Thermal modelling of THz quantum cascade lasers

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Abstract— **We present a fully three-dimensional thermal model of quantum cascade lasers (QCLs) structures based on the solution of the heat conduction equation using a finite-difference successive-over-relaxation technique. The results have been compared with experimental data collected by means of a micro-probe photoluminescence technique, in order to extract the longitudinal and transverse device temperature distributions.**

Understanding and engineering the thermal properties of quantum cascade lasers (QCLs), particularly terahertz emitters, has become a central issue as we strive for higher temperature operation. One important limit for the thermal performance of THz QCLs is the rather high value of the thermal resistance (15-25 K/W) that is determined by the large number of interfaces (1500-2000), the large active region thickness (> 12 μm), the low thermal conductivity of the $Al_{0.15}Ga_{0.85}As$ alloys and the thermal coupling between the active region and the heat sink which is determined by the specific waveguide and mounting configuration[1].

We will present a theoretical investigation of the thermal performance of THz QCLs under both continuous-wave and pulsed operation. Surface-emitting[2] and edge-emitting[3] THz devices will be studied with the aim of calculating the device temperature distributions along both the growth axis and the length of the laser ridge. In order to study the surface-emitting device, we have developed a fully three-dimensional thermal model of the QCL structure based up on the solution of the heat conduction equation using a finite-difference successive-over-relaxation (SOR) technique. The model takes into account the anisotropic QCL active region thermal conductivity caused by its superlattice-like nature[4] and includes a temperature dependent thermal conductivity. The 3D model allows us to calculate the longitudinal temperature distribution in device and the influence of the metallic grating on top of the laser ridge upon the temperature distribution.

Finally, a one-dimensional finite-difference time-domain (FDTD) thermal model based on a previous work[7] will also be presented. The model is based on the hyperbolic heat conduction equation, which as opposed to the parabolic heat equation, accounts for the finite velocity of the heat wave in the device structure. The model includes the anisotropic active region thermal conductivity and temperature dependent material properties (thermal conductivity, specific heat capacity and density) and allows us to simulate the thermal dynamics of the device under a range of pulsed operating conditions. From the simulation results, we are able to extract the device thermal time constants to evaluate the heat dissipation rate from the active region and through the substrate.

In order to validate the developed thermal models, the results have been compared with some experimental data which has been collected with a state-of-the-art micro-probe PL technique and allows investigation of the temperature profile of the laser surface down to a spatial resolution of ~ 1 μm[6, 7].

REFERENCES

[1] M. S. Vitiello, G. Scamarcio, V. Spagnolo, J. Alton, S. Barbieri, C. Worral, H. E. Beere, D. A. Ritchie, and C. Sirtori Appl. Phys. Lett. **89**, 021111 (2006).

[2] S. Kumar, B.S. Williams, Q. Qin, A. W. M. Lee, Q. Hu and J.L. Reno, Optics Express **113**, 15 (2007).

[3] M. S. Vitiello, G. Scamarcio, V. Spagnolo, S. Dhillon and C. Sirtori, submitted (2007).

[4] G. Chen, Phys. Rev. B **57**, 14958 (1998).

[5] C.A. Evans, V.D. Jovanovic, D. Indjin, Z. Ikonic, and P. Harrison, IEEE J. Quantum Electron **9**, 859 (2006).

[6] V. Spagnolo, G. Scamarcio, D. Marano, M. Troccoli, F. Capasso, C. Gmachl, A. M. Sergent, A. L. Hutchinson, D. L. Sivco, A. Y. Cho, H. Page, C. Becker and C. Sirtori, IEEE Proc. Optoelectronics **150**, 298 (2003).

[7] M. S. Vitiello, G. Scamarcio and V. Spagnolo, Proc. SPIE, **6133**, 61330K (2006).

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