Electroabsorption Modulators

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EE 698

Optical Modulation

- Direct modulation
  - **Output frequency shifts with drive signal**
    - Carrier induced (chirp)
    - Temperature variation due to carrier modulation
  - **Limited extinction ratio**
- Indirect or External modulation
  - **Electro-optic modulation**
    - Change optical path length with applied electric field
  - **Electroabsorption modulation**
    - Change amount of light absorbed with applied electric field
  - **Finite insertion loss (6-7 dB)**

Advantages of EA modulator

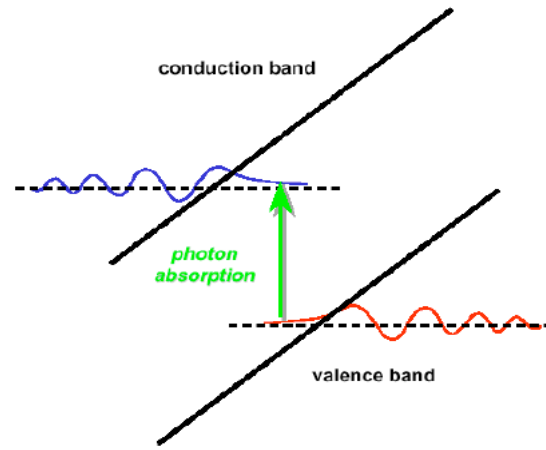
- Zero biasing voltage
- Low driving voltage
- Low/negative chirp
- High speed
- Lesser polarization dependence
- Integration with DFB laser
- Allows a single optical power source to be used for large number of information carrying beams

Electroabsorption modulator

- Mechanisms
  - **Franz-Keldysh effect**
    - Observed in conventional bulk semiconductors
  - **Quantum-confined Stark effect (QCSE)**
    - Quantum well structures
- Both of these electroabsorption effects are prominent near the bandgap of semiconductors

Franz-Keldysh effect

Tunneling allows overlap of electron and hole wavefunctions for photon energy less than bandgap

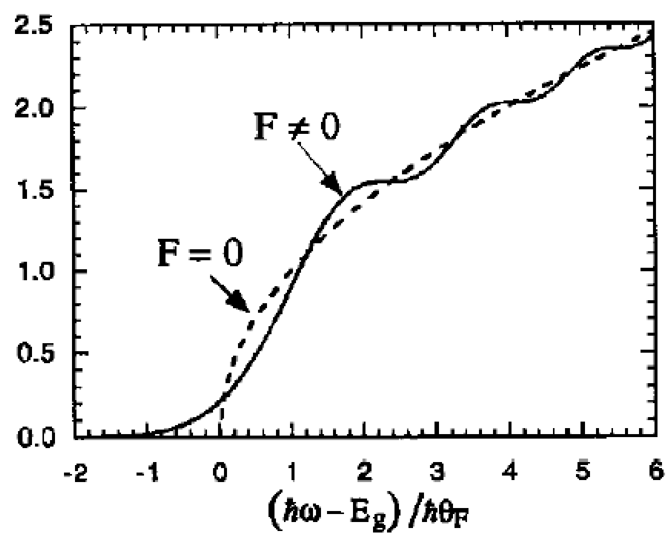


$$\alpha = K(E')^{1/2}(8\beta)^{-1}\exp\left(-\frac{4}{3}\beta^{3/2}\right)$$

where,

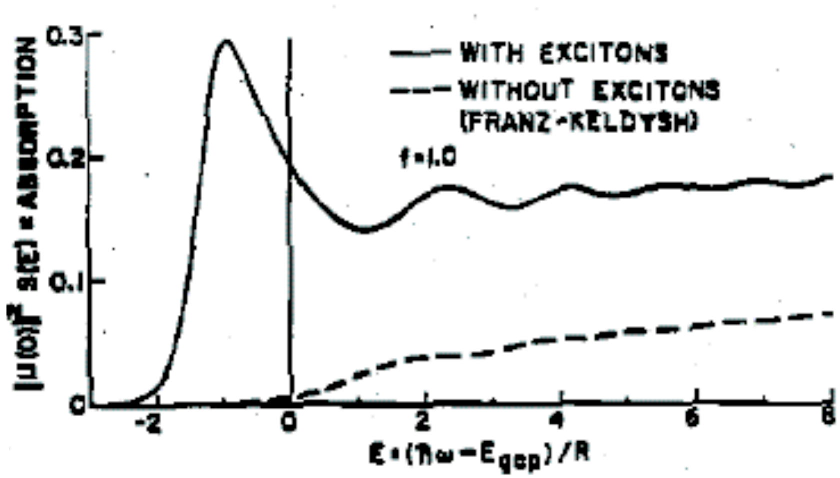
$$E' = \left(\frac{q^2E^2\hbar^2}{2m_r^*}\right)^{1/3}$$

$$\beta = \frac{E_g - \hbar\omega}{E'}$$



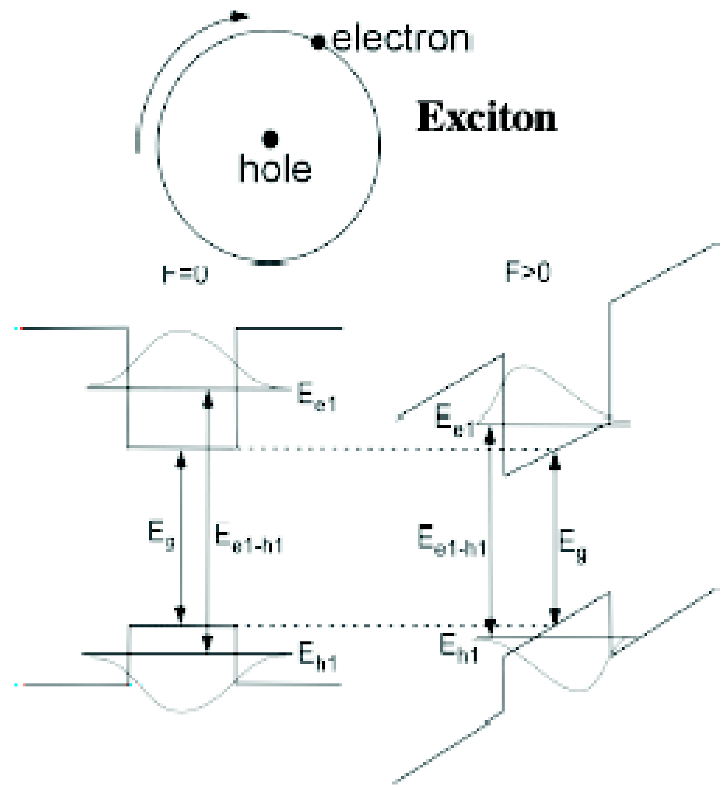
Excitonic electroabsorption (Stark effect)

- Excitonic effects gives rise to a step-like rise in absorption spectra
- Formation of excitons manifests themselves as a series of sharp resonances near the bandgap energy
- Formed in very pure semiconductors at low temperatures
- Excitons can be very easily field ionized



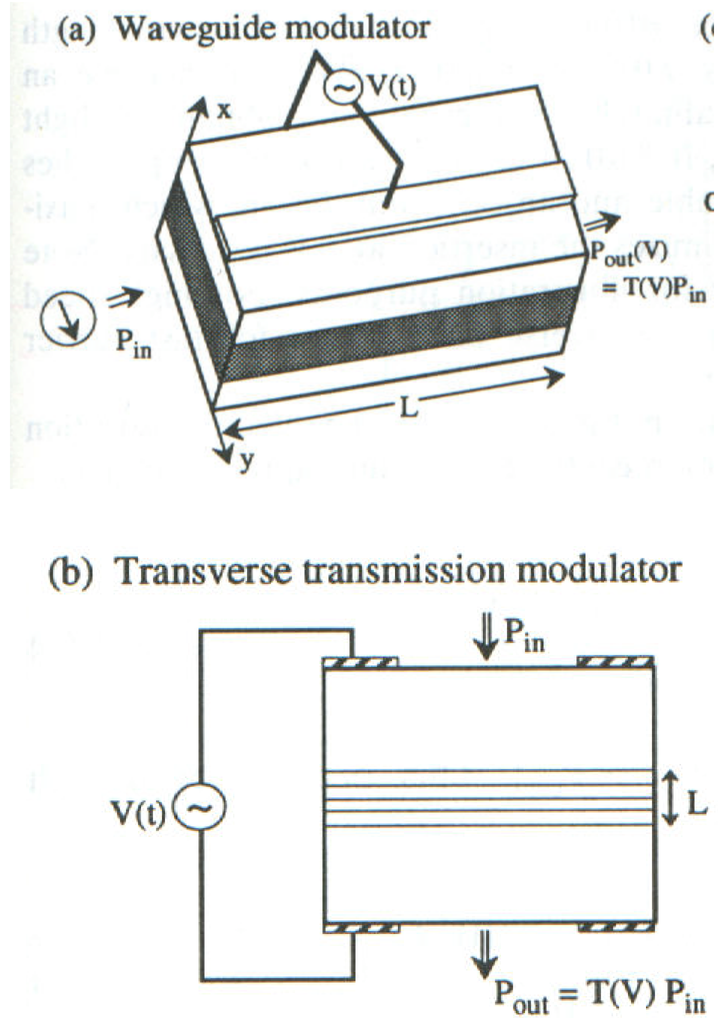
Quantum Confined Stark Effect

- Quantum well increases the overlap of electron and hole wavefunctions
- Electric field reduces overlap and results in a corresponding reduction in absorption and luminescence
- Exciton absorption peak is not greatly broadened because of confinement



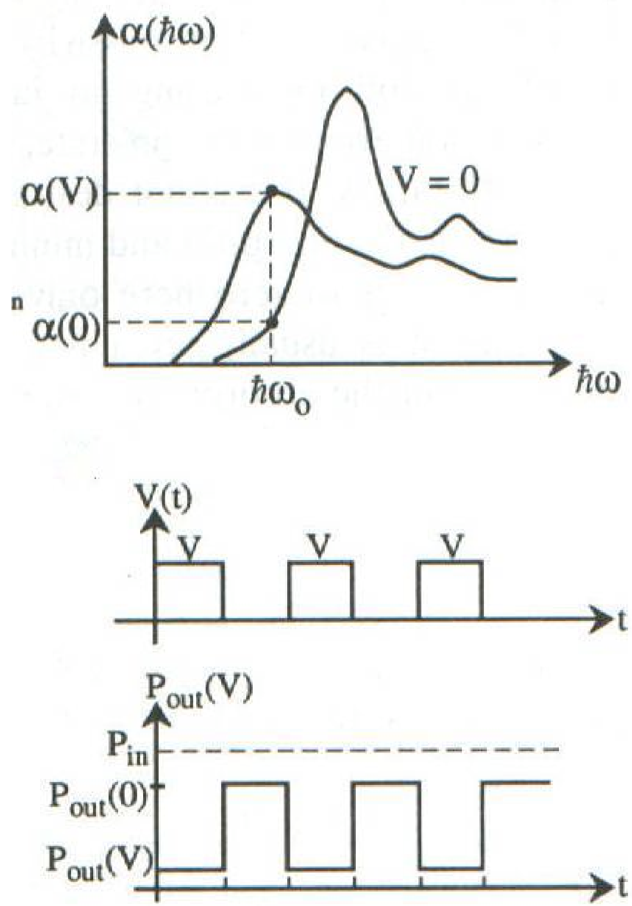
Device structure

- Primary materials for EA modulators are III-V semiconductors
- PIN structure
- Transmission type does not lead to high enough extinction ratio
- Waveguide type more commonly used - has higher optical confinement



Design considerations

- Operation principle
- Contrast ratio
- Insertion loss
- Modulation efficiency
- Chirp considerations and efficiency
- Packaging and integration



Extinction Ratio

$$R_{on/off} = \frac{P_{out}(V_{on} = 0)}{P_{out}(V_{off} = V)} = \frac{e^{-\alpha(0)L}}{e^{-\alpha(V)L}}$$

$$R_{on/off}(dB) = 10\log(R_{on/off}) = 4.343 \cdot \left[\alpha(V) - \alpha(0)\right]L$$

- BER directly effected by extinction ratio
- Contrast ratio can be made as large as possible by increasing the length of the modulator. But propagation loss then becomes an issue.

Insertion loss

- Absorptive loss
  - **Longer the modulator, larger the insertion loss.**
  - **Trade-off with Extinction Ratio**

$$\text{Loss} = \frac{P_{in} - P_{out}(V=0)}{P_{in}} = 1 - e^{-\alpha(0)L}$$

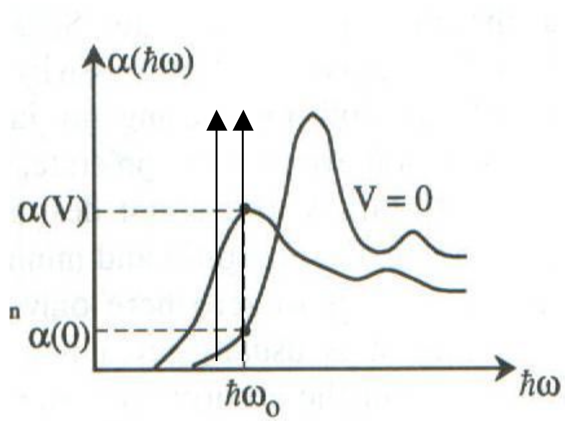
- Single mode fiber coupling loss
  - **Waveguide coupler can be used to reduce coupling loss**
  - **Can be as good as 1 dB**
  - **Typical numbers are 5-6 dB**

Modulation efficiency

- Modulation efficiency quantifies how much voltage do we need to modulate the optical signal.

$$\frac{R_{on/off}}{\Delta V} = 4.343\frac{[\alpha(V)-\alpha(0)]L}{\Delta V} = 4.343\frac{\Delta\alpha}{\Delta F}$$

- Smaller detuning will increase the modulation efficiency. However, it also results in a larger insertion loss.



Chirp

- Frequency sweep imposed as a result of power change

$$\alpha_e \equiv -\frac{2\omega}{c}\frac{\partial n_r}{\partial g} = -\frac{4\pi}{\lambda}\frac{\partial n_r}{\partial g}$$

- Imaginary part of refractive index is related to optical absorption coefficient by,

$$\alpha = \frac{2\omega}{c}k = \frac{4\pi}{\lambda}k$$

- Kramers-Kronig relation

$$\Delta n = \frac{\hbar c}{\pi} P \int_0^{\infty} \frac{\Delta\alpha}{E^2 - (\hbar\omega)^2} dE$$

Chirp Engineering

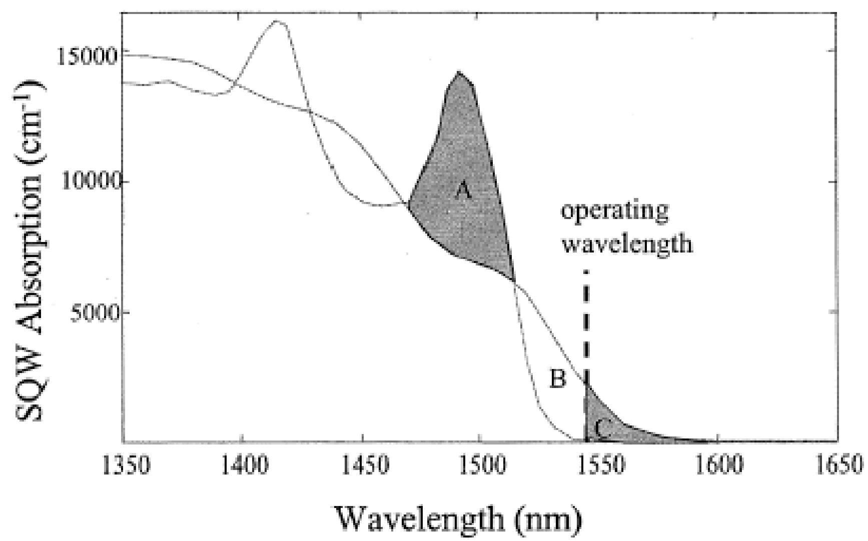
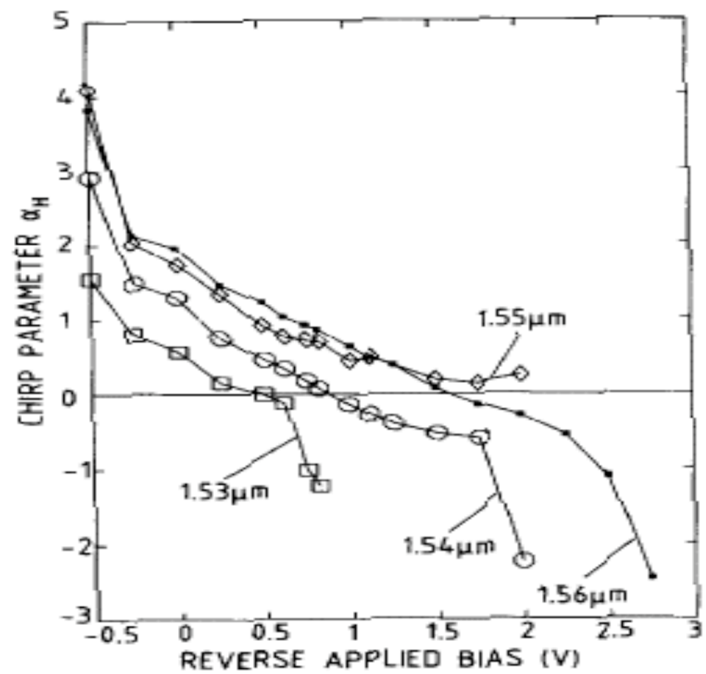
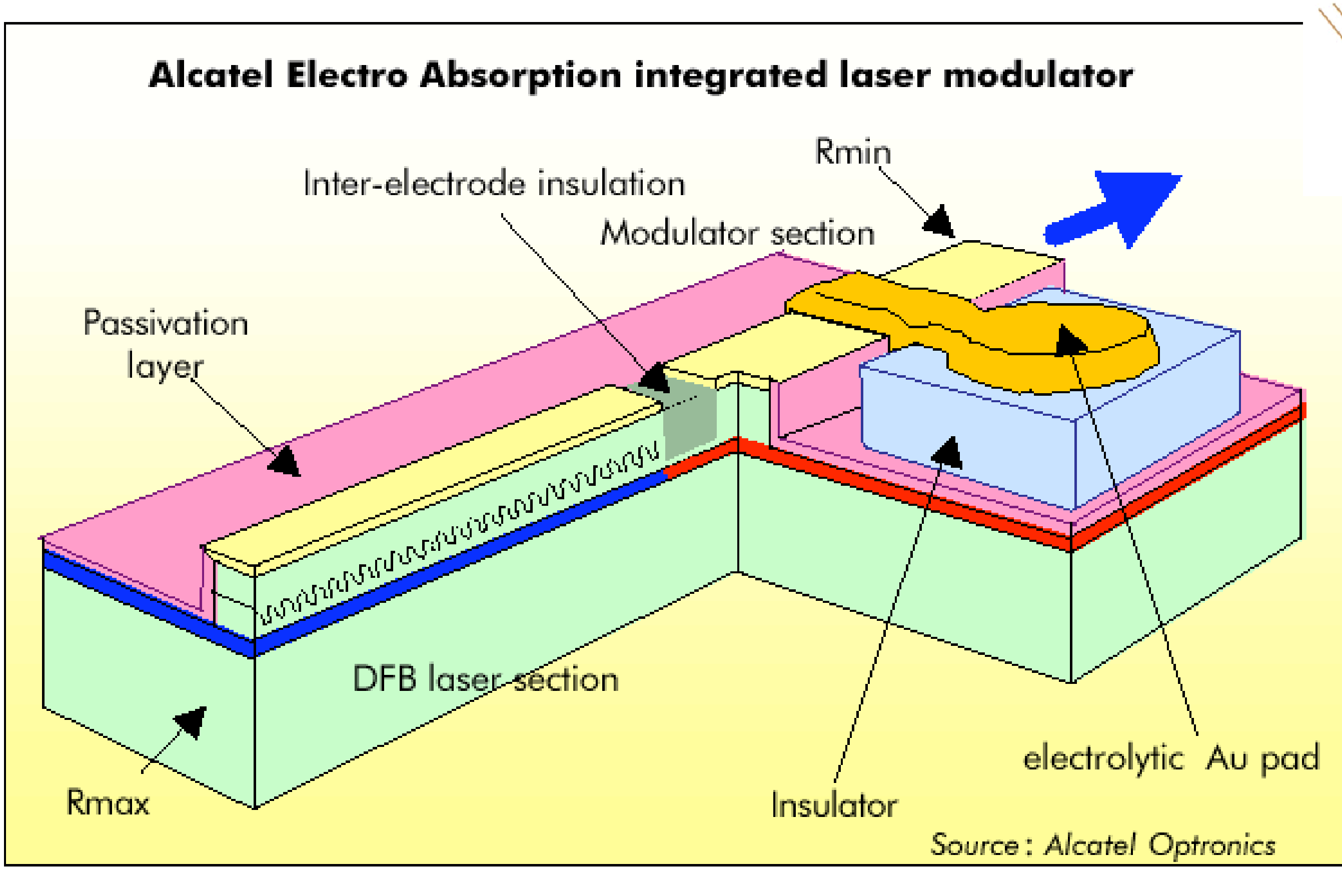


Fig. 15. Illustration of index change due to QCSE. The absorption changes in area B contribute to positive Δ n, while the absorption changes in areas A and C contribute to negative Δn.



$$\Delta n = \frac{\hbar c}{\pi} P \int_0^\infty \frac{\Delta\alpha}{E^2 - (\hbar\omega)^2} dE \qquad \Delta f_{FWHM} = \frac{\alpha_e}{2I}\frac{dI}{dt}$$

Integration



- 10Gb/s module, I_{th} = 20mA, P_{max} = 4mW @80mA , extinction ratio = 15dB for -2.5V

Acknowledgement

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- G. L. Li and P. K. L. Yu, J. Lightwave Tech., Sep 2003