# Fiber Optic Communications
# Lecture 6: Semiconductor Lasers 2

- Quantum Confinement
- Functionality

QUANTUM-WELL LASER

NICK HOLONYAK JR., JOHN BARDEEN'S FIRST GRADUATE STUDENT AT ILLINOIS, INVENTED THE FIRST PRACTICAL LIGHT-EMITTING DIODE (LED) AT GENERAL ELECTRIC BEFORE RETURNING IN 1963 TO ILLINOIS AS A FACULTY MEMBER. IN 1977, HOLONYAK AND HIS STUDENTS DEMONSTRATED THE FIRST QUANTUM-WELL LASER, WHICH ENABLED SUCH ADVANCES AS FIBER OPTIC COMMUNICATIONS, COMPACT DISC PLAYERS, AND NEW TECHNIQUES IN MEDICAL DIAGNOSIS AND SURGERY. HIS AWARDS INCLUDE THE NATIONAL MEDALS OF SCIENCE AND TECHNOLOGY, THE JAPAN PRIZE, THE RUSSIAN GLOBAL ENERGY PRIZE, AND THE LEMELSON-MIT PRIZE.

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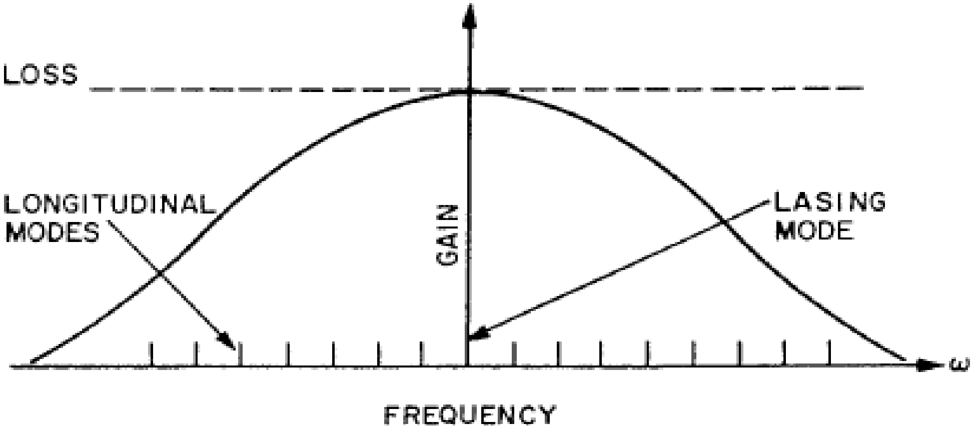
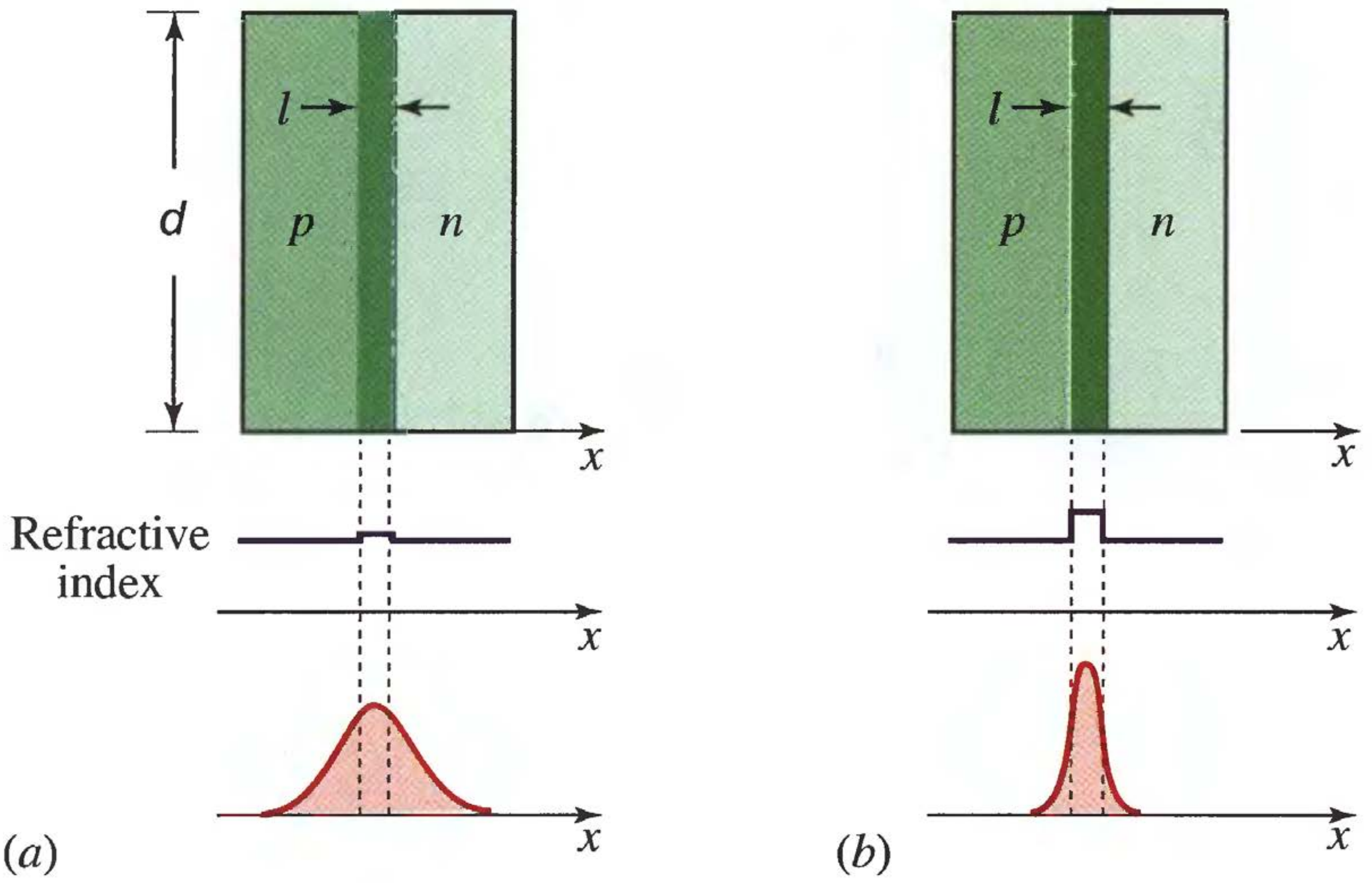
# Conditions for Laser Oscillation

Recall: 2 conditions must be satisfied for lasing:

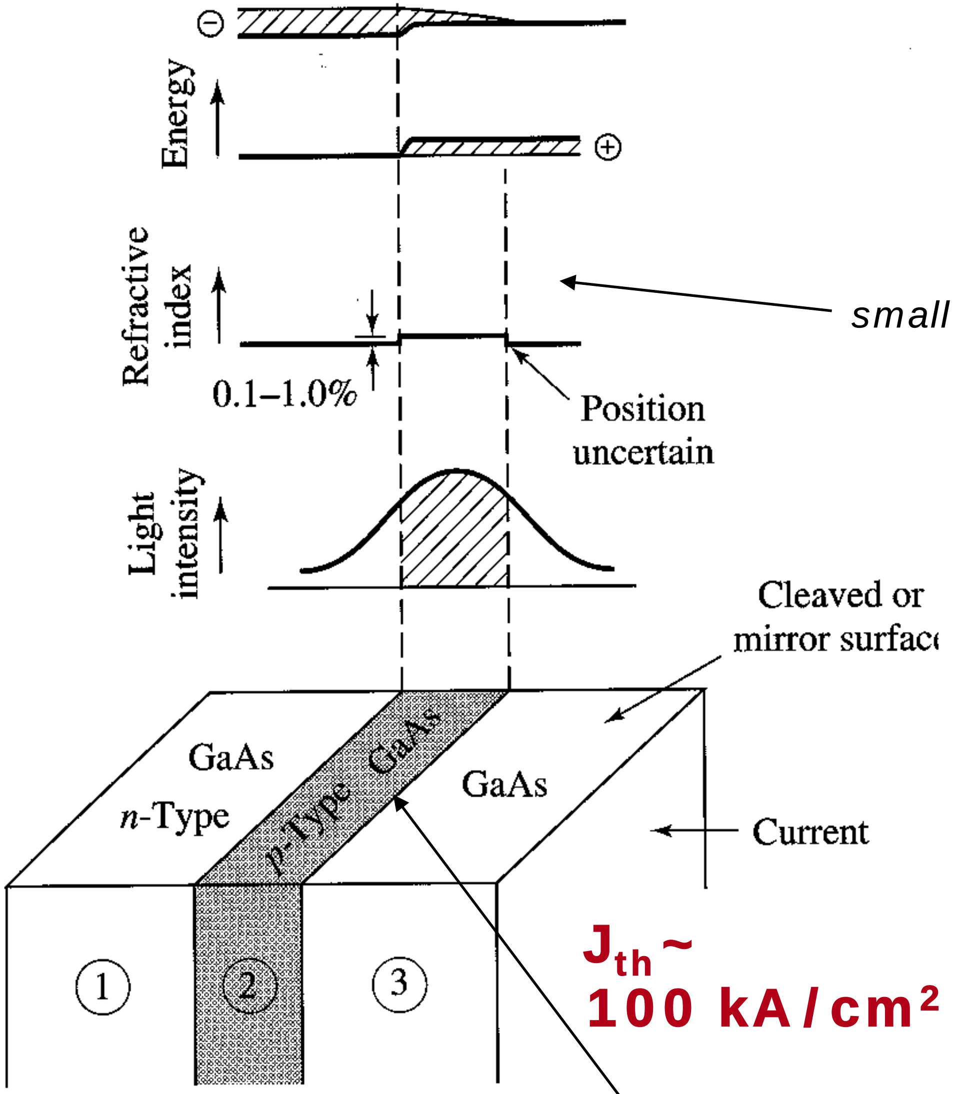
- The <u>gain condition</u> determines the minimum population difference, and the pumping threshold required for lasing
- The <u>phase condition</u> determines the frequencies at which oscillations take place



# Index-guided semiconductor lasers



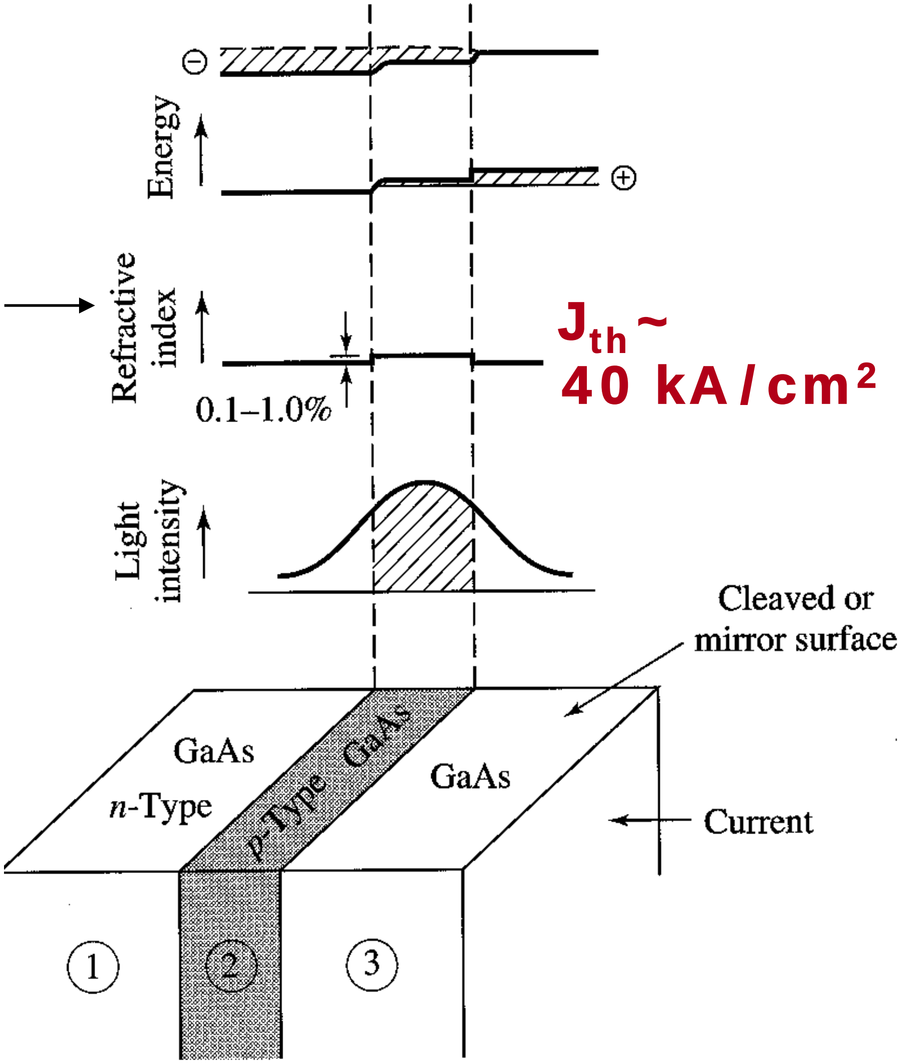
# Different fabrication techniques



$J_{th}\sim$ **100 kA/cm$^2$**

(a) Diffused homostructure diodes

*small*



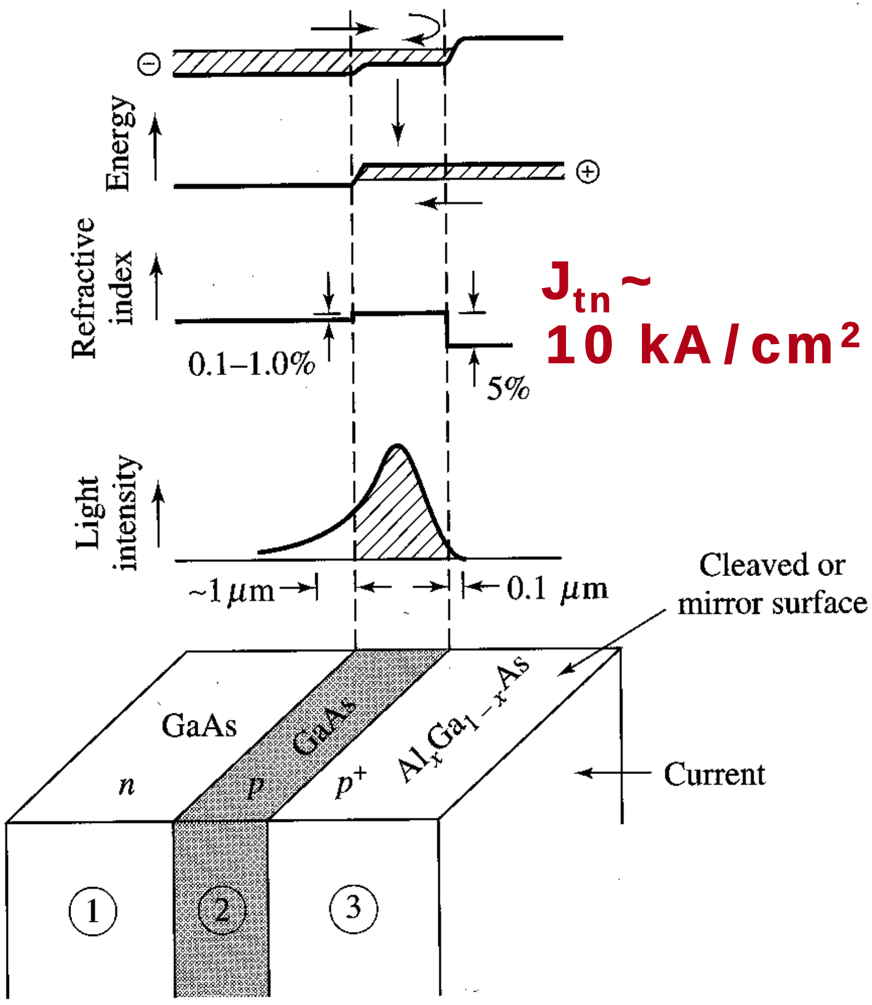
$J_{th}\sim$ **40 kA/cm$^2$**

(b) Liquid phase epitaxial homostructure diodes

*Not well defined, no carrier confinement*

*Boundaries well defined, sharp junction interfaces*

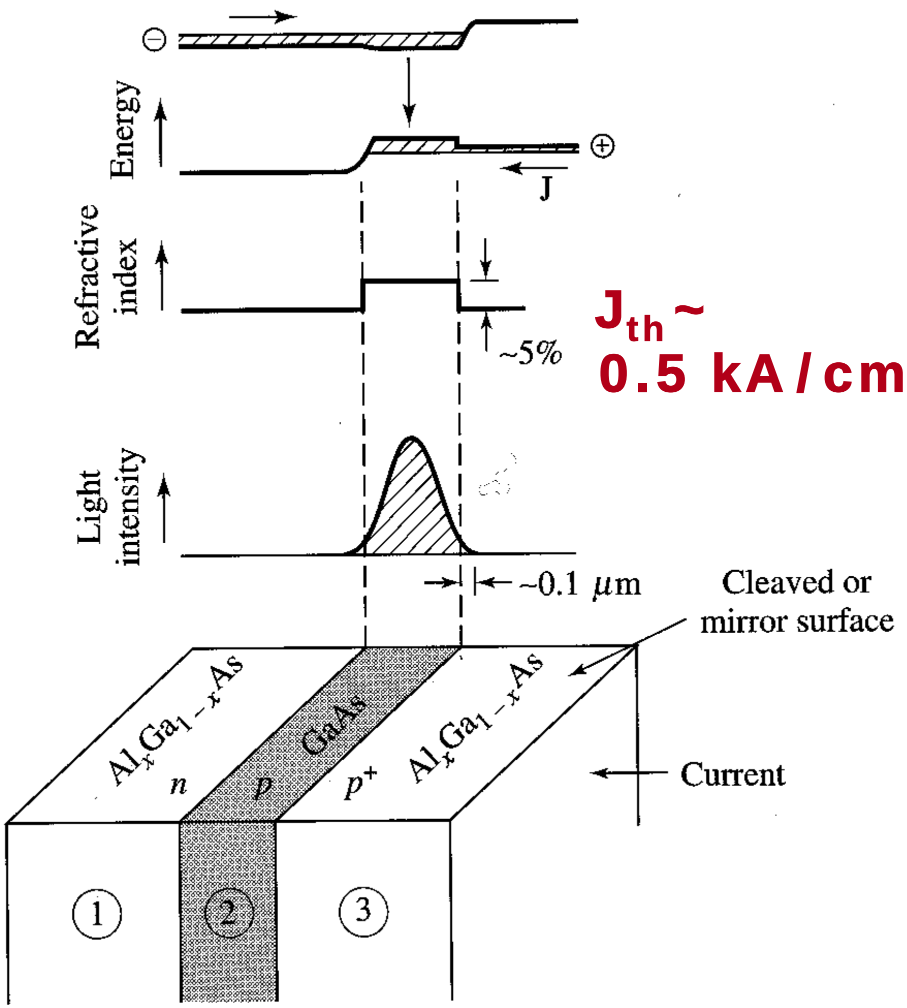
# Better confinement of optical power and carriers



**$J_{tn} \sim$ 10 kA/cm$^2$**

(c) Single heterostructure diodes

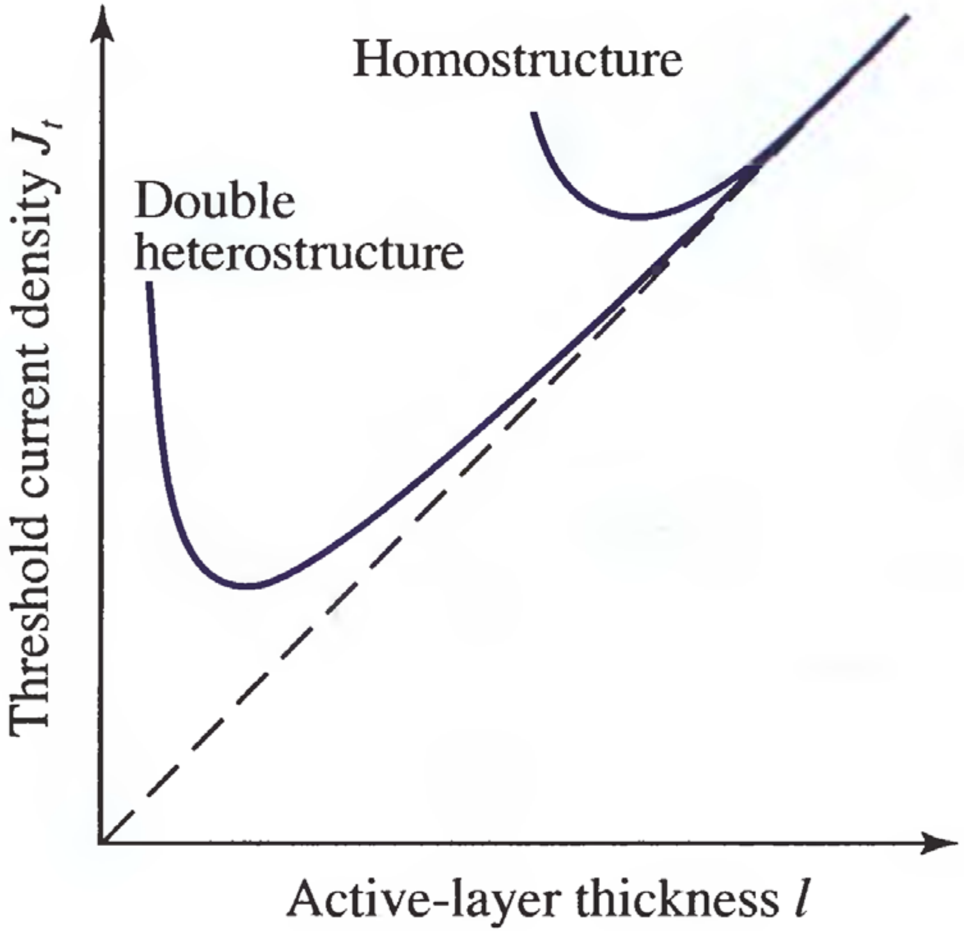
**SH lasers**



**$J_{th} \sim$ 0.5 kA/cm$^2$**

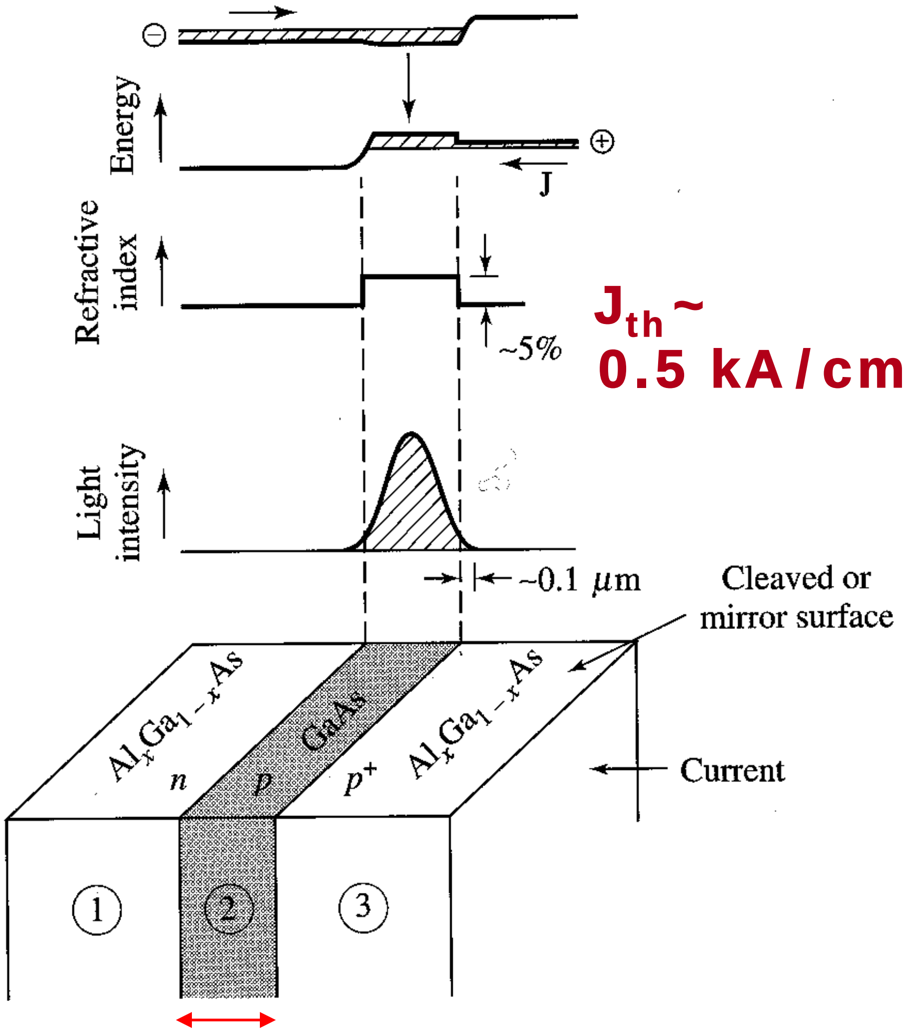
(d) Double heterostructure diodes

**DH lasers**



**The double-heterostructure las**
**superior performance.**

**For small $l$:**
**Poor light confinement**
**in thin active layers…**



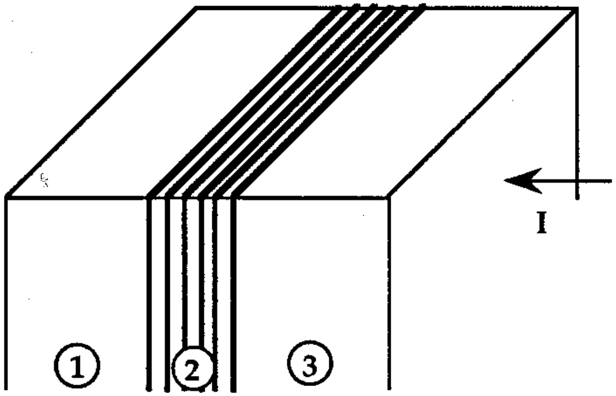
(d) Double heterostructure diodes

**$J_{th}$ ~ 0.5 kA/cm²**

**100 nm**

**Conventional injection lasers**

**$J_{th}$ ~ 0.08 kA/cm²**

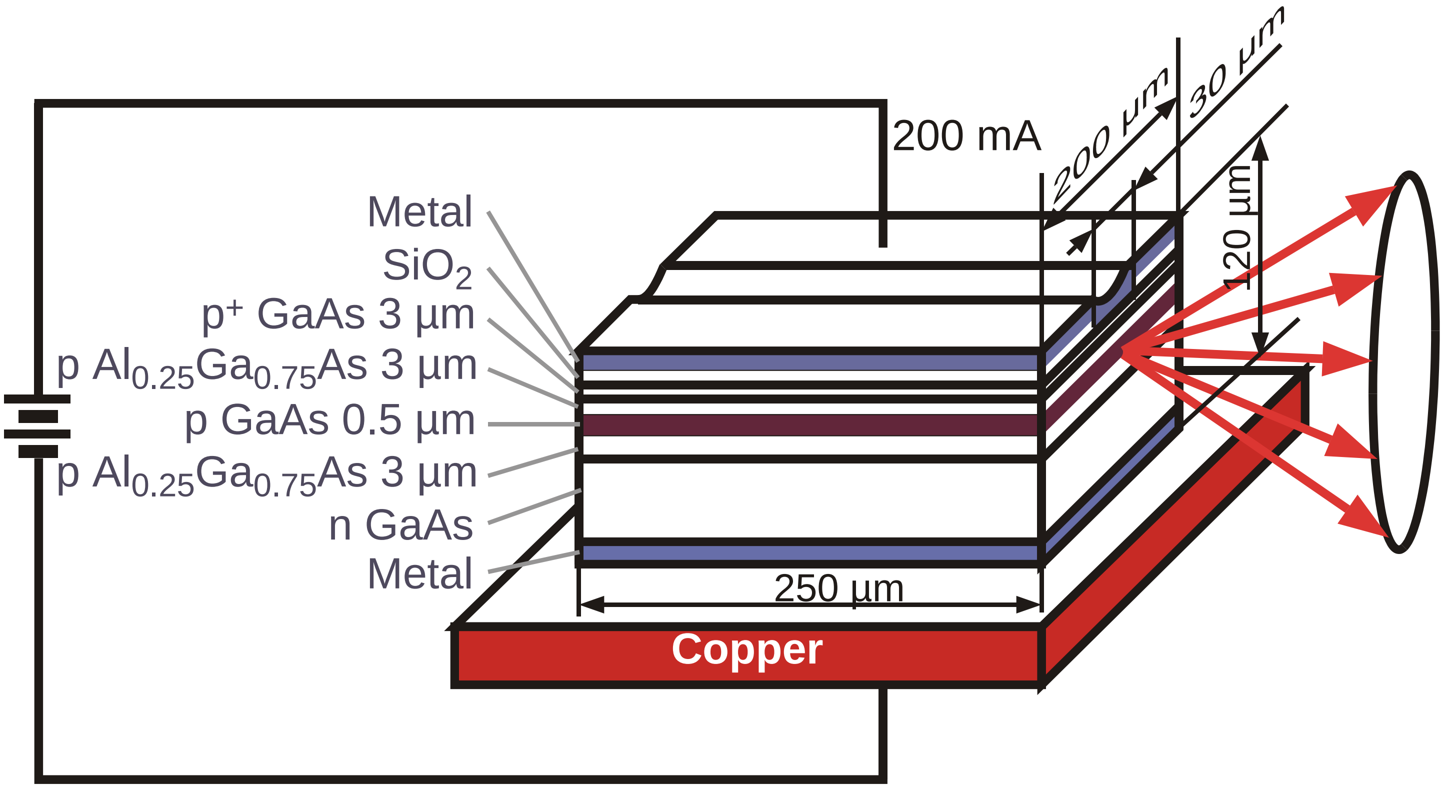


Quantum well laser

**10 nm layers**

**SQW injection lasers**
**MQW injection lasers**

# Schematic representation of the DHS injection laser in the first CW-operation at room temperature



Z. Alferov, “Double heterostructure lasers: Early days and future perspectives,” *IEEE J. on Selected Topics in Quantum Electronics*, Vol. 6, No. 6, pp. 832-840, (2000)

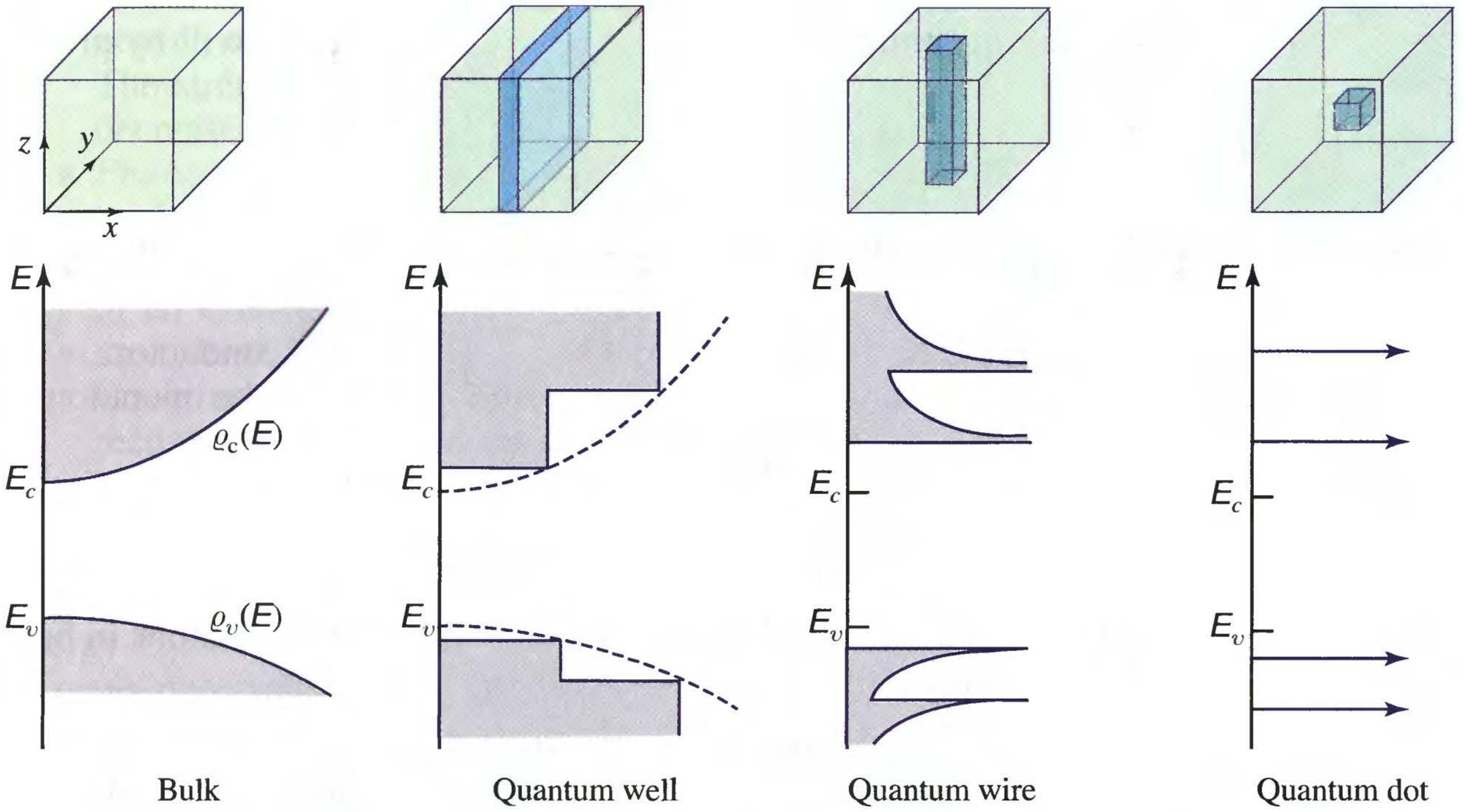
**In usual or conventional ILDs**

- Thickness of active layer > 100 nm
- Electrons are free to move in all directions

**In quantum well lasers**

- One or several thin layers
- Each layer is < 10 nm thick
- Electrons are not free to move in the direction normal to the layers
- “Quantum well”

**Single quantum well (SQW) lasers**
**Multiple quantum well (MQW) lasers**


z
y
x
E
$E_c$
$E_v$
$\varrho_c(E)$
$\varrho_v(E)$
Bulk
Quantum well
Quantum wire
Quantum dot

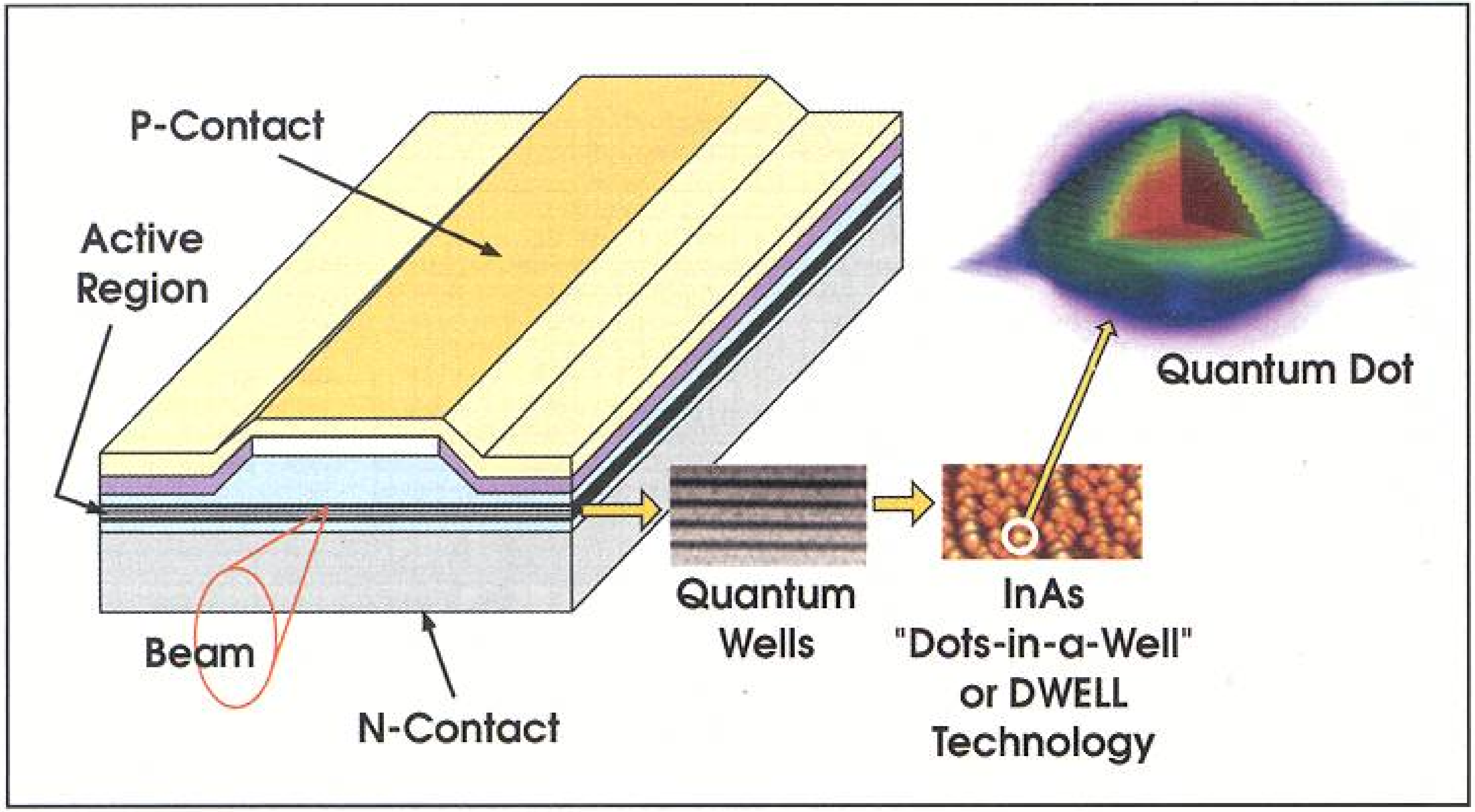
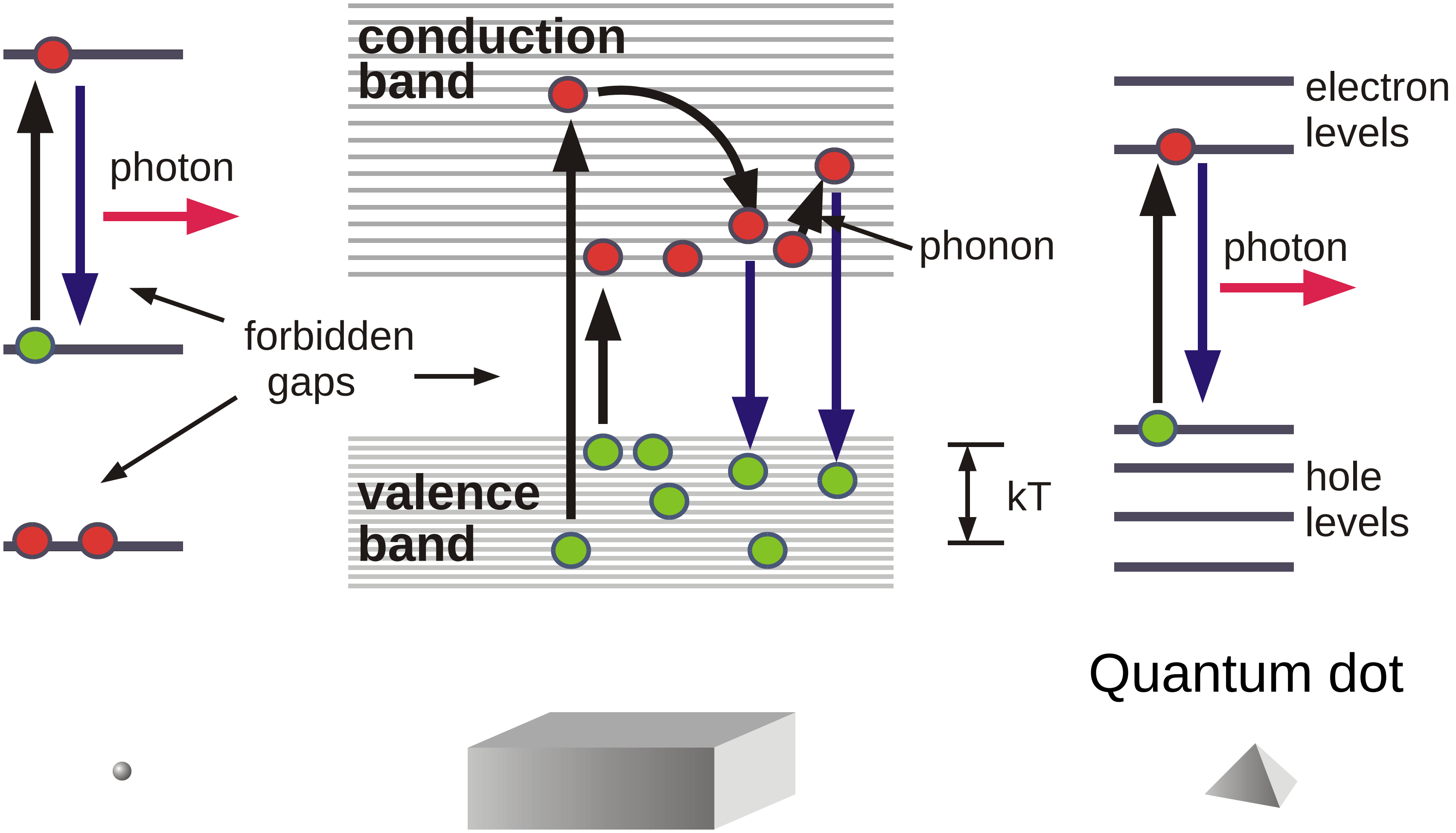
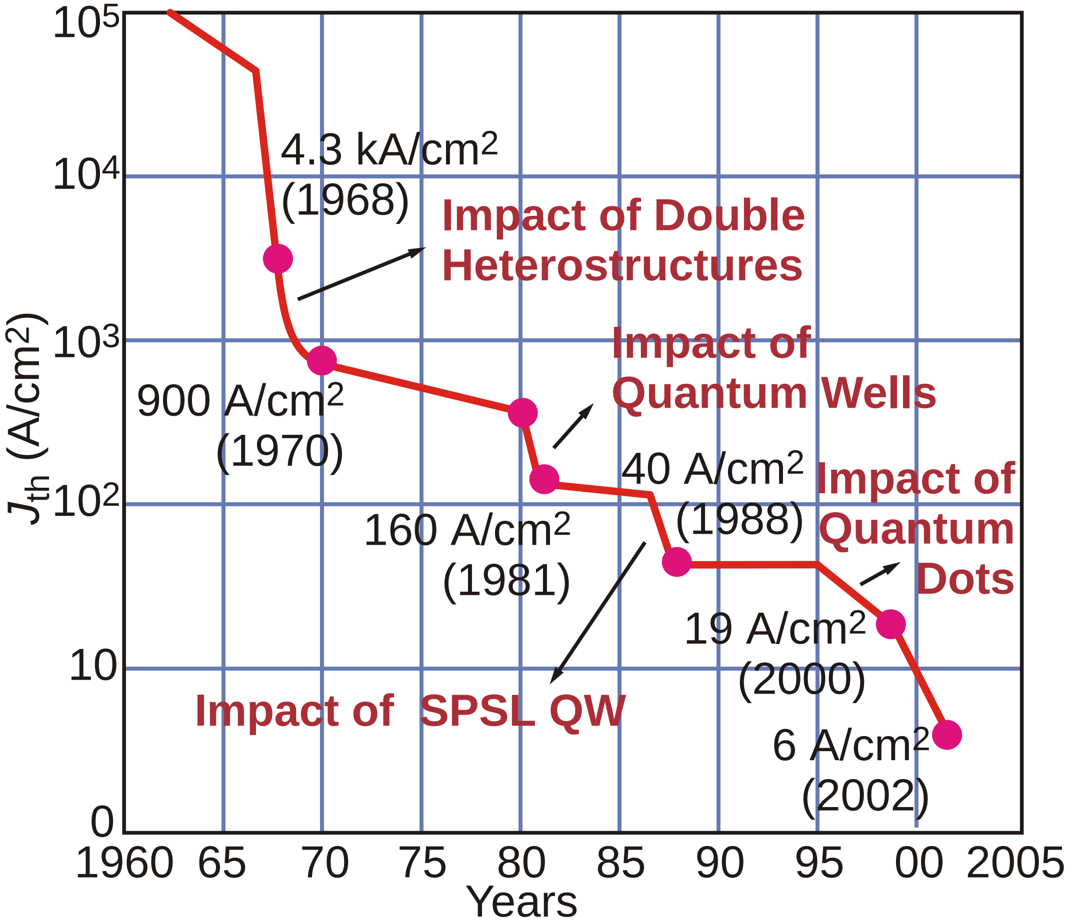


***Figure 2.*** *The purer signal of quantum-dot technology compared with quantum-well designs will enable isolator-free operation and potentially eliminate up to 25 percent of the component cost.*

# QUANTUM DOT – ARTIFICIAL ATOM





- Evolution and revolutionary changes
- Reduction of dimensionality results in improvements

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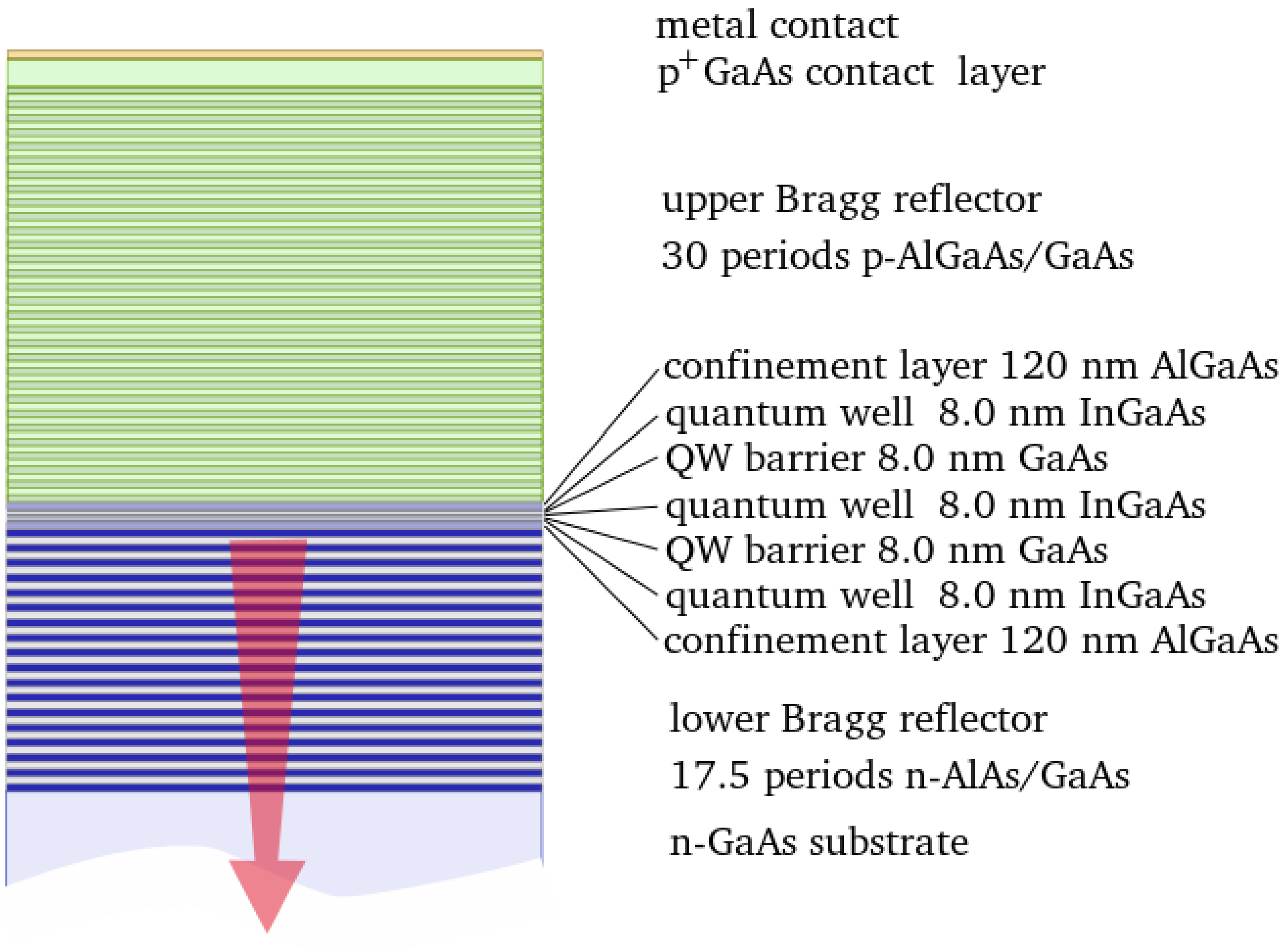
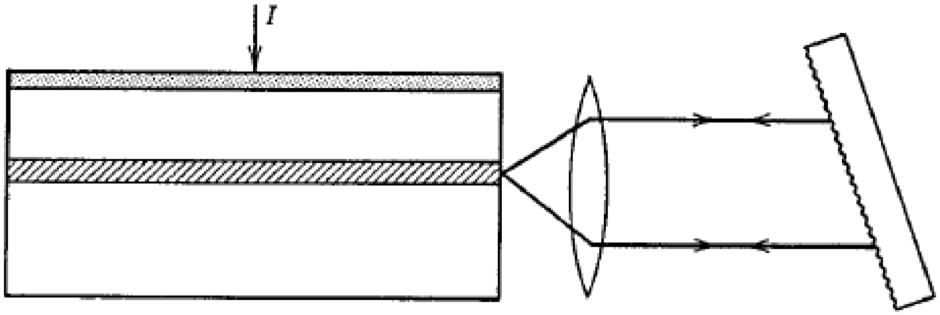
# Vertical Cavity Surface Emitting Lasers (VCSELs)

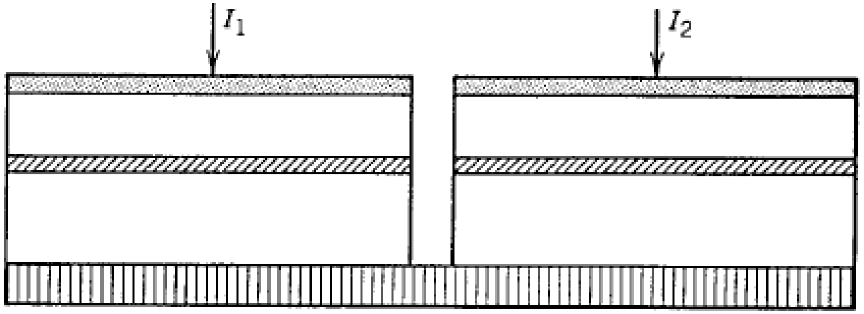


# Tunable Lasers



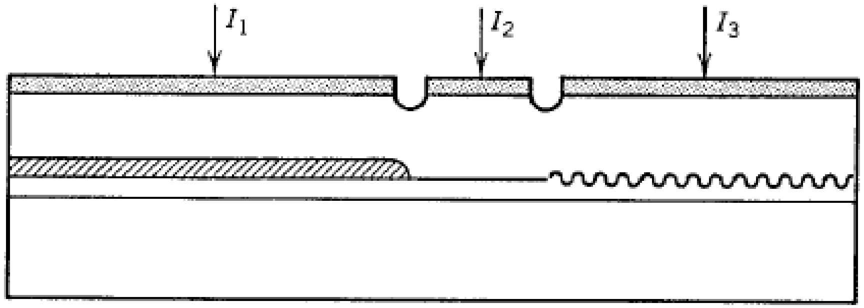
(a)

External-cavity laser



(b)

Cleaved-coupled-cavity laser



(c)

Multi-section DBR laser

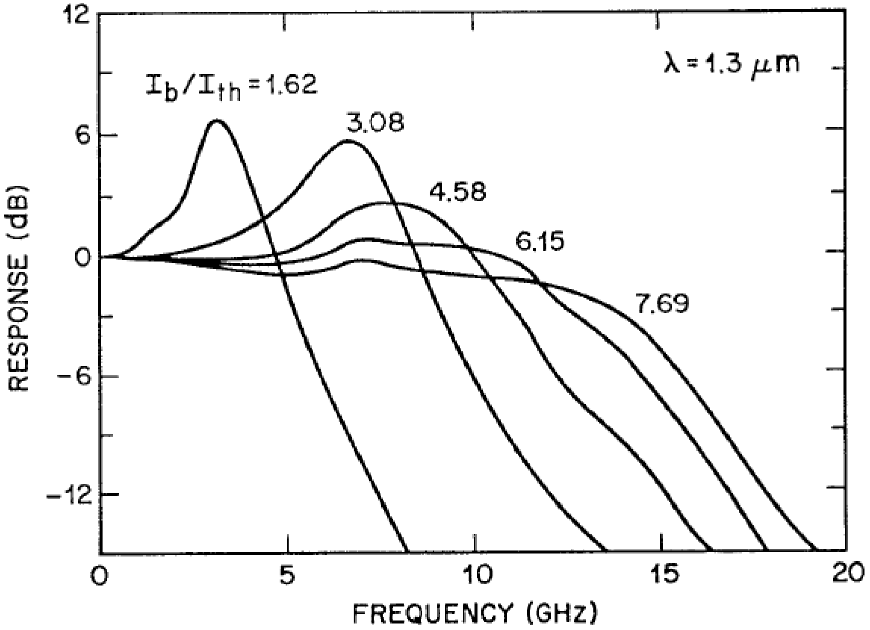
# Small-Signal Modulation

Gain modification:

$$G = G_N(N - N_0)(1 - \varepsilon_{\mathrm{NL}}P)$$

Phase modulation:

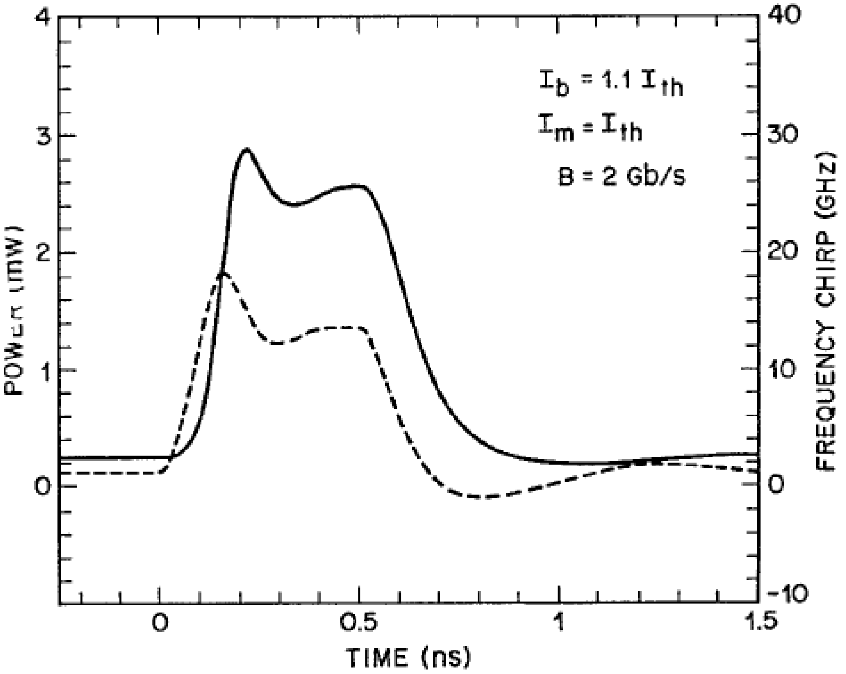
$$\frac{d\phi}{dt} = \frac{1}{2}\beta_c\left[G_N(N - N_0) - \frac{1}{\tau_p}\right]$$



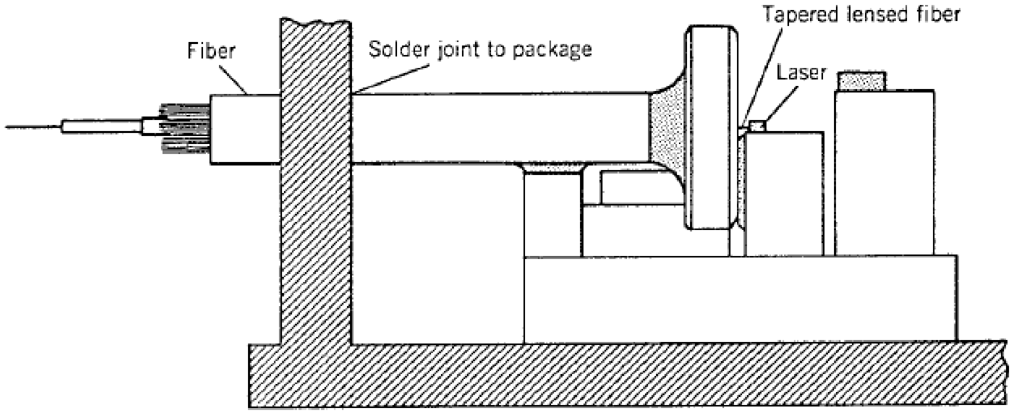
# Large-Signal Modulation

Frequency chirp:

$$\delta\nu(t) = \frac{1}{2\pi}\frac{d\phi}{dt} = \frac{\beta_c}{4\pi}\left[G_N(N-N_0) - \frac{1}{\tau_p}\right]$$

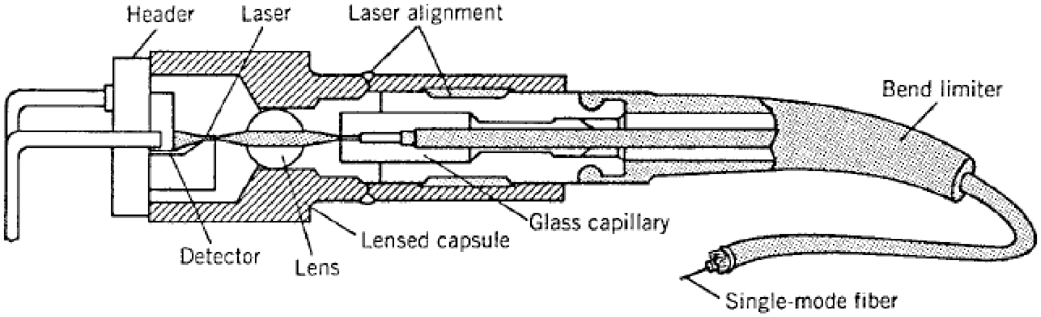


# Source-Fiber Coupling



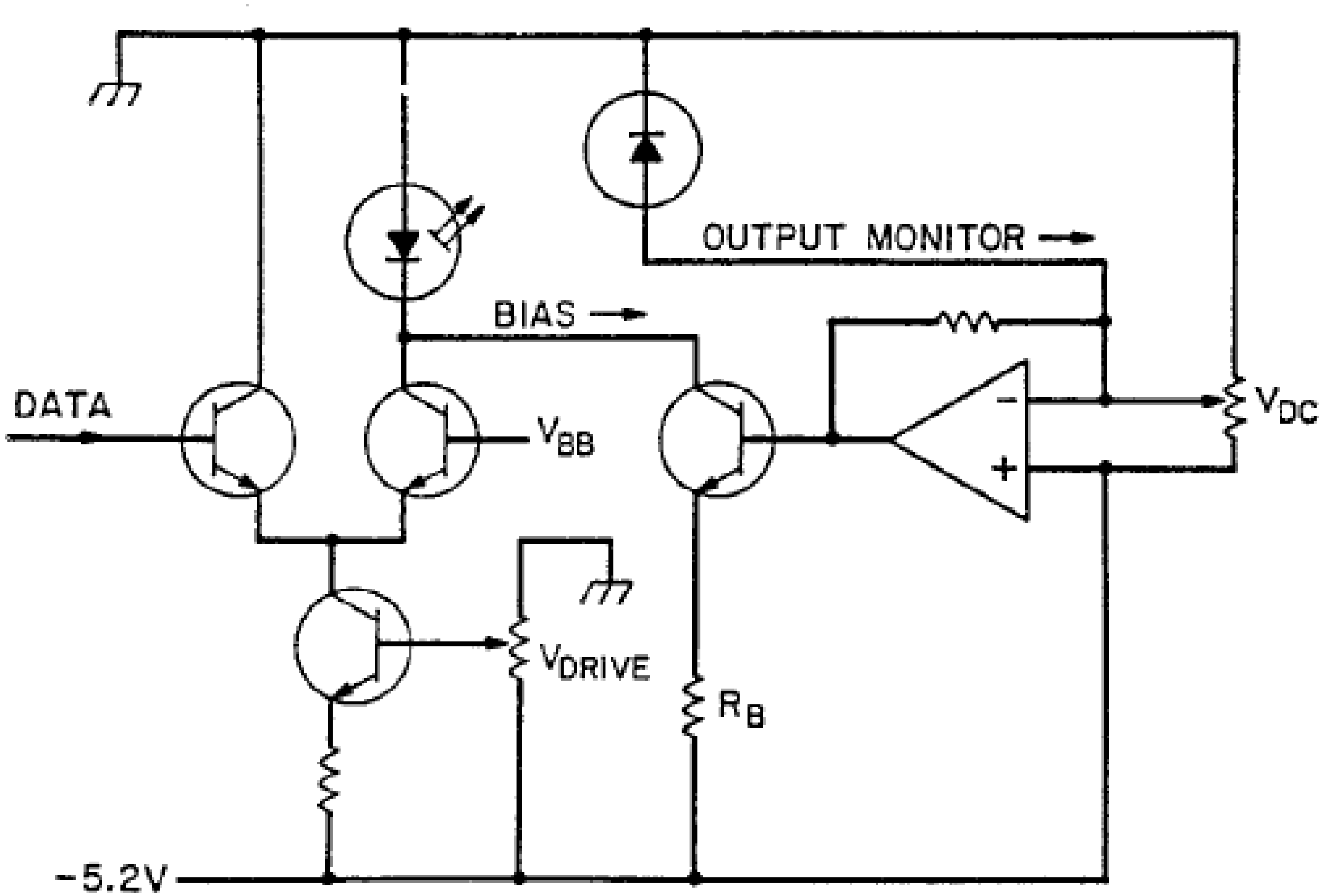
(a)

Butt-coupling



Lens-coupling

# Driving Circuits



# Laser Degradation