6.772/SMA5111 - Compound Semiconductors

Lecture 22 - Laser Diodes - 3; Detectors -1 - Outline

- **Modulating laser diodes** (Last topics from Lecture 21)
  - Small signal modulatioin
  - Step change response
- **Converting optical signals to electrical signals** (Detectors)
  - General issues
    - performance goals and metrics
  - Approaches to light detection
    - photoconductors vs. photodiodes
    - detectors with and without gain
    - integrating and staring detectors; photocapacitors
- **Photoconductors**
  - bulk photoconductors
    - gain mechanism
    - gain-speed trade-offs
  - QWIPs and QDIPs
    - structure, concept, design optimization
    - implementation for enhanced sensitivity
    - multi-color designs

Laser diodes: Active layer variations

Quantum cascade lasers:

An example of a novel materials combination and 10 μm lasing.

(Images deleted)

See K. Ohtani and H. Ohno, "InAs/AlSb quantum cascade lasers operating at 10 um," Appl. Phys. Lett. 82 (2003) 1003-5.

Laser diodes: Active layer design, cont.

Shaping the beam vertically:

The slab-coupled optical waveguide laser, SCOWL. An example of a vertical design intended to increase the guide thickness vertically and obtain a more symmetrical beam profile.

(Images deleted)

See J.N. Walpole et al, "Slab-Coupled 1.3 um Semiconductor Laser with Single-Spatial Large-Diameter Mode," IEEE Photonics Tech. Lett. 14 (2002) 756-8.

Laser diodes: Active layer design, cont.

Shaping the beam vertically:

The antiresonant reflecting optical waveguide, ARROW. An example of a popular vertical design used to increase the guide thickness vertically and obtain a more symmetrical beam profile. Higher order modes are suppressed, and an active (gain) layer can be incorporated into one of the low index layers.

(Image deleted)

See Fig. 7.22 in Coldren, L. A., and S. W. Corzine. *Diode Lasers and Photonic Integrated Circuits.* New York: Wiley Interscience, 1995.

Waveguiding operation

(Image deleted)

See A. Bhattacharya et al, "High power narrow beam singlemode ARROW-type InGaAs/InGaAsP/InGaP diode lasers," Elect. Lett. 31 (1995) 1837-1838.

Example structure

<u>Laser diodes</u>: Active layer design, cont.

Shaping the beam vertically:

Additional ARROW laser results showing the actual layer profile used and beam profiles illustrating the enhanced beam profile.

Layer structure

(Images deleted)

See A. Bhattacharya et al, "High power narrow beam singlemode ARROW-type InGaAs/InGaAsP/InGaP diode lasers," Elect. Lett. 31 (1995) 1837-1838.

Far-field patterns at several pumping levels

Laser diodes: horizontal design, cont.

Distributed Feedback, cont.:

Data taken on Pb-salt lasers comparing temperature tuning characteristics of Fabry-Perot and DFB laser diodes

Variation of emission spectra with temperature.

Device structure

(Image removed)

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Ref: Liquid-phase epitaxy grown PbSnTe distributed feedback lasers with broad continuous single-mode tuning range," IEEE J. Quant. Elect. QE-16 (1980) 1039-43.

Laser diodes: surface emitting lasers

Grating-coupled surface emitting laser, GCSEL:

Figures from an paper doing an analysis of the GCSEL. In this device the second order grating provides feedback to form the laser cavity, and provides output coupling normal to the surface

(Image removed)

Device structure

Device cross-section

(Image removed)

Ref: S.Bonnefont, et al, "Analysis of the sensitivity of grating-coupled surface-emitting lasers to geometrical parameter variations," IEEE J. Quant. Elect. 32 (1996) 1469-1477.

Laser diodes: surface emitting lasers, cont.

GCSELs, cont:

An example of using a second order grating output element in combination with a first-order grating DBR cavity to obtain emission from the top surface of the device. Note that the second order is detuned slightly so the emission is not vertical, but rather at a slight angle.

(Image removed)

Output grating operation

Device structure

(Image removed)

Ref: N. Eriksson, et al, "Highly directional grating outcouplers with tailorable radiation characteritics," IEEE J. Quant. Elect. 32 (1996) 1038-47.

Laser diodes: surface emitting lasers, cont.

GCSELs, cont:

An example of using a holographic grating output element in combination with a first-order grating DBR cavity to obtain focused emission from the top surface of the device. In this illustration the output beam is focused to a single spot, but more complicated beam patterns are possible (see following slide).

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Device structure

(Image removed)

Focusing optics of holographic grating.

Ref: N. Eriksson, et al, "Surface-emitting unstable-resonator lasers with integrated diffractive beam-forming elements," IEEE Phot. Tech. Lett. 9 (1997) 1570-2.

Laser diodes: surface emitting lasers, cont.

GCSELs, cont:

Two examples of focused outputs from a holographic grating output element used in combination with a first-order grating DBR cavity to obtain focused emission from a laser.

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Far field image of output of structue focusing beam to a single point.

Far field image of output of structue focusing beam to an array of spots.

Ref: N. Eriksson, et al, "Surface-emitting unstable-resonator lasers with integrated diffractive beam-forming elements," IEEE Phot. Tech. Lett. 9 (1997) 1570-2.

<u>Laser diodes</u>: VCSELs, cont.

VCSEL Structure:

An example of a long-wavelength (1.55 *μ*m) VCSEL fabricated with a deposited dielectric stack for the upper mirror, and bonded to a GaAs/AlGaAs DBR lower mirror.

(Image removed)

Ref: Y. Ohiso, et al, "Single Transverse mode operation of 1.55 μm buried heterostructure vertical-cavity surface-emitting lasers," IEEE Phot. Tech. Lett. <u>14</u> (2002) 738-40.

<u>Laser diodes</u>: VCSELs, cont.

VCSEL Structure:

An example of aVCSEL with a deposited dielectric stack upper mirror, and an undoped GaAs/AlGaAs lower DBR. Note that both contacts are made very near the active layer and no current flows through either mirror stack.

(Image removed)

(Image removed)

Photomicrograph of device

Ref: L. M. F. Chirovsky, et al, "Impant-apertured and index-guided vertical-cavity surface-emitting lasers," IEEE Phot. Tech. Lett. <u>11</u> (1999) 500-2;

Device structure

Laser diodes: frequency response

Small signal sinusoidal modulation

Second-order system behavior stemming from coupled nature of the system

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CW light output verses current

Small signal modulation characteristics at various bias levels (indicated on curve on left).

Ref: Yariv, Optical Electronics, Figs. 15-19 a and b

Laser diodes: frequency response

Large signal (step) response

The large signal step response shows to primary characteristics: a turn-on delay, and ringing

See Figs. 5.12 and 5.13: Coldren, L.A and Corzine, S. W., Diode Lasers and Photonic Integrated Circuits
New York: Wiley Interscience, 1995

(Image removed)

(Image removed)

Current, carrier, and photon population transients for step inputs simulated for conditions corresponding to an in-plane laser (on left) and a VCSEL (on right).

Ref: Coldren and Corzine, Figs. 5.12 (left) and 5.13 (right)_

- Comparison of the absorption edge of several direct- and indirect-gap semi-conductors

Notice the abruptness of the absorption edge, and the difference in the strength of the absorption just above the band-edge.

xx[3]

Singh Fig. 10.4

Photoconductors - quantum well infrared photodetectors QWIPs

EBandBV, Fig. 11.18

Above: Schematic illustration of QWIP structure and function.

Right: Energy separation between n = 1 and 2 levels in quantum wells with indicated aluminum fractions and well widths.

EBandBV, Fig. 11.17

Photodiodes - Near IR heterostructure p-i-n detectors

Left: Mesa-etched, front-illuminated InGaAs P-i-n with InAlAs window
Right: Mesa-etched, back-illuminated AlGaAs/GaAs P-i-N

Singh Figs. 10.13 (left) and 10.1.4 (right)

Photodiodes - GaN-based solar blind p-i-n detectors

Left: Layer structure used in solar-blind p-i-n photo-diode

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Fig. 1

(Image removed)

Right: Spectral response of GaN-based solar blind p-i-n photodiode structure pictured above

Fig. 5

Ting Li, et al, "Low-Noise Back-Illuminated AlxGa1-xN-Based p-i-n Solar-Blind Ultraviolet Photodetectors," IEEE J. WQuant. Electron. 37 (2001) 538.

Photodiodes - avalanche photodiodes (APDs)

Left: Planar structure ion implanted guard ring; top-side input

Singh Fig. 10.4

Right: Back illuminated mesa-geometry. The sloped mesa side-walls eliminate edge break-down

Singh Fig. 10.4