IQCLSW
2014

International Quantum Cascade Lasers School & Workshop

Policoro, Italy, 7-14 September 2014

QCLs: 20 years of discoveries
1994-2014

Room temperature quantum cascade detector

Peter Reininger, Benedikt Schwarz, Andreas Harrer, Tobias Zederbauer, Hermann Detz, Aaron M. Andrews, Roman Gansch, Werner Schrenk, Gottfried Strasser
Institute for Solid State Electronics and Center for Micro- and Nanostructures, Vienna University of Technology, Austria
Author e-mail address: peter.reininger@tuwien.ac.at

1. Introduction

An upcoming class of mid-infrared intersubband photodetectors is the quantum cascade detector (QCD) [1]. We demonstrate a QCD operating at 7.7µm up to room-temperature under Globar illumination. To further enhance the photodetectors performance, we fabricated a QCD as photonic crystal slab (PCS) [2]. The PCS is built as purely dielectric structure that utilizes an artificially induced periodic variation of the refractive index. By employing this specifically designed resonant cavity, the QCD is improved in three distinct ways. The PCS makes the device sensitive to surface normal incident light, the photon lifetime at the designed resonance frequencies is increased significantly and with typical hole radii, the device resistance is increased by 50% to 100% [3].

2. Diagonal transition quantum cascade detector

The optical transition of a standard QCD is based on an intersubband transition between a lower energy level and two strongly coupled upper energy levels [4]. High performance operation can only be achieved for devices for which the upper levels are in perfect alignment. The diagonal transition QCD exhibits a transition between two localized states in different wells (figure 1). This highly diagonal transition offers a large dipole matrix element and is robust in terms of growth variation. The first measured sample already reached room-temperature operation with a FTIR in continuous-scan operation under only Globar illumination.

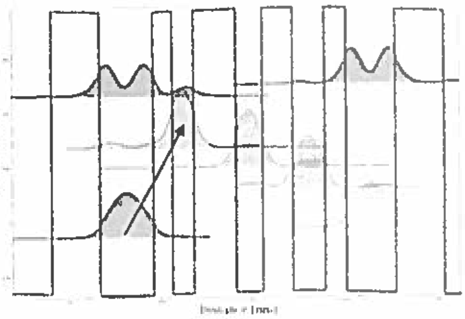

Fig. 1. The optical transition in this particular design occurs between the two energy levels indicated by the black arrow. The transition is highly diagonal, resulting in a large dipole matrix element, while keeping the overlap, and thus the LO-phonon backscattering low. The transition into the second energy level in the broad well has a smaller dipole matrix element and much lower extraction efficiency than the active transition.

3. Photonic crystal QCD

The spectral response of a QCD typically exhibits one strong absorption peak at the designed intersubband transition energy. Photons with higher or lower frequency do not contribute to the photocurrent. The PCS is designed such that the chosen mode coincides with the absorption spectrum of the QCD. Figure 2(a) shows the photonic bandstructure of the fabricated PCS versus the spectral response of the PCS-QCD. The large open circle indicates the single PCS-resonance that is visible in the measured photocurrent spectrum. Figure 2(b) shows the photocurrent response of a standard QCD and three PCS-QCDs devices at liquid nitrogen temperature. All devices show the broad absorption peak of the QCD at 143 meV. The PCS devices exhibit another peak at 160 meV, that shifts to higher energies for larger hole radii. In accordance with the results from the revised plane wave expansion method simulations, that peak could be identified at PCS resonances. At the PC resonance frequency, the photocurrent is enhanced by a factor of four.

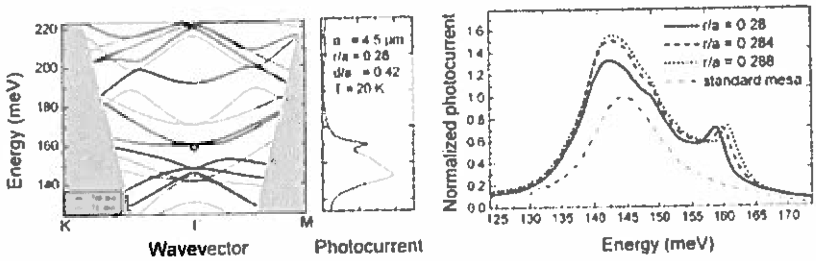

Fig. 2. (a) The photonic bandstructure of the fabricated PCS versus the spectral response of the PCSQCD. The large open circle indicates the PCS-resonance that is visible in the measured photocurrent spectrum. (b) The photocurrent spectrum of a standard QCD and three PCS-QCDs devices, measured at liquid nitrogen temperature. At the PCS resonance frequency, the photocurrent of the PCS devices is 4 times larger than standard mesa devices.

4. Conclusion

In conclusion, we presented a new quantum cascade detector concept that is based on a diagonal transition in the active well. The new design shows room-temperature operation under Globar illumination. To further improve the device performance, we fabricated a QCD as photonic crystal slab. A significant improvement of the device performance, exhibiting a photocurrent enhancement of up to a factor of 4, has been achieved. We demonstrated that the PCS resonances are only visible within the responsivity spectrum of the QCD. Thus, such devices are perfectly suited for applications that require sensing of distinct spectral lines, while suppressing detection of side-band radiation.

The authors acknowledge the support by the PLATON project 35N within the Austrian NANO initiative, the FP7 EU-project ICARUS and the Austrian SFB (FWF F4909-N23) NextLite.

5. References

[1] D. Hofstetter, M. Beck, and J. Faist, "Quantum-cascade-laser structures as photodetectors," Appl. Phys. Lett. 81, 2683 (2002).

[2] P. Reininger, B. Schwarz, A. Harrer, T. Zederbauer, H. Detz, A. M. Andrews, R. Gansch, W. Schrenk, and G Strasser, "Photonic crystal slab quantum cascade detector," Appl. Phys. Lett. 103, 241103 (2013)

[3] S. Kalchmair, H. Detz, G. Cole, A. M. Andrews, P. Klang, M. Nobile, R. Gansch, C. Ostermaier, W. Schrenk, and G. Strasser,"Photonic crystal slab quantum well infrared photodetector," Appl. Phys. Lett. 98, 011105 (2011).

[4] F. R. Giorgetta, E. Baumann, M. Graf, Q. Yang, C. Manz, K. Köhler, H. E. Beere, D. Ritchie, E. Linfield, A. G. Davies, Y. Fedoryshyn, H Jäckel, M. Fischer, J. Faist, and D. Hofstetter, "Quantum cascade detectors," IEEE J. Quantum Electron. 45, 1039 (2009).