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Modelling surface acoustic wave modulation of the carrier concentration in quantum cascade lasers for broadband tuneability

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Frequency-tuneable quantum cascade lasers are highly desirable for a wide range of spectroscopy applications including atmospheric and trace gas sensing. In 2003, Kisin *et al.* [1] proposed using the piezoelectric field generated by a surface acoustic wave (SAW) to tune QCLs over a broad range of wavelengths. A periodic spatial-modulation of the carrier density is established within the QCL active region, leading to selection of the emission frequency via distributed feedback (DFB). Since the frequency of the SAW may be varied, the periodicity of the DFB may be altered providing tuneability of the QCL emission frequency.

In this work, we simulate the effect of SAW modulation on the carrier density within the active region of a QCL. The top inset of Fig. 1 shows the simulated device structure; the SAW is generated by the interdigitated transducer (IDT) and propagates along the substrate and into the QCL ridge. The QCL active region is treated as a buried 2DEG where carriers are free to move under the influence of the potential induced by the SAW, the magnitude of which is determined by solving the time-dependent acoustic wave equations of motion. As the SAW propagates from the substrate into the QCL ridge, part of the acoustic energy is scattered into a bulk mode causing the SAW potential to deviate from a perfect sinusoid. The bottom inset of Fig. 1 shows the variation in the potential induced by the SAW and the resulting modulation in carrier concentration, which we assume to be invariant perpendicular to the x-axis. Fig. 1 shows simulated gain spectra for the QCL design in Ref. [2] with different carrier concentrations that result from the potential induced by the SAW at different points along the length of the active region. Since the spectral contribution with the highest gain peak will dominate, the lasing frequency would be blue-shifted with respect to the unperturbed gain peak shown by the dashed line in Fig. 1.

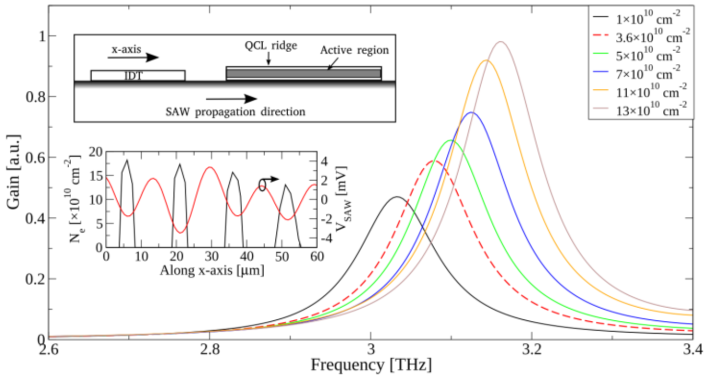

Fig. 1: Variation in gain spectra for different carrier concentrations that occur along the length of the active region from the induced SAW potential with unperturbed carrier concentration shown by the dashed line. The top inset shows a schematic diagram of the SAW–QCL device. The bottom inset shows the variation in the carrier concentration with the potential induced by the SAW.

[1] M. Krisinand and S. Luryi, "Piezoacoustic modulation of gain and distributed feedback in quantum cascade lasers with widely tunable emission wavelength", Appl. Phys. Lett. 82, 847 (2003)

[2] H. Luo, S.R. Laframboise, Z.R. Wasilewski, G.C. Acers, H.C. Liu and J.C. Cao, "Terahertz quantum-cascade lasers based in a three-well active module", Appl. Phys. Lett. 90, 04112 (2007)