

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

- **Modulating laser diodes** (Last topics from Lecture 21)
 - Small signal modulation □
 - 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 μm ," 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 incor- □
porated 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

Laser diodes: Active layer design, cont. □

Shaping the beam vertically: □

Additional ARROW □
laser results showing □
the actual layer pro- □
file 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

Temperature tuning curves

(Image deleted)

See J.N. Walpole et al, "CW Operation of Distributed Feedback PbSnTe lasers," Appl. Phys. Lett. 30 (1977) 524-6.

(Image deleted)

See J.N. Walpole et al, "Distributed feedback PbSnTe double-hetero-structure lasers," Appl. Phys. Lett. 29 (1976) 397-9.

Device structure

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

(Images deleted)

See "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

Device cross-section

Device structure

(Images deleted)

See 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.

Device structure

Output grating operation

(Images deleted)

See N. Eriksson et al, "Highly directional grating outcouplers with tailorable radiation characteristics," 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). □

(Images deleted)

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

Device structure

Focusing optics of □
holographic grating. □

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.

(Images deleted)

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

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

**Far field image of □
output of structure □
focusing beam to an □
array of spots. □**

Laser diodes: VCSELs, cont. □

VCSEL Structure: □

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

(Images deleted)

See Y. Ohiso et al, "Single Transverse Mode Operation of 1.55 μm Buried Heterostructure Vertical-Cavity Surface-Emitting Lasers," IEEE Phot. Tech. Lett. 14 (2002) 738-40.

Laser diodes: VCSELs, cont. □

VCSEL Structure: □

**An example of a VCSEL 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. □**

(Images deleted)

See L.M.F. Chirovsky et al, "Impant-apertured and index-guided vertical-cavity surface-emitting lasers," IEEE Phot. Tech. Lett. 11 (1999) 500-2.

Device structure

Photomicrograph of device

Laser diodes: frequency response □

Small signal sinusoidal modulation □

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

(Images deleted)

See Figures 15-19(a) and (b) in Yariv, *Optical Electronics*.

CW light output verses current

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

Laser diodes: frequency response □

Large signal (step) response □

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

(Images deleted)

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

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). □

Semiconductors Photodetectors - bulk band-to-band absorption □

- □ 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. □

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

(Image deleted)

See Fig. 1 in Ting Li et al, "Low-Noise Back-Illuminated Al_xGa_{1-x}N-Based p-i-n Solar-Blind Ultraviolet Photodetectors," IEEE J. WQuant. Electron. 37 (2001) 538.

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

(Image deleted)

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

See Fig. 5 in Ting Li et al, "Low-Noise Back-Illuminated Al_xGa_{1-x}N-Based p-i-n Solar-Blind Ultraviolet Photodetectors," IEEE J. WQuant. Electron. 37 (2001) 538.