Quantum Cascade photonic crystal surface emitting injection laser

R. Colombelli[1], K. Srinivasan[3], M. Troccoli[2], O. Painter[3], C. Gmachl[1], F. Capasso[2], D. M. Tennant[1,4], A. M. Sergent[1], D. L. Sivco[1], and A. Y. Cho[1]

1: Bell Laboratories, Lucent Technologies, Murray Hill, NJ 07974, USA
2: Division of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA
3: Department of Applied Physics, California Institute of Technology, Pasadena, CA 91125, USA
4: New Jersey Nanotechnology Consortium, Murray Hill, NJ 07974, USA

Abstract: A surface emitting Quantum Cascade injection laser is presented. Direct surface emission is obtained by using a 2D photonic-band-gap structure that simultaneously acts as a microcavity. The approach may allow miniaturization and on-chip-integration of the devices.

OCIS codes: (000.0000) General

Since their invention in 1994 [1] Quantum Cascade (QC) lasers have rapidly established themselves as tunable coherent sources in the mid-infrared range of the electromagnetic spectrum. Due to the transverse magnetic (TM) polarization of intersubband transitions, QC lasers cannot be designed as conventional surface-emitting lasers. However this would be a desirable feature for several applications. Previous attempts to develop vertically emitting QC lasers used second-order gratings superimposed on standard edge-emitters, but the resulting devices were not suitable for miniaturization. We here demonstrate the first QC photonic crystal injection laser.

We incorporate a photonic crystal (PC) lattice within a QC heterostructure to create a laser emitting on a band-edge mode (Fig. 1a, mode "A"), which employs a 2-dimensional distributed feedback effect. The 2D photonic bandstructure (Fig. 1a) for TM-polarized modes in a hexagonal lattice of air holes shows a number of band-edges states from which laser action can occur. The normalized frequency values in this bandstructure are used to determine the hole radius and lattice spacing used in device fabrication.

Fig. 2b shows a top view of the fabricated device: a deep waveguide etch is used to minimize substrate losses without increasing the size of the PC lattice[2]. As a result, the is wavelength-scale, and we therefore call it a "microcavity band-edge laser."

The semiconductor material is a QC laser that emits at $\lambda \approx 7.8$ μm and uses a thin surface-plasmon waveguide to reduce the required etch depth. The PC pattern was defined using electron-beam lithography, dielectric mask transfer, and inductively-coupled plasma reactive ion etch. The top electrical contact is deposited and insulated from the substrate using a Si_xN_y pattern which defines the region of current flow.
Low temperature electro-luminescence (EL) measurements (Fig. 1c) reveal three major resonances ('A', 'B', and 'C'. Further increase in the applied current causes the highest wavenumber peak within the 'A' band of resonances to reach laser threshold (Fig 1d).

In Fig. 1c finite-difference time-domain (FDTD) simulations of the spectrum for our device and the tuning of the three major resonances (inset) are shown superimposed upon measured data. The lasing line is determined to come from the high wavenumber side of band-edge 'A'. Far-field measurements of the laser intensity indicate a distinct symmetry of the lasing mode. Comparison with simulations provides a unique identification of the lasing mode.

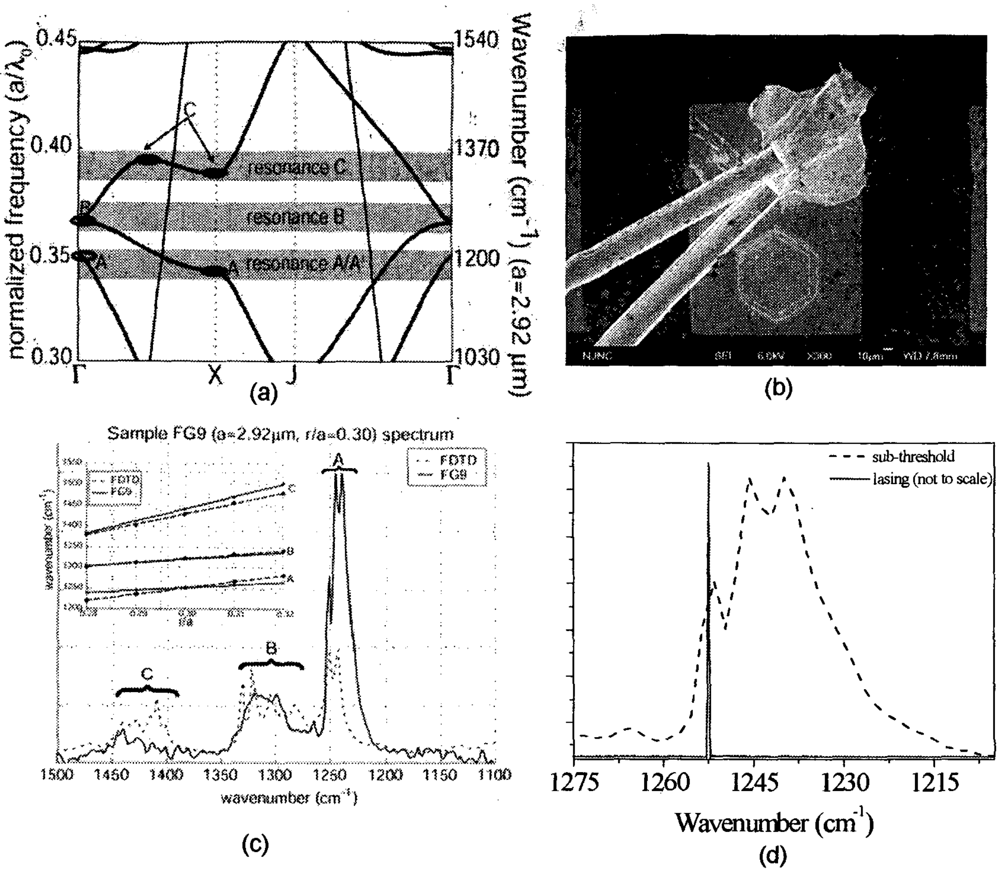

Fig. 1. (a) Hexagonal lattice TM bandstructure using an effective index to approximate the vertical waveguide (r/a=0.30, n_{eff}=3.345). (b) SEM of fabricated device. (c) Sub-threshold EL (solid curve) and FDTD spectrum (dashed curve)for a typical device. Tuning data *vs* r/a of 'A', 'B', and 'C' peaks in inset. (d) EL (dotted line) and lasing (solid line) for the same device.

References

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