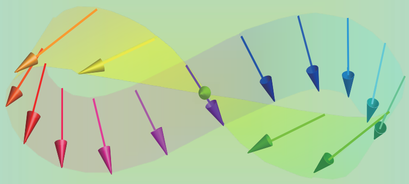
# Nanoelectronics
# 16

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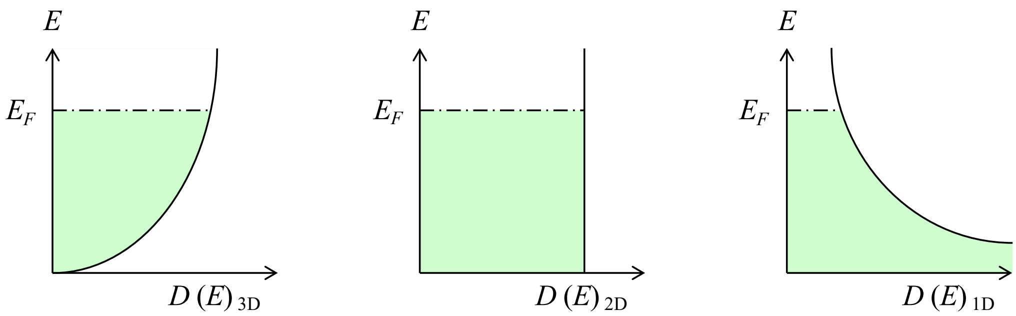
THE UNIVERSITY *of York*


12:00 Thursday, 09/March/2023 (P/T 005A)

## Quick Review over the Last Lecture

Density of states (DOS) in different dimensions :




$D(E)_{3D} \propto$ $D(E)_{2D} \propto$ $D(E)_{1D} \propto$

# Contents of Nanoelectonics

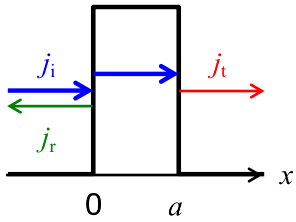


# 16 Optical Nanodevices

- Bandgap
- Light emitting diode
- Laser
- Near-field optics

# Absorption Coefficient

Absorption fraction $A$ is defined as




Here, $j_r = Rj_i$, and therefore $(1 - R)\, j_i$ is injected.

Assuming $j$ at $x$ becomes $j - dj$ at $x + dx$,

$$-dj = \alpha j dx \qquad (\alpha : \text{absorption coefficient})$$

With the boundary condition : at $x = 0$, $j = (1 - R)\, j_i$,

$$j = (1 - R)\, j_i \exp(-\alpha x)$$

With the boundary condition : $x = a$, $j = (1 - R)\, j_i e^{-\alpha a}$,

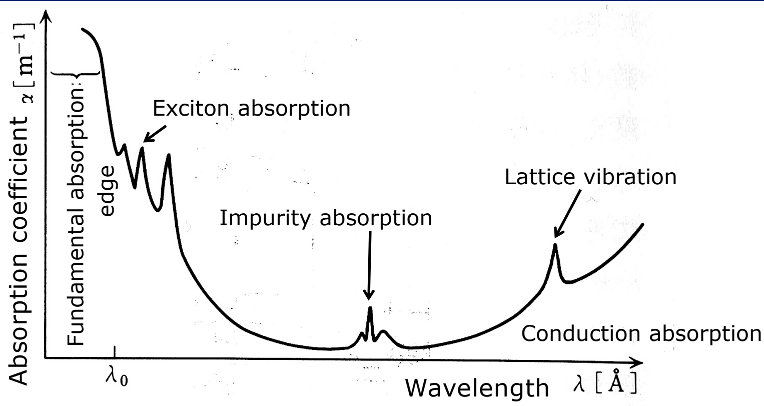
part of which is reflected ; $R\,(1 - R)\, j_i\, e^{-\alpha a}$

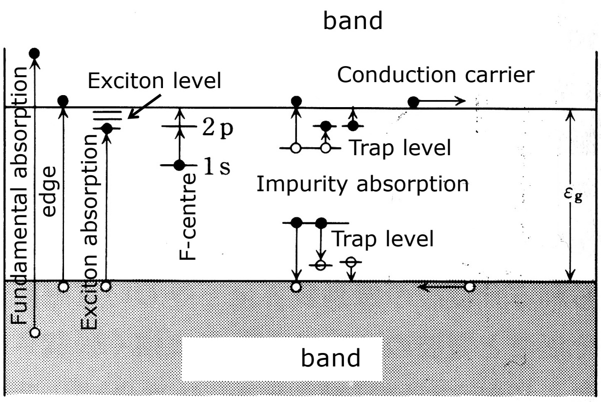
and the rest is transmitted ; $j_t = [1 - R - R\,(1 - R)]\, j_i\, e^{-\alpha a}$

$$j_t = (1 - R)^2\, j_i \exp(-\alpha x)$$

$$\therefore T = \frac{j_t}{j_i} = (1 - R)^2 \exp(-\alpha x)$$

# Optical Absorption

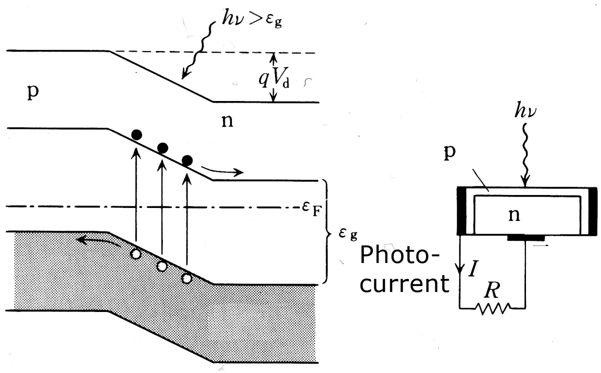



* M. Sakata, *Solid State Physics* (Baifukan, Tokyo, 1989).

# Photo Diode

Photovoltaic effect :

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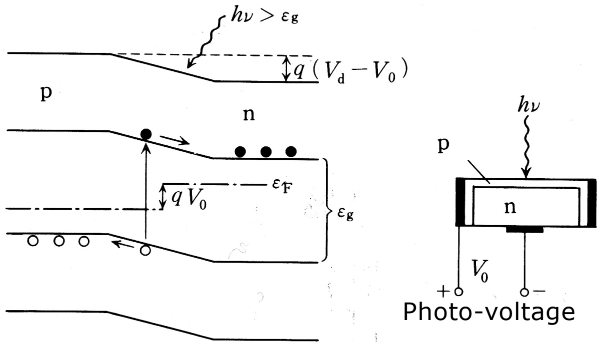
energy conversion

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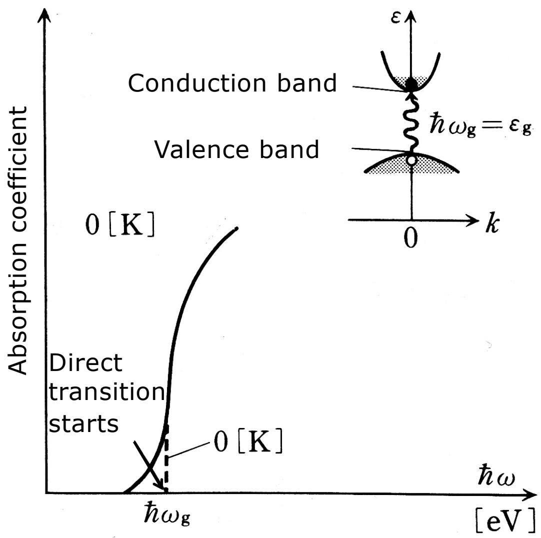
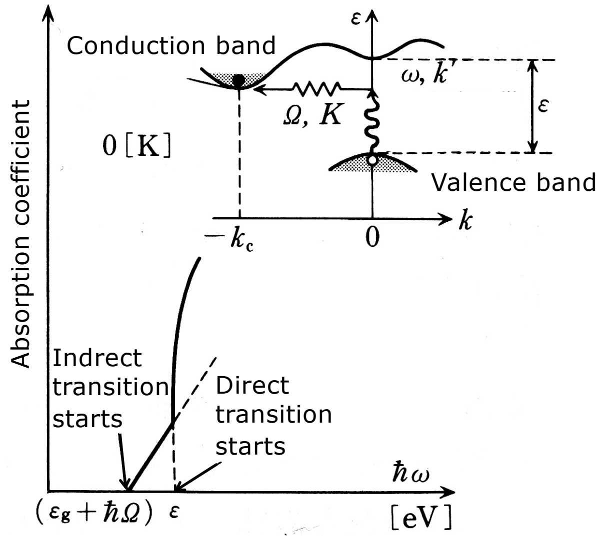
* M. Sakata, *Solid State Physics* (Baifukan, Tokyo, 1989).

# Semiconductor Band Gap




Excited electrons will be recombined with holes with emitting photons.

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* M. Sakata, *Solid State Physics* (Baifukan, Tokyo, 1989).

## Semiconductor Band Gap in Si, Ge and GaAs

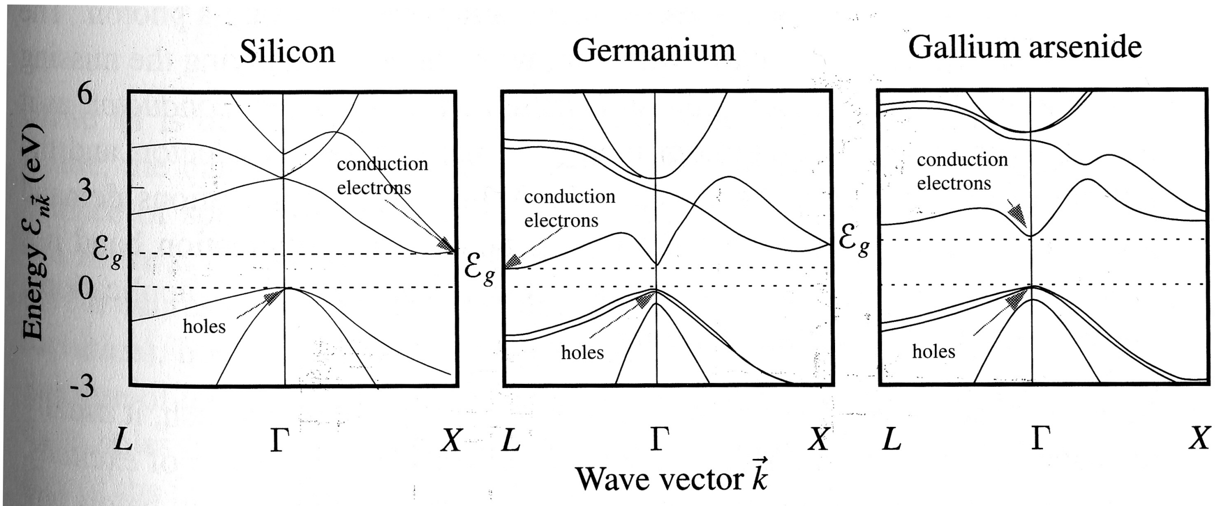


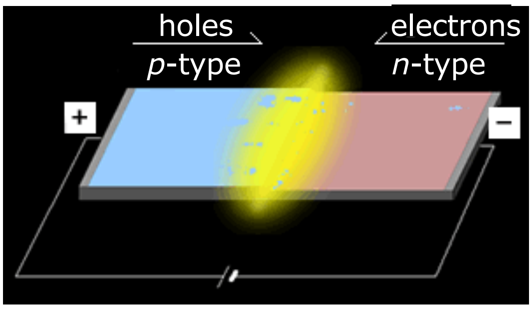

**Figure 19.8.** Essential features of band structures of silicon, germanium, and gallium arsenide. All have band gaps on the order of 1 eV. The bottom of the conduction band for silicon and germanium does not lie at Γ, so these materials have an indirect gap. Gallium arsenide, by contrast, has a direct gap. These diagrams are extracted from Figures 23.15 and 23.16, which contain information on how they were obtained.

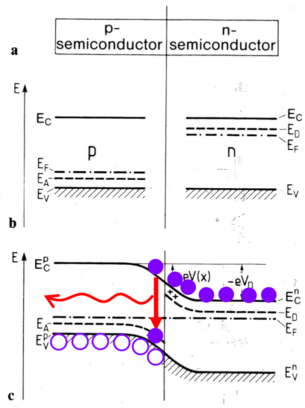
* M. P. Marder, *Condensed Matter Physics* (John-Wiley, New York, 2000).

## Light Emitting Diode

How does a light emitting diode works ?

- In a *pn* junction, electrons recombine with holes.
- Wavelength light colour depends on bandgaps.



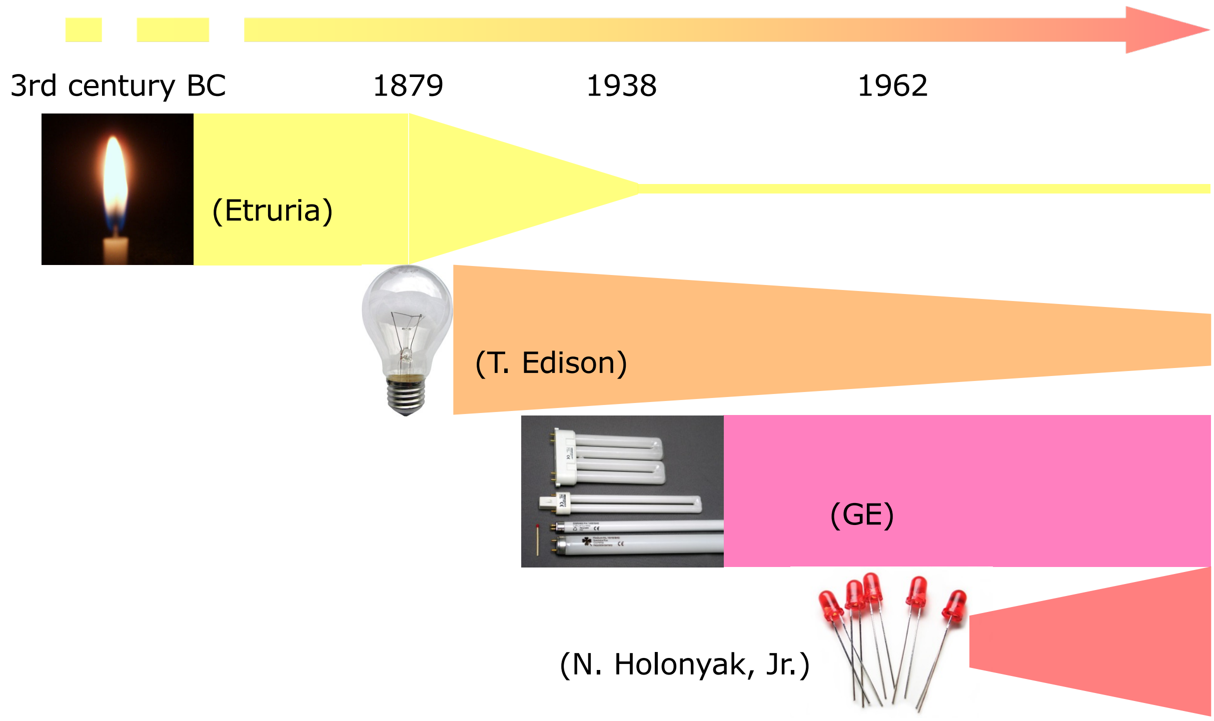

| | | | | |
|---|---|---|---|---|
| InGaN | ZnTeSe | AlGaInP | AlGaAs | GaAs(Si) |
| (450 nm) | (512 nm) | (570 nm) | (660 nm) | (980 nm) |
| 2.76 eV | 2.42 eV | 2.18 eV | 1.88 eV | 1.27 eV |

| | | | | |
|---|---|---|---|---|
| ZnCdSe | GaP | InGaN | GaP(Zn) | InGaAsP |
| (489 nm) | (555 nm) | (590 nm) | (700 nm) | 1300 nm |
| 2.54 eV | 2.23 eV | 2.10 eV | 1.77 eV | 0.95 eV |

* H. Ibach and H. Lüth, *Solid-State Physics* (Springer, Berlin, 2003);

# Light Emitting Diode (Cont' d)

4th generation light in human history :

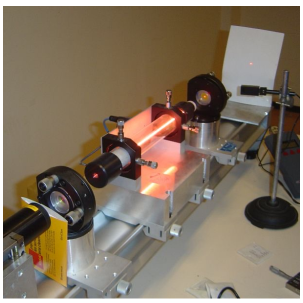


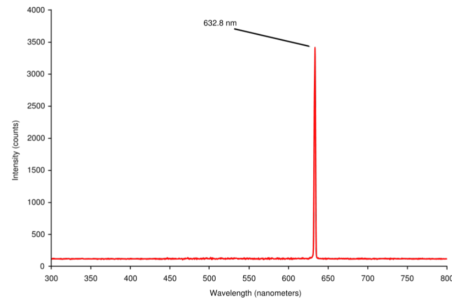

* http://exasyat5.tmit.ac.jp/study/kiso/comb.html;
** http://www.wikipedia.org/

# Principle of Laser

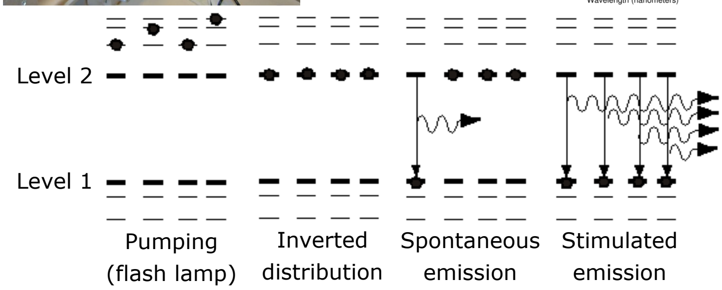
Light amplification by stimulated emission of radiation (        ) :

first demonstrated by Theodore H. Maiman in 1960.

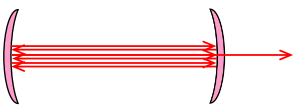









Coherent light is generated by resonater

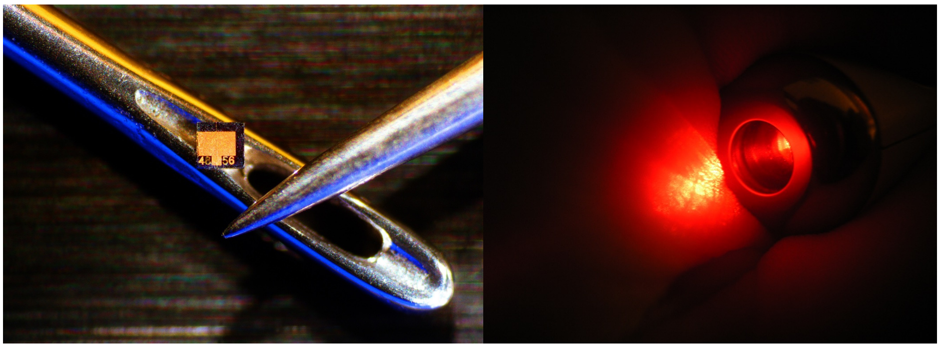


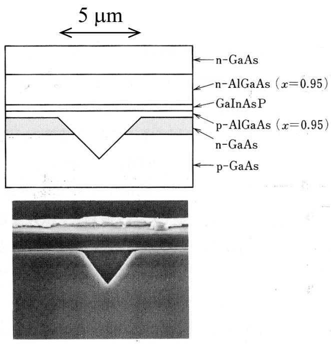
* http://photos.aip.org/
** http://www.wikipedia.org/
*** http://www.jaist.ac.jp/ms/labs/mizutani/qa/qa5/laser.html

# Quantum-Well Laser

Quantum-well (QW) laser was first fabricated by J. P. van der Ziel *et al.* in 1975 :

Typical laser diode :



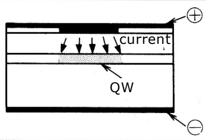
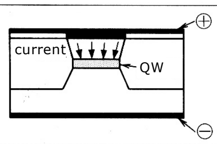
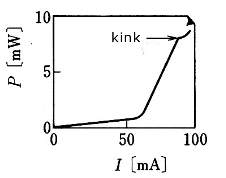
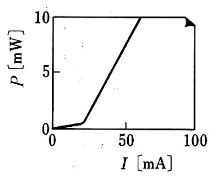
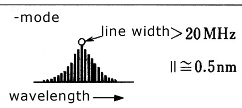
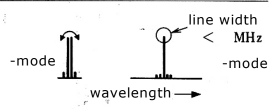
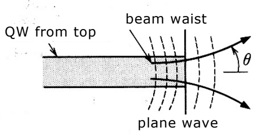
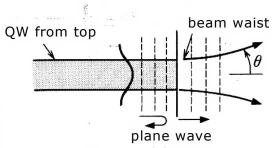
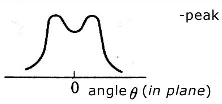
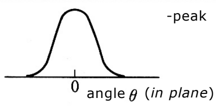




* http://www.wikipedia.org/

** K. Iga (Ed.), *Semiconductor Laser* (Ohm-sha, Tokyo, 1994).

# Quantum-Well Laser Structures

Major semiconductor quantum-well (QW) lasers :

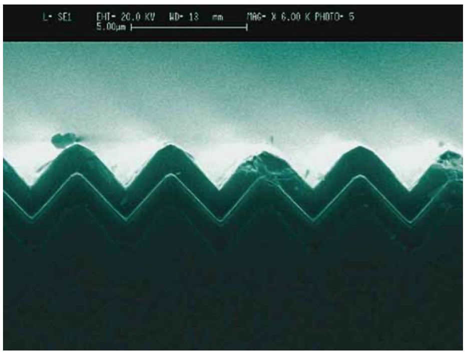
| | Gain-guided laser | Index-guided laser |
|---|---|---|
| Cross-sections |   |   |
| Current - power characteristics |   |   |
| Spectra |   |   |
| Emission modes |   |   |
| Beam shapes |   |   |

* K. Iga (Ed.), *Semiconductor Laser* (Ohm-sha, Tokyo, 1994).

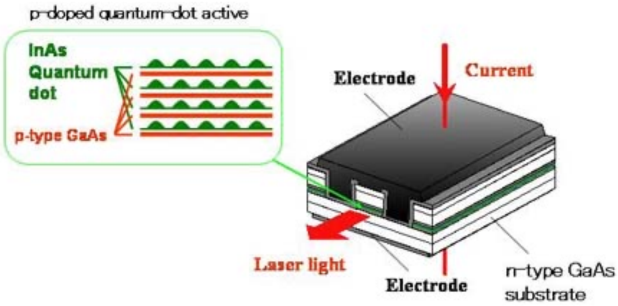
# Lasers with Quantum Nano-wire / Dots

In 1982, Y. Arakawa and H. Sakaki proposed 1D / 0D lasers :

Example of a quantum-wire laser :



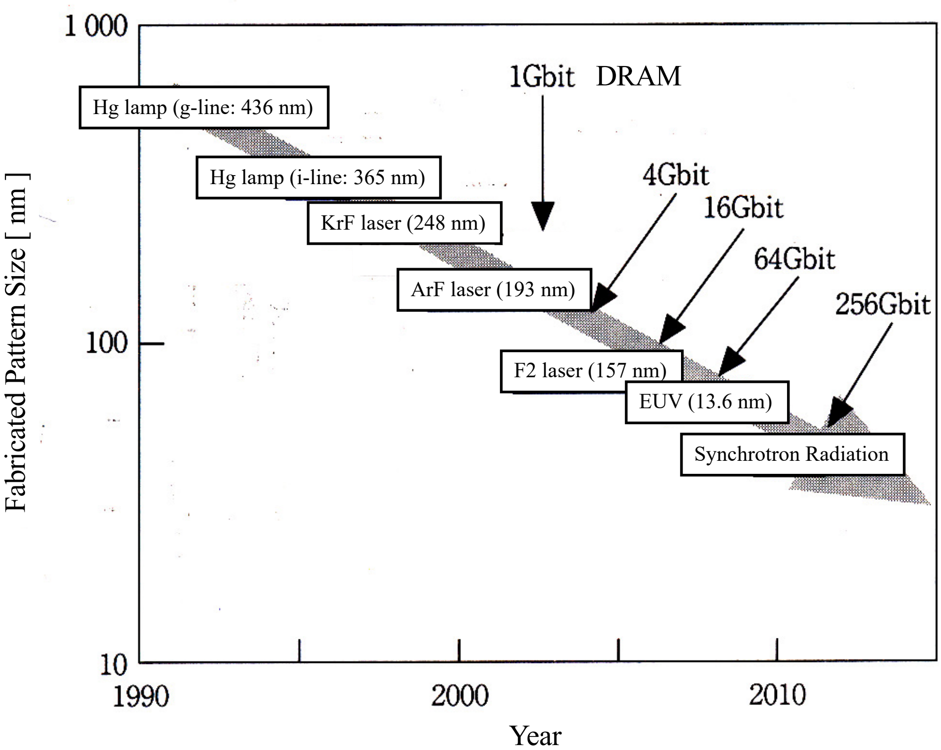
Example of a quantum-dot laser :




* http://wwwrsphysse.anu.edu.au/admin/pgbrochure/solidstate.html
** http://www.fujitsu.com/global/news/pr/archives/month/2004/20040910-01.html

# Limitation of Optical Nanofabrication

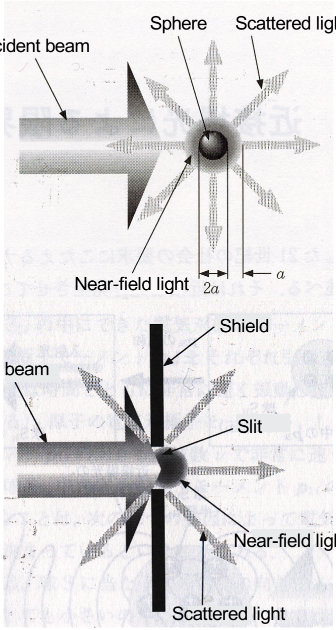
Development of photolithography :

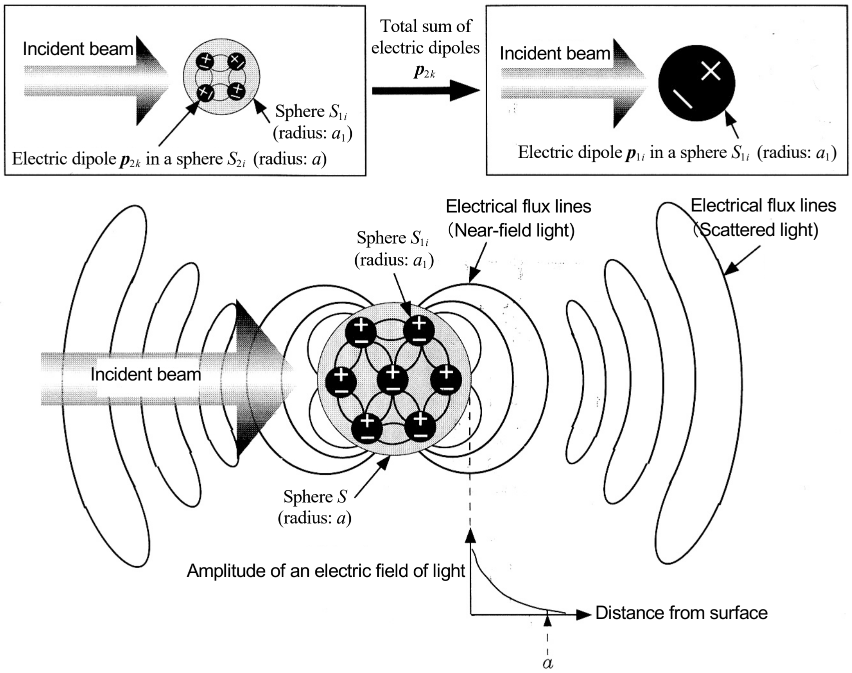



* M. Otsu and K. Kobayashi, *Kinsetsuba-kou no Kiso* (Ohm-sha, Tokyo, 2003).

# Near-Field Optics

Principles of near-field optics :

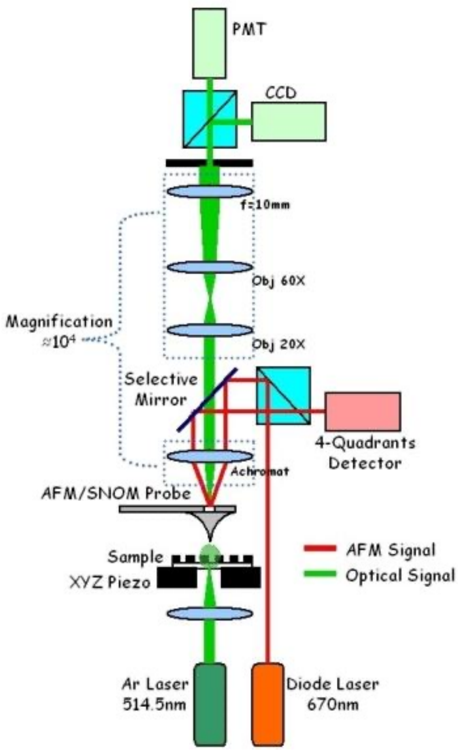


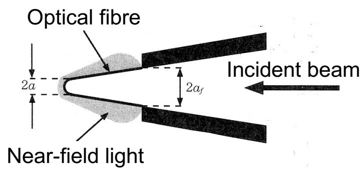



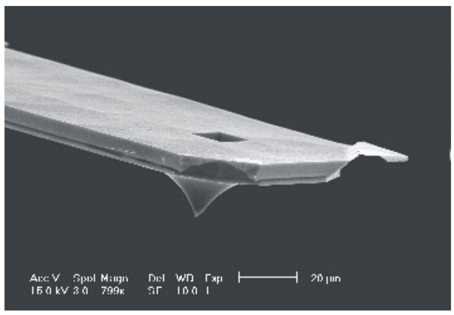

* M. Otsu and K. Kobayashi, *Kinsetsuba-kou no Kiso* (Ohm-sha, Tokyo, 2003).

# Scanning Near-Field Optical Microscope

Scanning near-field optical microscope (SNOM) :



* M. Otsu and K. Kobayashi, *Kinsetsuba-kou no Kiso* (Ohm-sha, Tokyo, 2003).

** http://www-optics.unine.ch/former/microoptics/cantilever_SNOM/cantilever_SNOM.html