Lecture 23 - Detectors -2 - Outline

- **Photodiodes**
  - **p-n photodiodes: review of physics; photovoltaic mode; TIA's**
  - **p-i-n photodiodes: design concepts; vertical and lateral designs**
  - **Schottky barrier photodiodes**
  - **m-s-m photodiodes**
  - **avalanche photodiodes: comparison with p-i-n/TIA combination**
  - **phototransistors**
- **Photoconductors**
  - **bulk photoconductors**
    - **gain mechanism**
    - **gain-speed trade-offs**
  - **QWIPs and QDIPs**
    - **structure, concept, design optimization**
    - **implementation for enhanced sensitivity**
    - **mult-color designs**

Laser diodes: surface emitting lasers

In-plane, surface emitting lasers (IPSELs): two examples using external deflectors

(Image deleted)

See J.P. Donnelly et al, APL 61 (1992) 1487-9.

(Image deleted)

See J-H. Kim et al, APL 58 (1991) 7-9.

In these structures dry etching is used to create the vertical end-facets and to create a deflector to redirect the light (and, on the right, to focus it also).

Laser diodes: surface emitting lasers

IPSELs: two examples using total internal reflection from 45° facets and interface reflection

In these structures a 45° dry-etched facet is used to redirect the light, while the cavity is formed by a horizontal air-semiconductor interface.

(Image deleted)

See C-P. Chao et al, APL 59 (1991) 1532-4.

(Image deleted)

See S.S. Ou et al, APL 58 (1991) 16-18.

Laser diodes: frequency response

Large signal (step) response

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

(Images deleted)

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.

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).

Laser diodes: high speed response

VCSEL analysis

Figures from a modeling and analysis of the small and large signal response of single-mode VCSELs (see below)

(Images deleted)

See J.S. Gustavsson et al, JQE 38 (2002) 203-212.

Small signal response at bias currents of 0.4, 0.55, 0.8, 1.25, 2.5, 3.6, and 5 mA.

Transient response to 1-Gbit/s NRZ bit sequence with "off" and "on" currents 0.5 and 8.5 mA.

Laser diodes: materials summary

Wavelengths covered by laser diodes, and the materials used to achieve them: then and now

1. **Short λ visible:** GaInAlN on GaN, Sapphire, SiC - big push now
   II-VI's (ZnSeTe) - first blue and blue-green LDs
2. **Long λ visible:** AlGaInP/AlInP on GaAs - commercial
3. **0.8 to 1.0 μm:** AlGaAs/InGaAs(QW) on GaAs - commercial
4. **1.3, 1.55 μm:** InGaAsN on GaAs - currently hot
   InGaAsP on InP; InGaAlAs on InP - commercial
5. **2-5 μm:** quantum cascade - hot now
   AlGaAsSb on GaSb - current standard
   IV-VIs (e.g. PbSSe) - big in 70s, 80s
6. **10-30+ μm:** quantum cascade - hot now
   IV-VIs (e.g. PbSnTe) - big in 70s, 80s

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 AlxGa1-xN-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 photo-diode

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

(Image deleted)

See Fig. 5 in 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)

(Images deleted)

See P. Yuan et al, "Avalanche Photodiodes with an Impact-Ionization-Engineered Multiplication Region," IEEE Phot. Tech. Lett. 12 (2000) 1370-2.

Above: Cross-section and concept

Right: Performance compared to other devices: *top* - photo response, and - *bottom* - excess noise factors

Photodiodes - avalanche photodiodes (APDs)

(Images deleted)

See K.A. McIntosh et al, "GaAsP/InP Avalance Photodiodes for Photon Counting at 1.06 um," APL 81 (2002) 2505-2507.

Cross-section

Single device

4-by-4 array

Photoconductors - single-color QWIP imaging array

(Images deleted)

See Chapter 5 in J. Trezza et al, Heterogeneous Optoectonics Integration, E. Towe, ed.
SPIE Press, Bellingham, WA, 2000.

Photoconductors - two-color QWIP imaging array

(Images deleted)

See Chapter 5 in J. Trezza et al, Heterogeneous Optoectonics Integration, E. Towe, ed.
SPIE Press, Bellingham, WA, 2000.