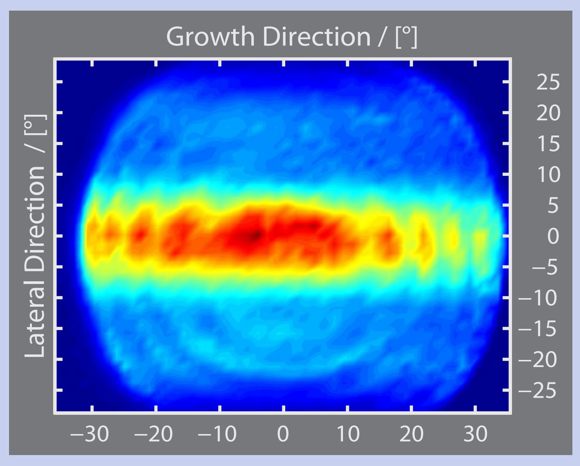
Double Al$_{(x)}$Ga$_{(1-x)}$As waveguide



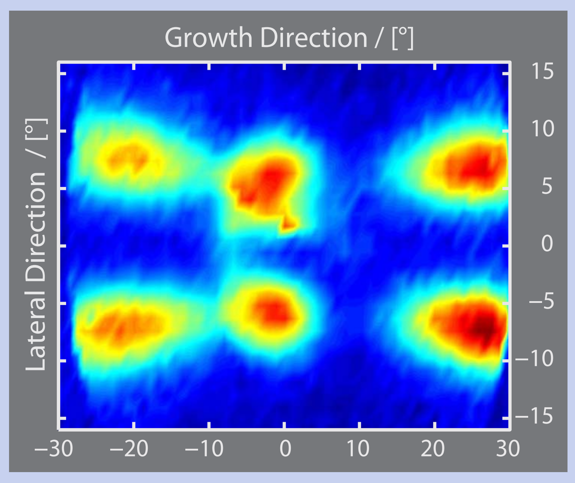
External conversion efficiency vs. ridge width



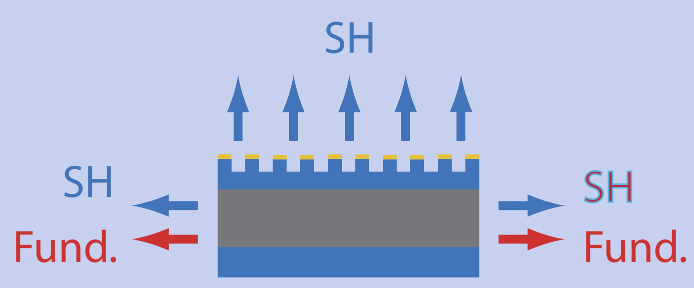
Fundamental Far Field



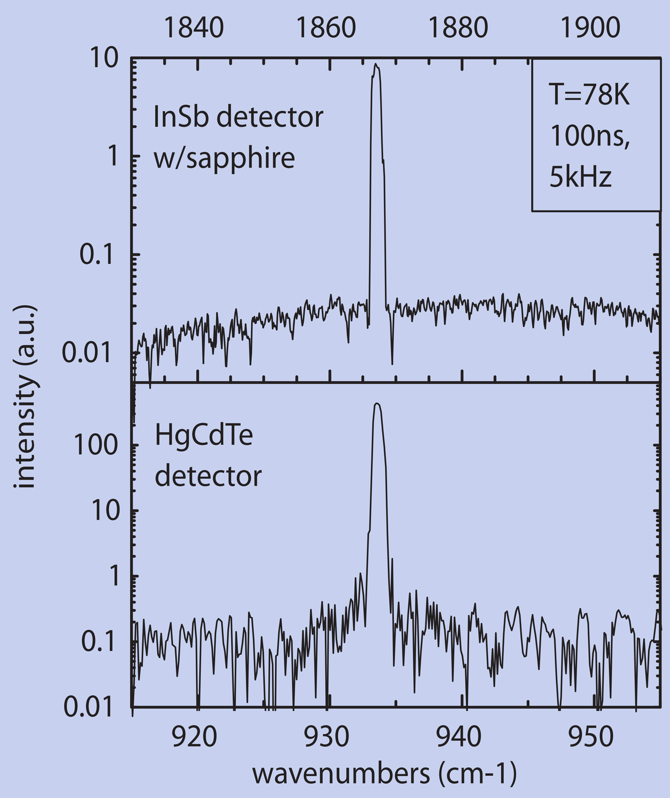
Second-Harmonic Far Field



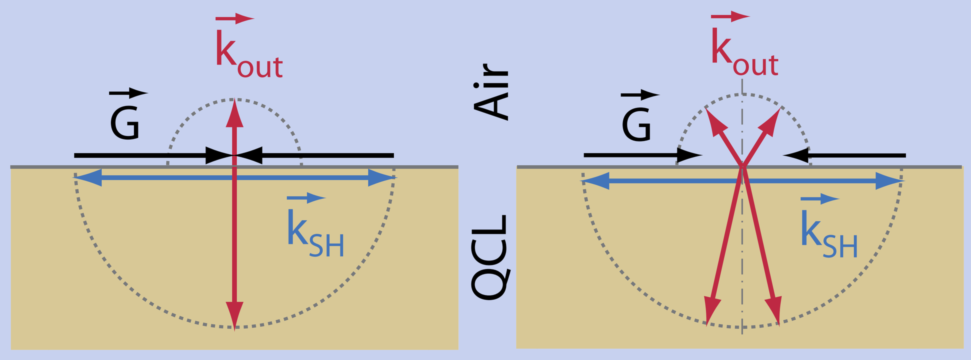
Surface Emission from 2nd order DFB SH devices

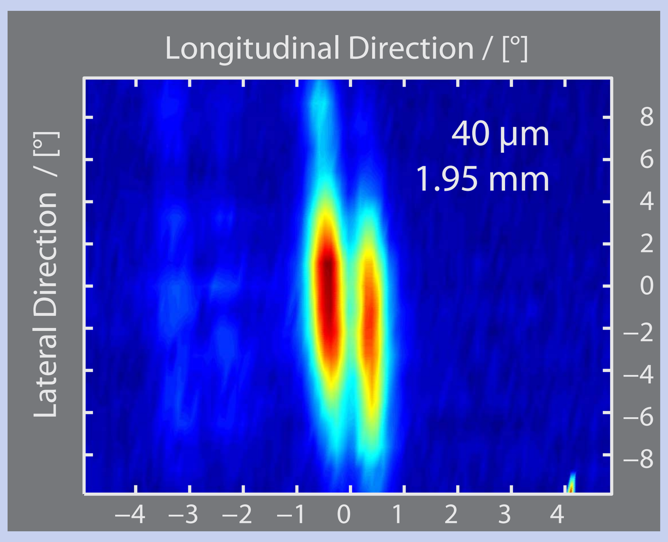


The grating was designed to be 1st order for the fundamental mode and hence it is 2nd for the SH mode. The device is only emitting SH via the surface.



DFB laser surface farfield measurements





The phase mismatch and interference effetcs are mechanism for multi lobe emission as the SH wave vector does not perfectly match the 2nd order Bragg condition.

Summary and Outlook

We presented SH generation in GaAs/AlGaAs quantum cascade lasers due to intersubband nonlinearities. We investigated different active regions, active region doping levles and waveguides with respect to the nonlinear conversion efficiency. The SH radiation can be coupled out by a surface DFB grating, where the surface emission pattern can give information on the phase-mismatch between the fundamental and SH fields. Future goals include the investigation of intracavity difference-frequency generation in QC lasers and the application of grating-coupled emission for this purpose.

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