Materials Science of Electronic and Optoelectronic Devices

Tadao Tanabe

平成２９年度後期　授業実施予定

課　　　　　程　：　大学院　・　学部（どちらかを選択）

科　　目　　名　：　応用電子材料学

曜日・講時・講義室：　金曜日・1講時・講義室3

担　当　教　員　：小山裕教授, 佐藤俊一教授, 吉川彰教授

田邉匡生准教授, 小澤祐市准教授

第	１回	１０月　６日（金）	１講時（小山）	Oct. 6 Oyama
第	２回	１０月１３日（金）	１講時（田邉）	**Oct.13 Tanabe：Photonic Device-Basic**
第	３回	１０月２０日（金）	１講時（田邉）	**Oct. 20 Tanabe：-Application**
第	４回	１０月２７日（金）	１講時（佐藤）	Oct. 27 Sato
第	５回	１１月１０日（金）	１講時（小澤）	Nov.10 Kozawa
第	６回	１１月１７日（金）	１講時（吉川）	Nov.17 Yoshikawa
第	７回	１１月２４日（金）	１講時（試験）	Nov.24 Examination

Basic of Photonic devices (Tanabe)

(1) INTRODUCTION

What is LIGHT?
Application of light to our life
Relation between light and materials

(2) Handling of LIGHT

Generation
Propagation :absorption
Condensing(space)
Condensing(time)/modulating
Amplification
Selecting
Detecting

(3) Understanding of LIGHT for device fabrication

wavelength/frequency
linewidth
pulse duration
beam mode
polarization
power density

(4) Photonic Technology

(5) Applications

(2) Handling of LIGHT

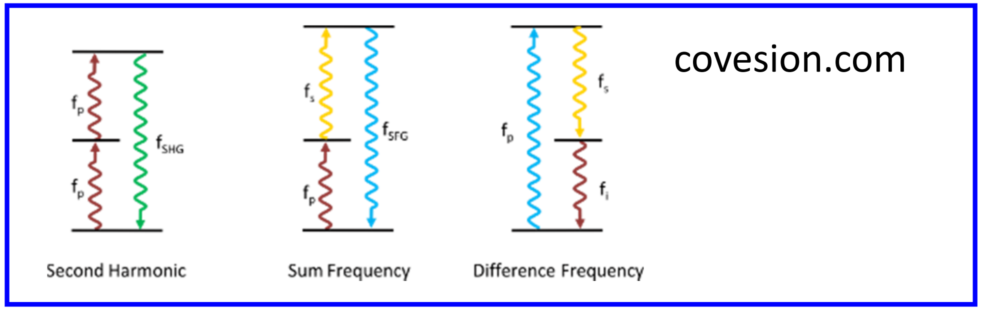
Generation

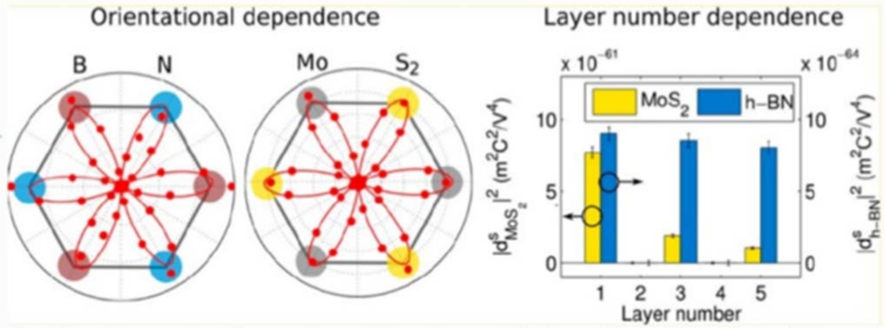
heating

energy gap in semiconductor

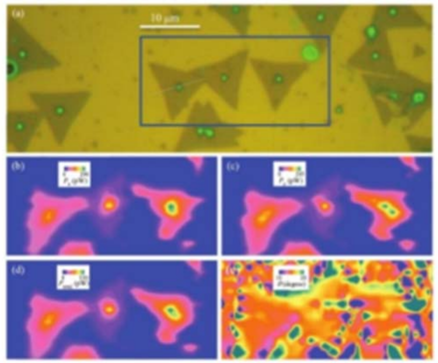
nonlinear optical process

(frequency-mixing: DFG, SFG, SHG)



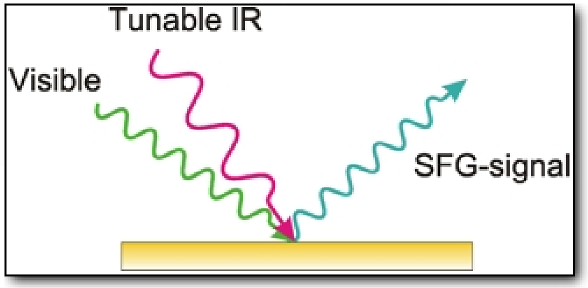


Probing Symmetry Properties of Few-Layer MoS_2 and h-BN by Optical Second-Harmonic Generation Nano Lett. **13,** 3329 **(2013)**



Second harmonic microscopy of MoS_2

PRB **87,** 161403 (2013)



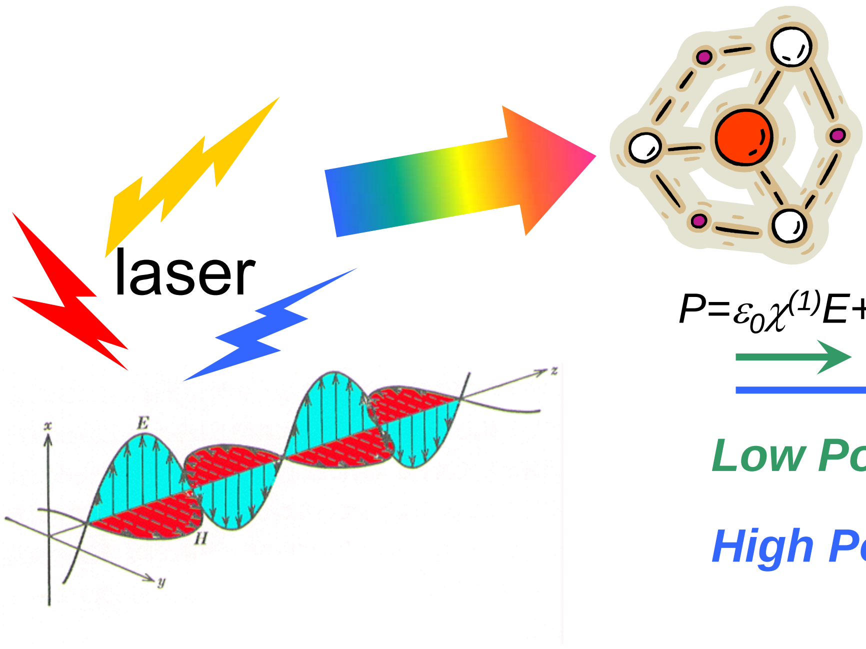
nb.uw.edu

Claudio Attaccalite, CNRS researcher at Neel Institute Grenoble

(2) Handling of LIGHT

Generation

- *heating*
- *energy gap in semiconductor*
- *nonlinear optical process*
- *(frequency-mixing: DFG, SFG, SHG)*



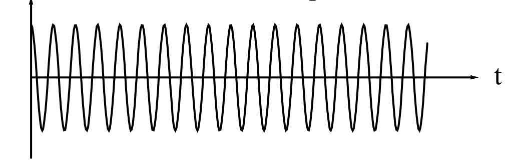
$P = \varepsilon_0 \chi^{(1)} E + \varepsilon_0 \chi^{(2)} E^2 + \varepsilon_0 \chi^{(3)} E^3 + \cdots$

Low Power : Linear

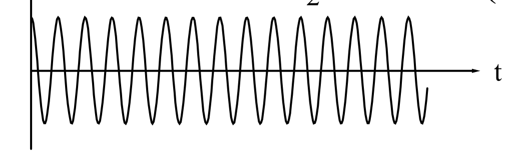
High Power: nonlinear

difference-frequency generation (DFG)

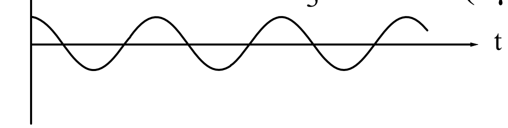
ω_1=282THz(1.064μm)



ω_2=232THz(1.3μm)



ω_3=50THz(6μm)



DFG ω_3=50THz(6μm)

SFG ω_3=514THz(0.584μm)

THG:846THz(0.354μm)

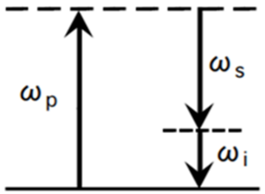
SHG1 ω_3=564THz(0.532μm)

FHG:1128THz(0.266μm)

SHG2 ω_3=464THz(0.647μm)

SHG@1961

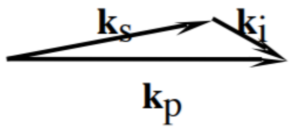
Michigan Univ. P.A. Franken、A.E. Hill、C.W. Peters, G. Weinreich



energy conservation law

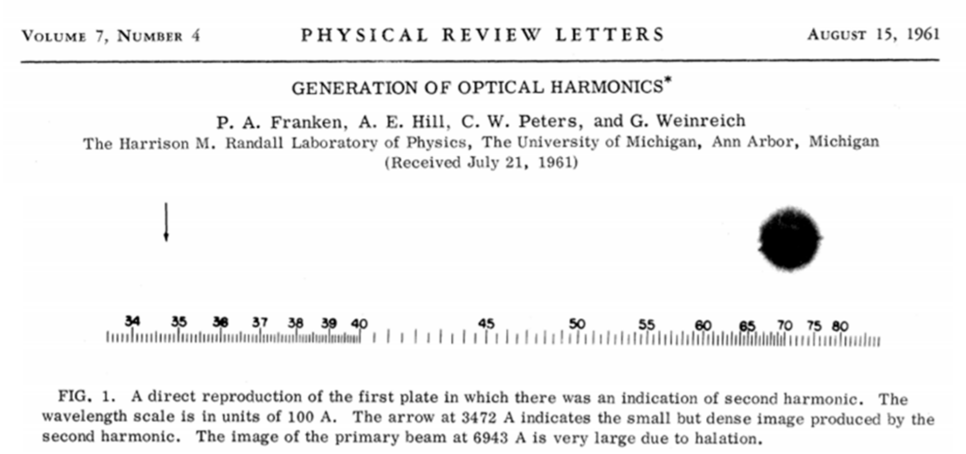
$\omega_p = \omega_s + \omega_i$

$1/\lambda_p = 1/\lambda_s + 1/\lambda_i$



momentum conservation law

$k_p = k_s + k_i \quad K = 2\pi n/\lambda$


VOLUME 7, NUMBER 4 PHYSICAL REVIEW LETTERS AUGUST 15, 1961

GENERATION OF OPTICAL HARMONICS*

P. A. Franken, A. E. Hill, C. W. Peters, and G. Weinreich
The Harrison M. Randall Laboratory of Physics, The University of Michigan, Ann Arbor, Michigan
(Received July 21, 1961)

FIG. 1. A direct reproduction of the first plate in which there was an indication of second harmonic. The wavelength scale is in units of 100 A. The arrow at 3472 A indicates the small but dense image produced by the second harmonic. The image of the primary beam at 6943 A is very large due to halation.

$$E = h\upsilon = h\frac{\omega}{2\pi} = h\frac{c}{\lambda}\left(=\hbar\omega\right)$$

h: Planck constant

ν: Frequency

ω: angular frequency

c: light speed (3×10^8 m/s)

λ: wavelength

(2) Handling of LIGHT

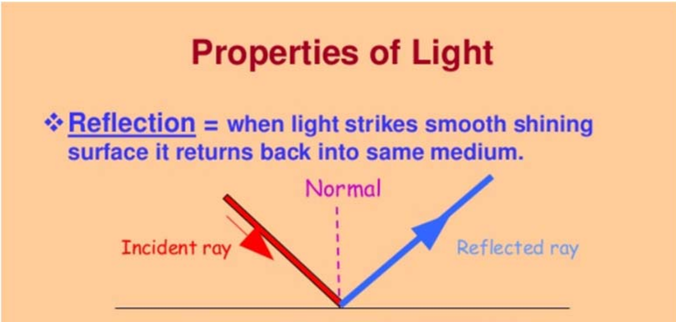
Propagation :absorption

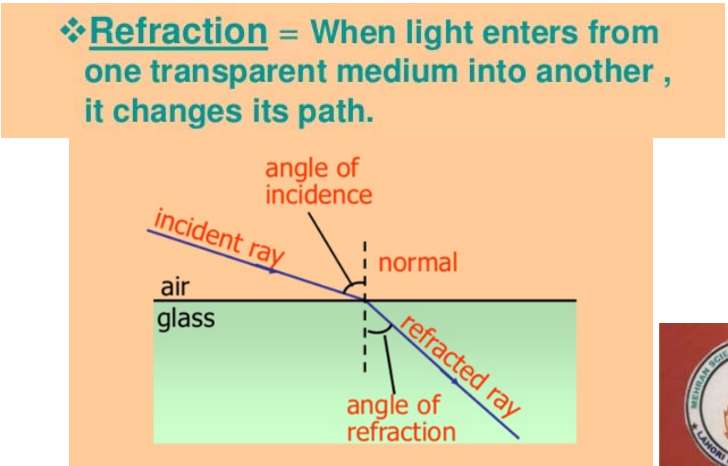
in air, liquid and solid

:reflection, refraction, diffraction, absorption and scattering

waveguide

optical fiber



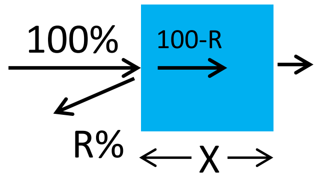


Absorption

$$\alpha = -\frac{\ln(\frac{T_1}{T_2})}{x_1 - x_2}$$

T : Transmittance

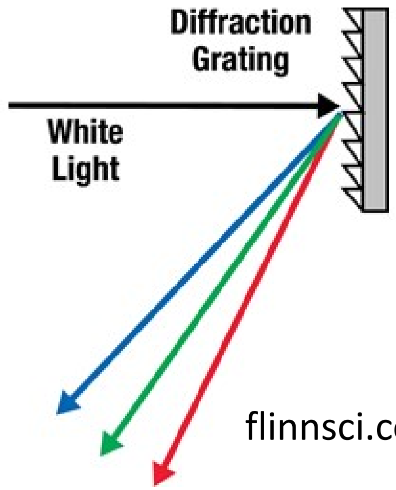
X_1, x_2 : Thickness



T%（measurement）

$$T\% = (100-R)\, e^{-\alpha \cdot x}$$

Diffraction



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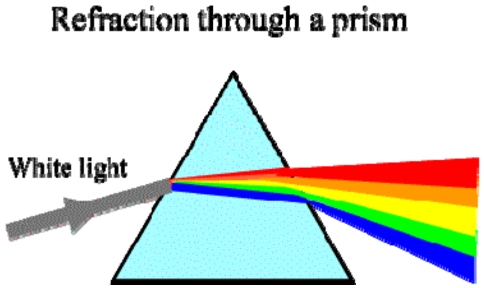


physics.louisville.edu

(2) Handling of LIGHT

Propagation :absorption

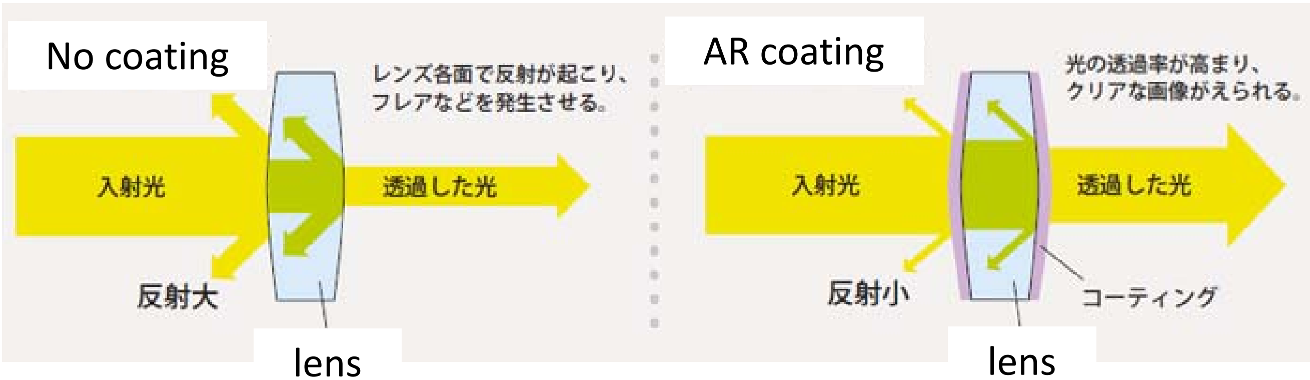
in air, liquid and solid

:reflection, refraction, diffraction, absorption and scattering

waveguide

optical fiber

Anti-Reflection coating



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(2) Handling of LIGHT

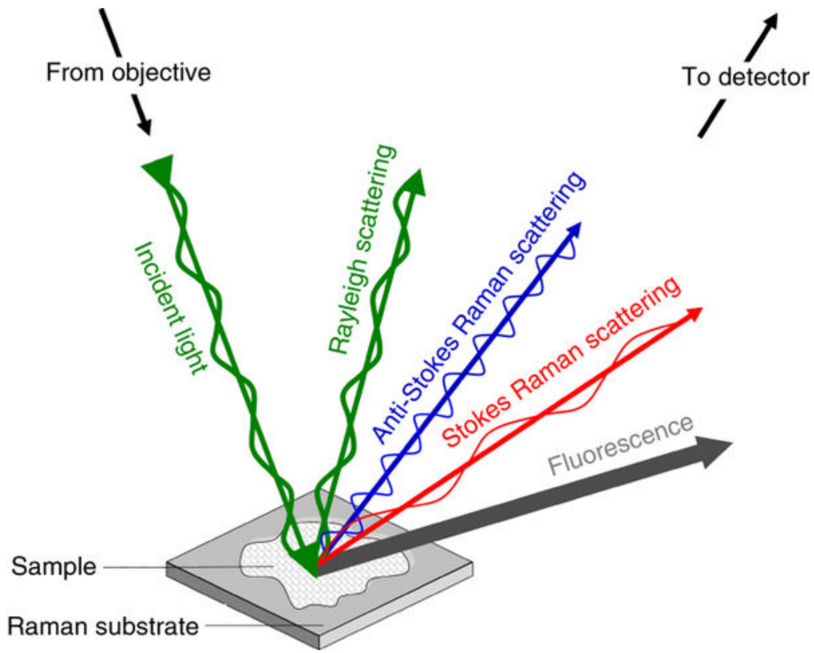
Propagation :absorption

in air, liquid and solid

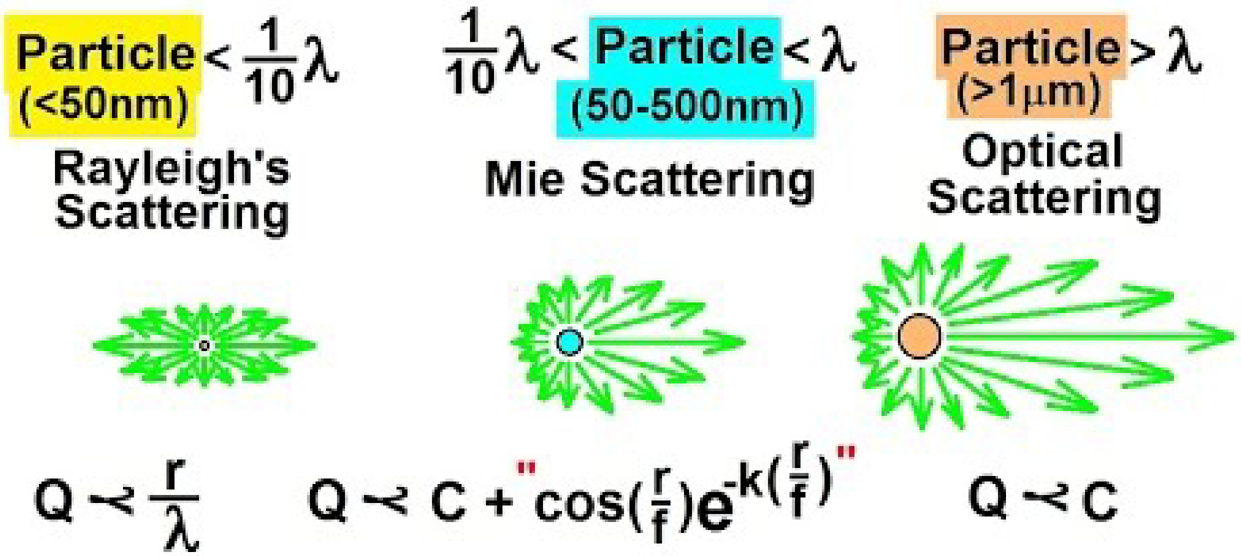
:reflection, refraction, diffraction, absorption and *scattering*

waveguide

optical fiber



Nature Protocols 11, 664–687 (2016)



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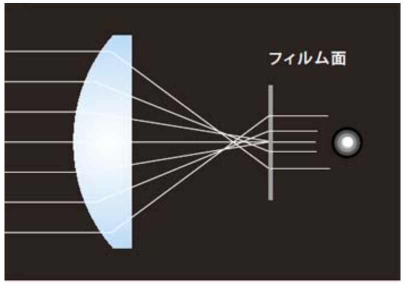
(2) Handling of LIGHT

Condensing(space)

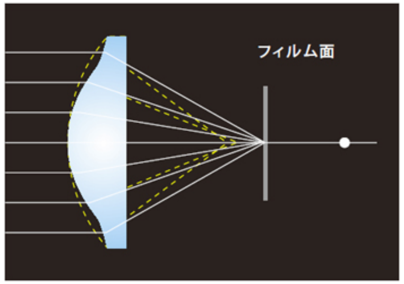
index lens

parabolic mirror

Spherical Lens



Aspherical Lens



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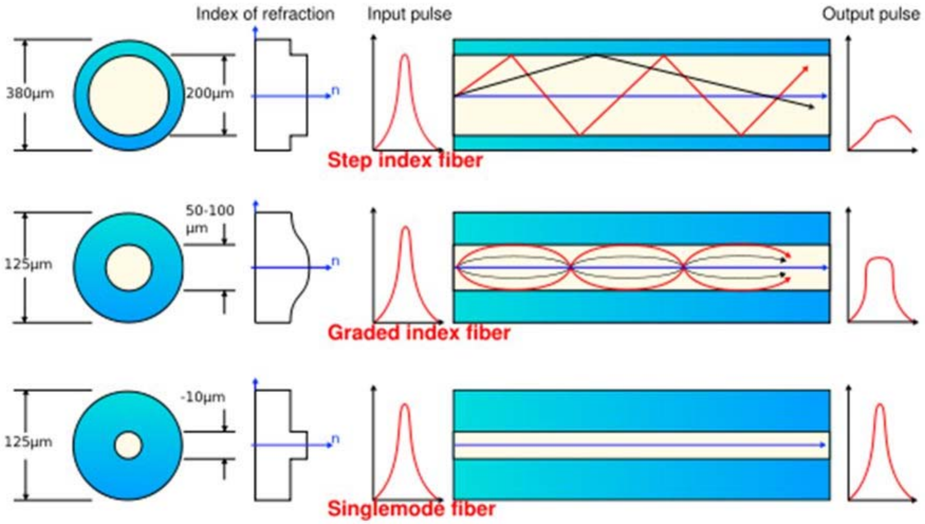


Standardní optická vlákna

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

Scientific Background
Nobel Prize in Physics 2009

where $P(0)$ and $P(L)$ are the input and output power respectively, and L is the fiber length. The attenuation of the first optical fibers was typically 1000 dB/km, implying that only 1 % of light got transmitted in twenty meters of fiber. Other options, such as guiding of light through sequences of lenses or even gas tubes with temperature gradients to focus light were proposed and sometimes tested, but without much success. Various waveguides in the optical region were investigated. Both A.E. Karbowiak at STL (The Standard Telecommunication Laboratories), Harlow, UK and J.C. Simon and E. Spitz at CSF (Compagnie générale de télégraphie Sans Fil) in France realized that propagation of single modes into waveguides (for example, thin films) should be beneficial to optical communication, reducing dispersion and propagation losses. At Tohuku University, Japan (J.-I. Nishizawa, I. Sasaki) as well as at Bell laboratories, USA (S.A. Miller), optical fibers with a varying refractive index were proposed. In a gradient-index fiber, dispersion effects arising because spatial modes propagate at different velocities in the fiber are reduced compared to the step-index multimode fiber (see Fig. 2). These fibers were going to be exploited later, being the first-generation optical fibers to be used at 870 nm. However, none of the solutions could find any satisfactory remedy to the attenuation problem.

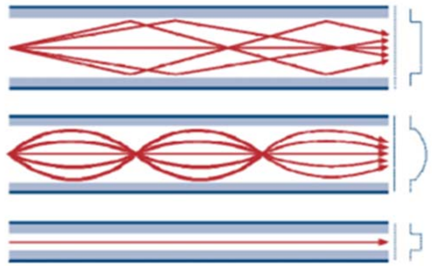
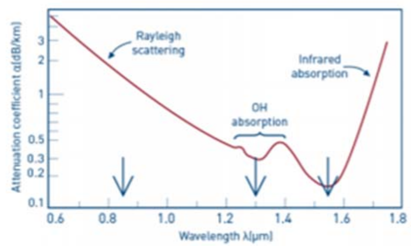


Fig. 2: Different types of fibers, step-index multimode, single mode and gradient index multimode. The propagation of a few rays is also indicated in red, as well as the distribution of the refractive index to the right.

Charles K. Kao was a young engineer at STL working on optical communication. He started under the direction of Karbowiak, and then became in charge of a small group, which at first had only one coworker, G.A. Hockham. Kao was born in 1933 in Shanghai, China, and educated in Hong-Kong. He graduated in Electrical Engineering in 1957 at University of London and got a PhD at the University of

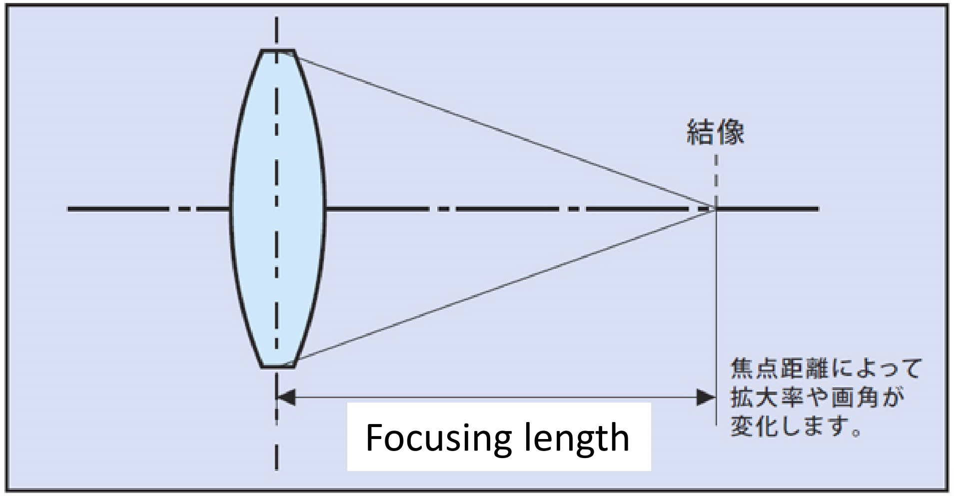


(2) Handling of LIGHT

Condensing(space)

index lens

parabolic mirror



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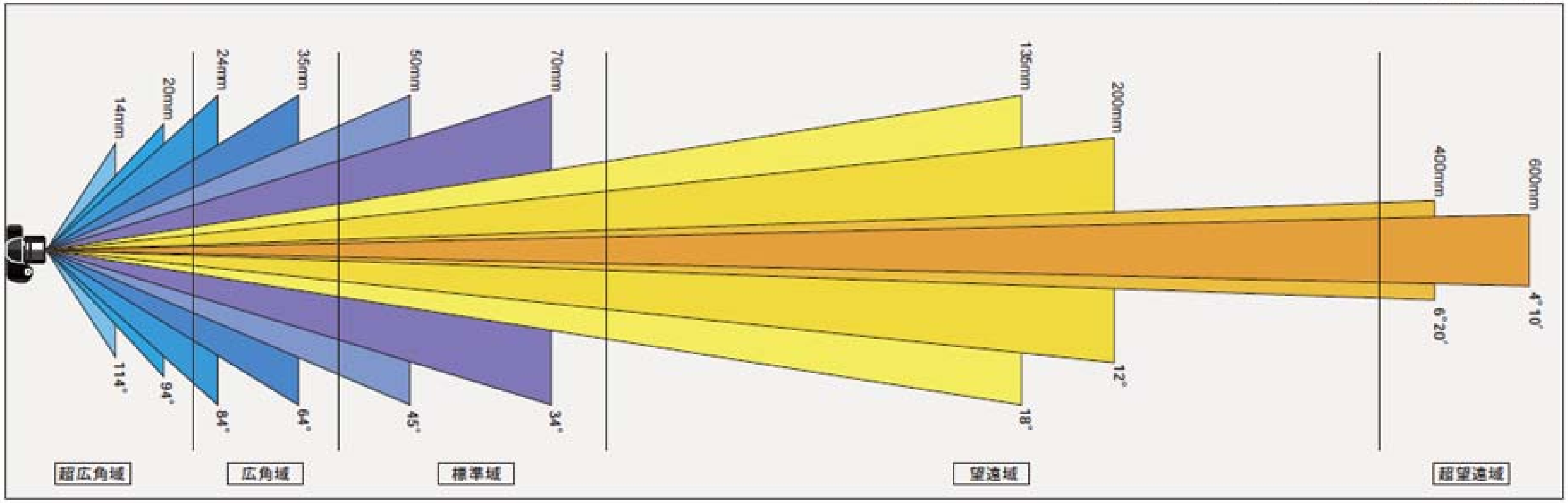
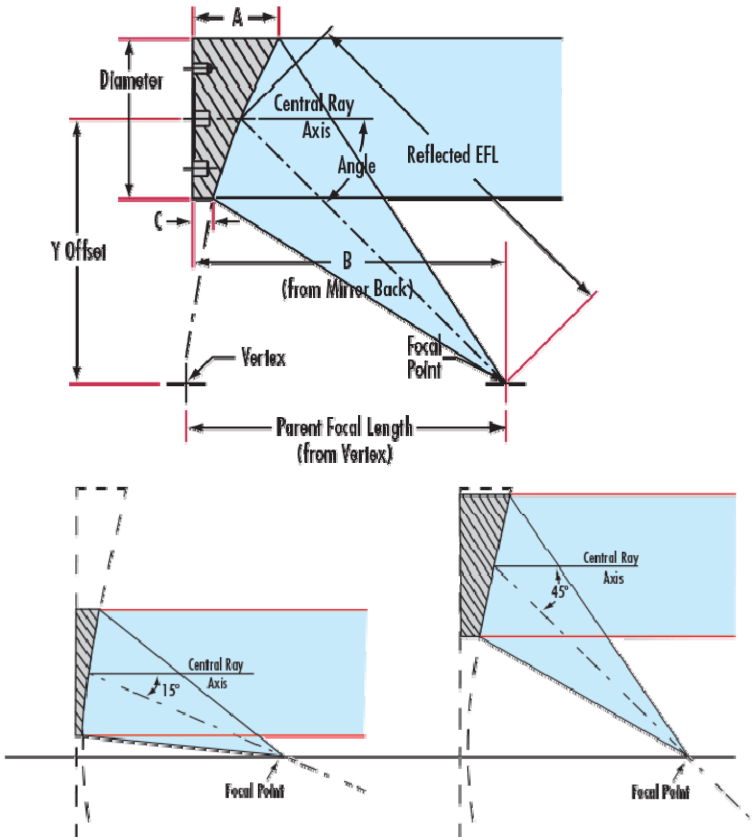


(2) Handling of LIGHT

Condensing(space)

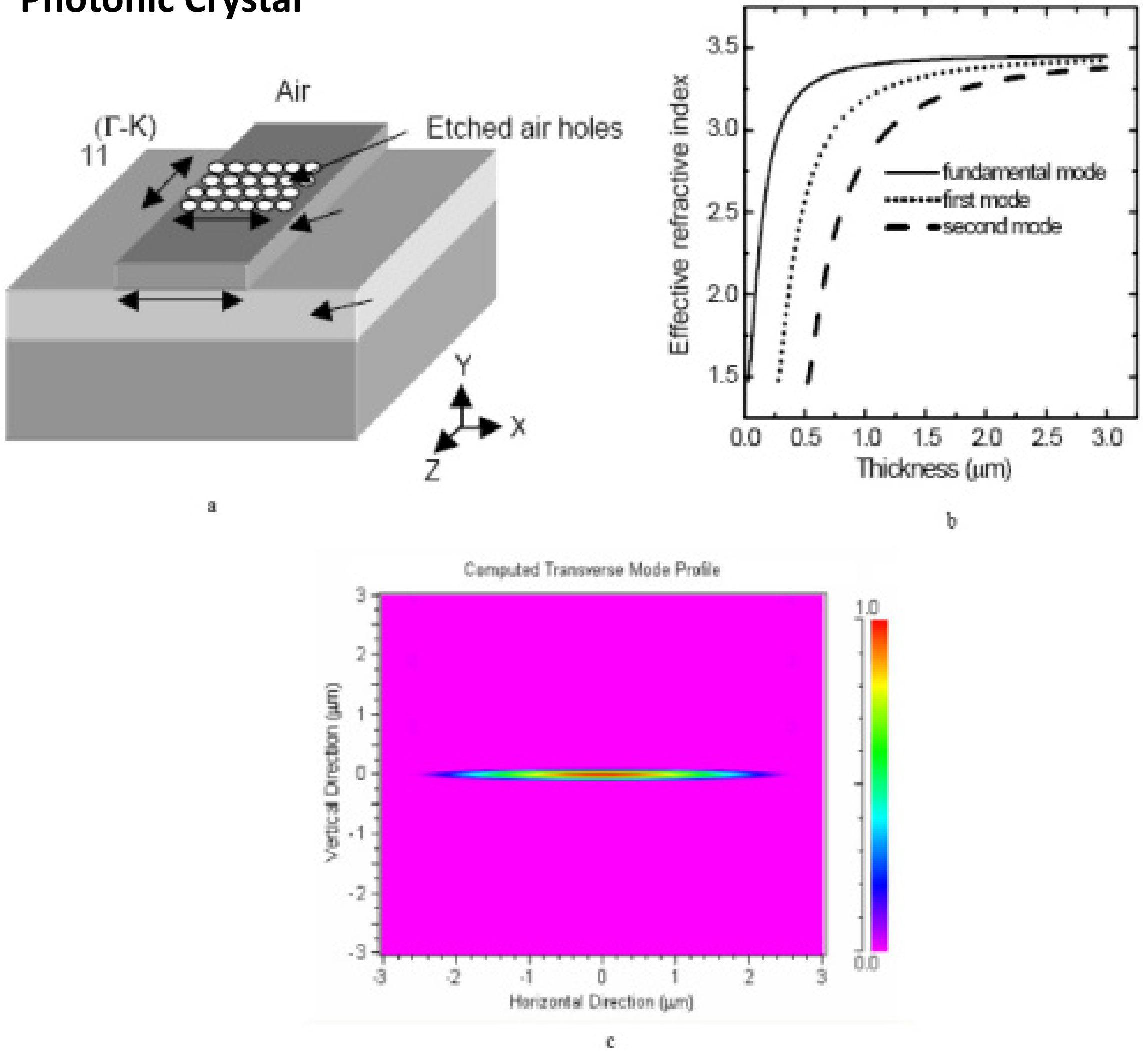
index lens
parabolic mirror

Off-Axis Parabolic Metal Mirrors



edmundoptics.jp

Photonic Crystal



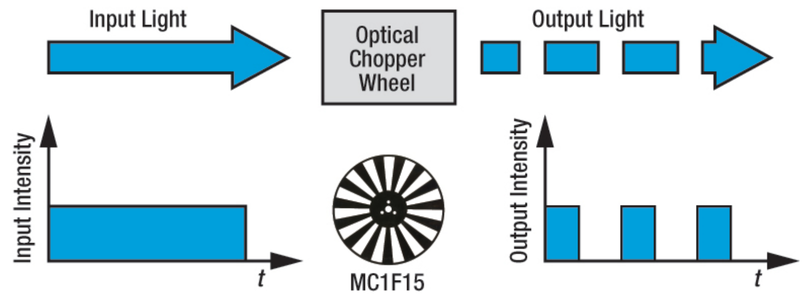
Optics Express Vol. 12, Issue 17, pp. 3934-3939 (2004)

(2) Handling of LIGHT

Condensing(time) / modulating

- *shutter*
- *mode lock*
- *Q-switching*

ms



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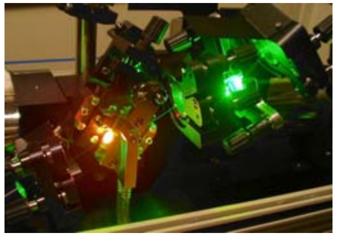

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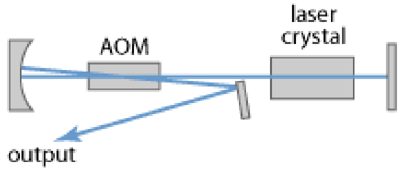
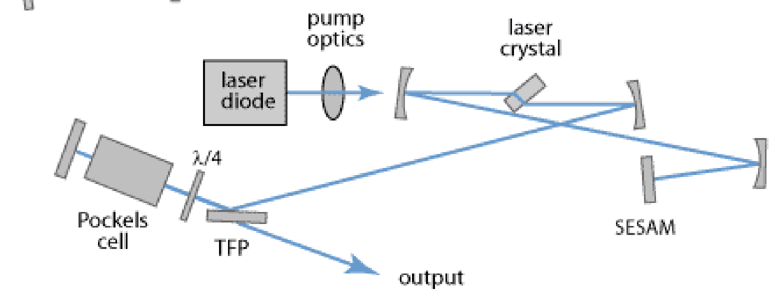

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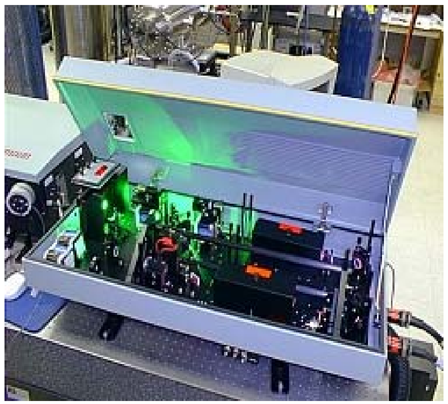

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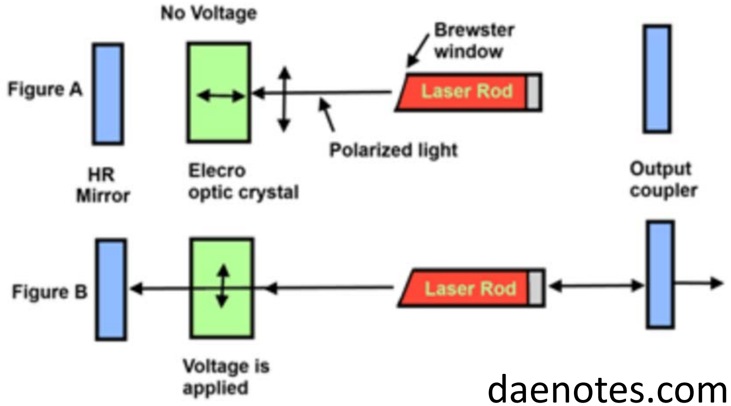

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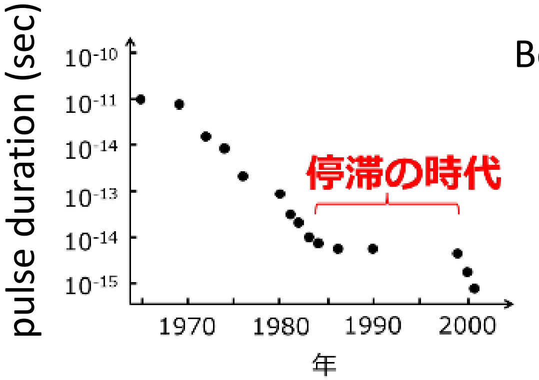
(2) Handling of LIGHT

Condensing(time) / modulating

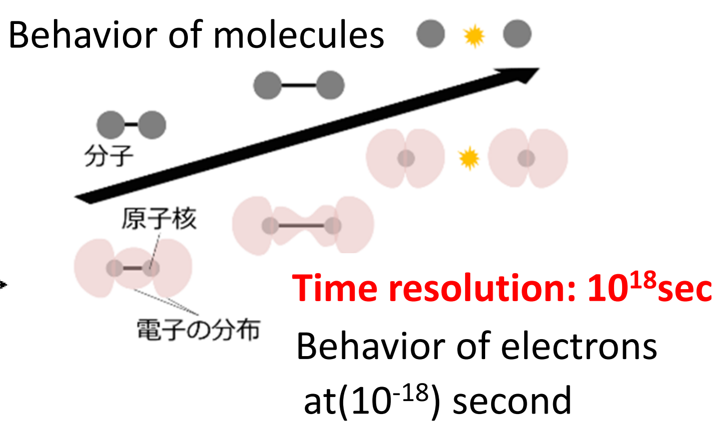
- shutter
- mode lock
- Q-switching

Nobel Prize in Chemistry 1999
Ahmed Zewail

investigation of fundamental chemical reactions, using ultra-short laser flashes, on the time scale on which the reactions actually occur.



Until now



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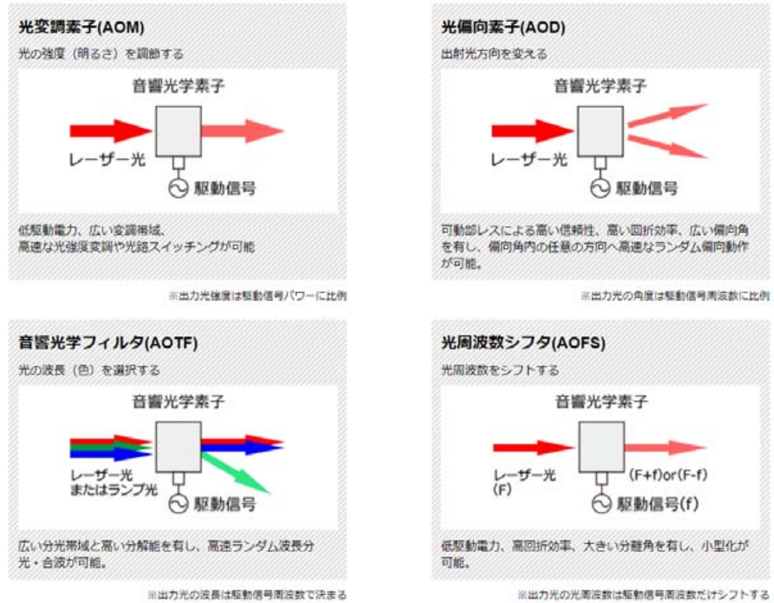
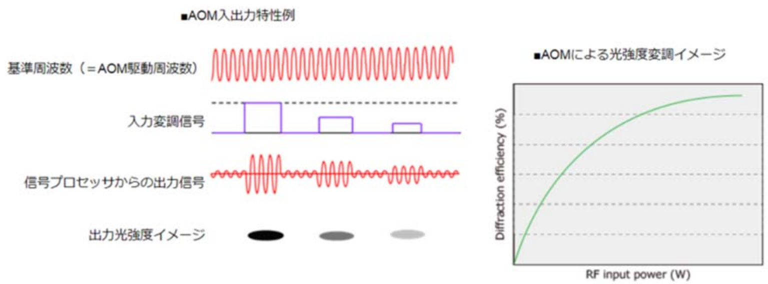
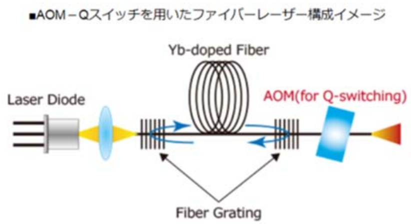


高速な光強度変調やスイッチングが可能なため、
・固体レーザー光源の強度変調
・パルスファイバーレーザー用Qスイッチ
などに利用されている。





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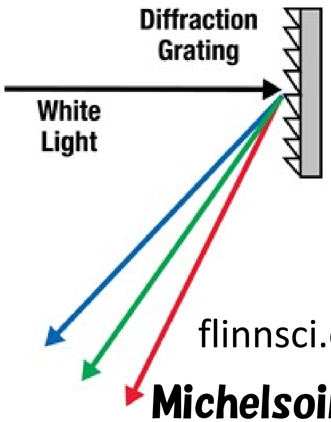
(2) Handling of LIGHT

Amplification

- ***stimulated emission in fiber***
- ***Raman effect***

Selecting

- ***filter***
- ***grating***
- ***interference***
- ***Raman effect***



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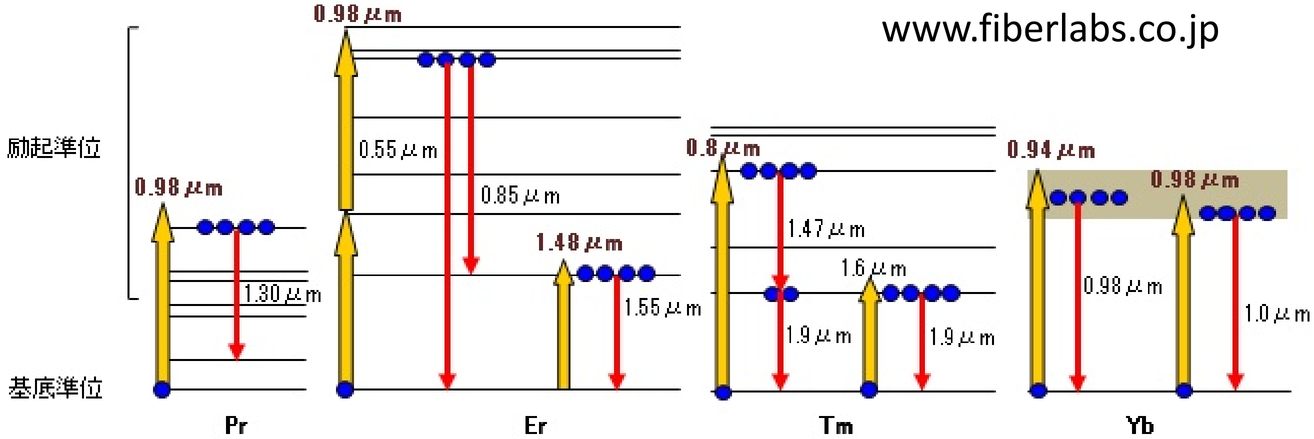
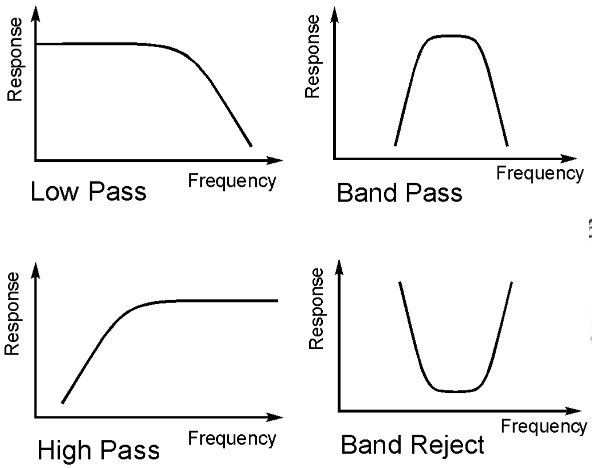


www.fiberlabs.co.jp

Filter



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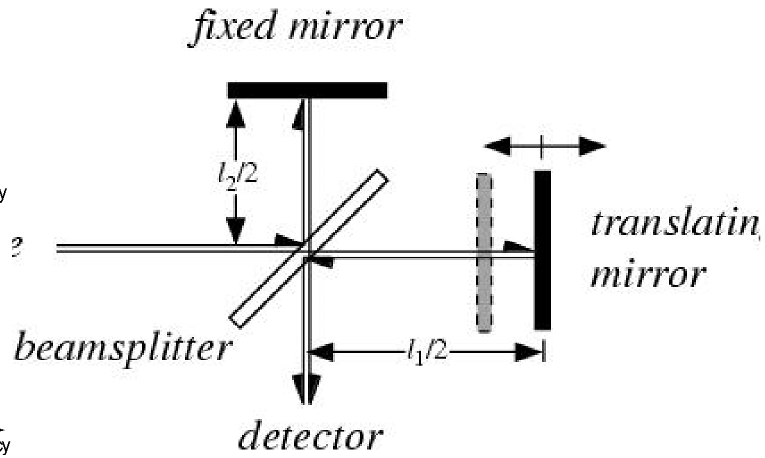
Michelsointerferometer



http://hank.uoregon.edu

Fabry-Perot interferometer

physik.uni-siegen.de

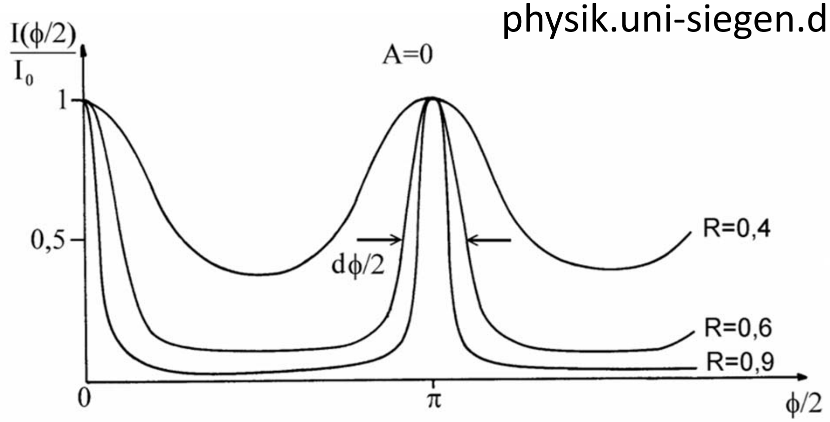


Figure 3: Airy function for different reflection coefficients R

(2) Handling of LIGHT

Amplification

stimulated emission in fiber

Raman effect

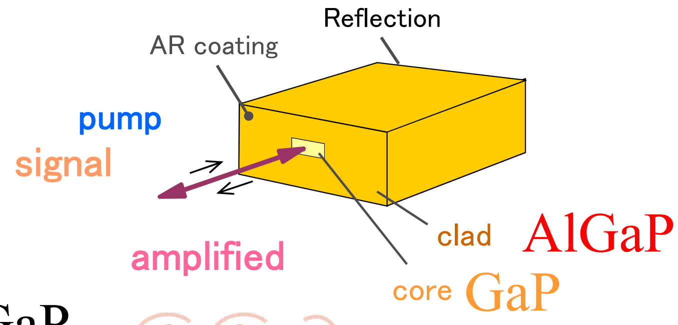
Selecting

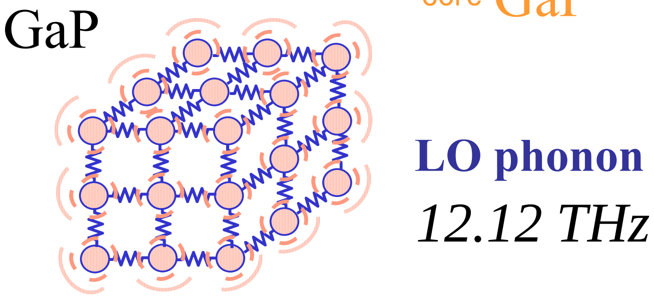
filter

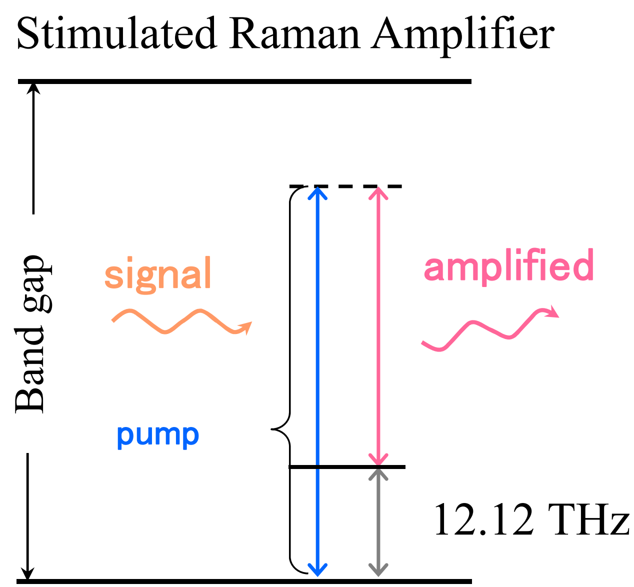
grating

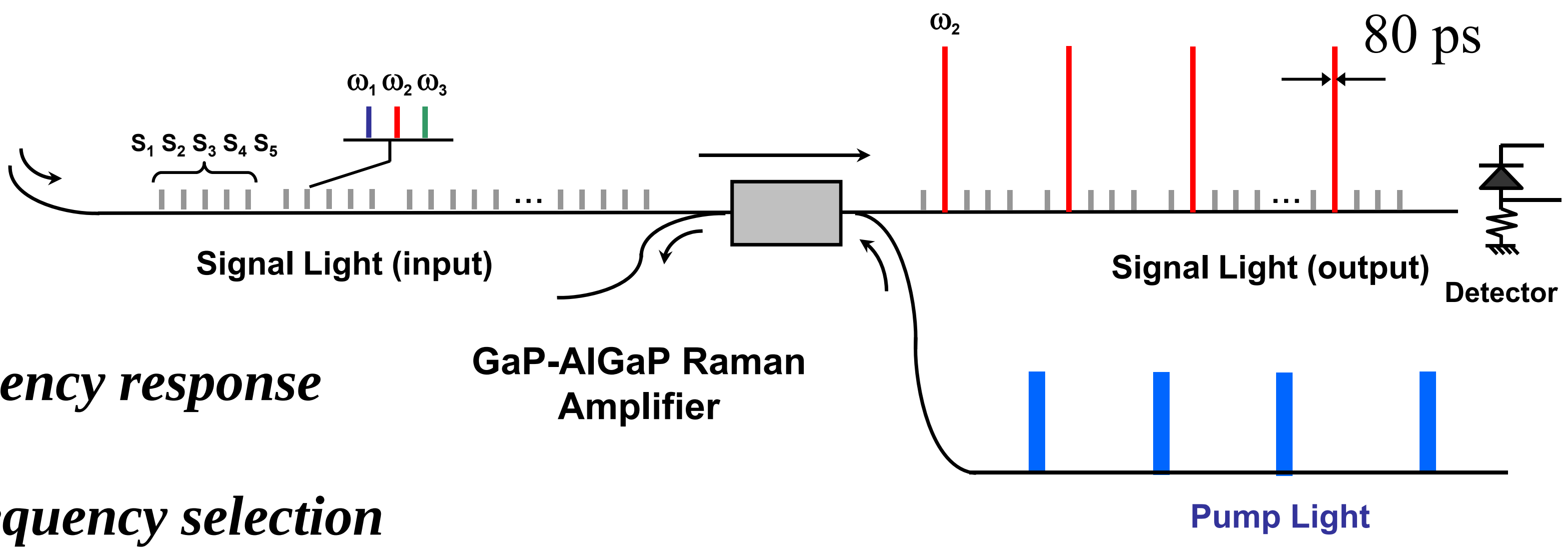
interference

Raman effect









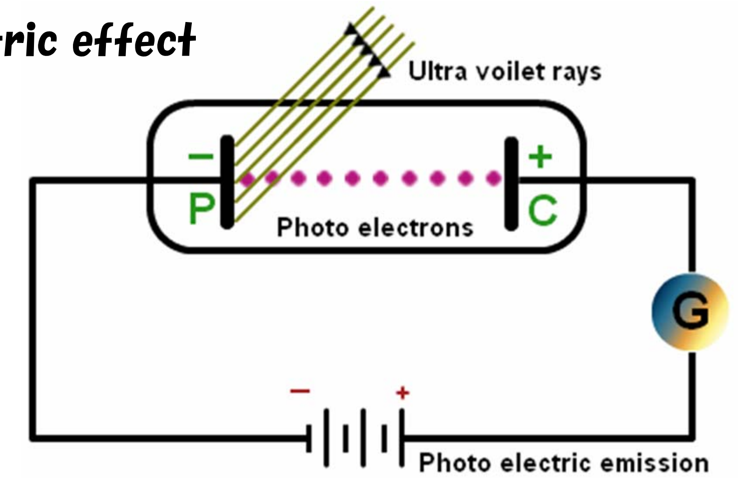
- *high-frequency response*
- *high gain*
- *narrow-frequency selection*

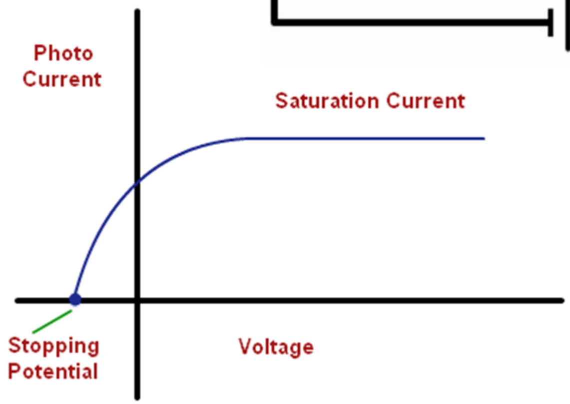
(2) Handling of LIGHT

Detecting

- photoelectric effect
- energy gap in semiconductor
- bolometer / pyroelectric effect

photoelectric effect





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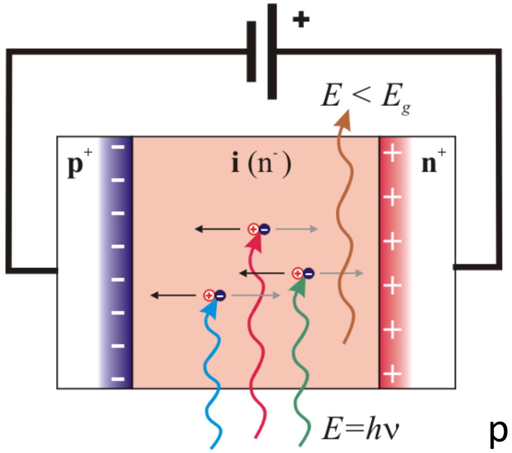
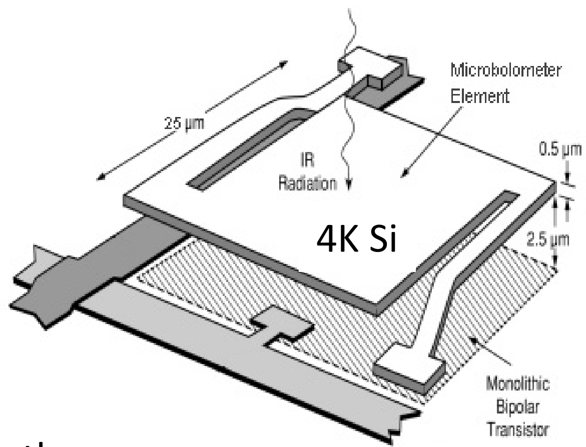
energy gap in semiconductor



physicsopenlab.org

bolometer / pyroelectric effect



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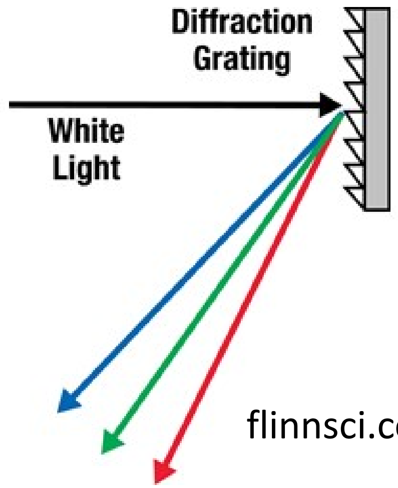
(3) Understanding of LIGHT conditions

wavelength/frequency
linewidth
pulse duration :propagation distance
beam mode
polarization
power density :beam diameter



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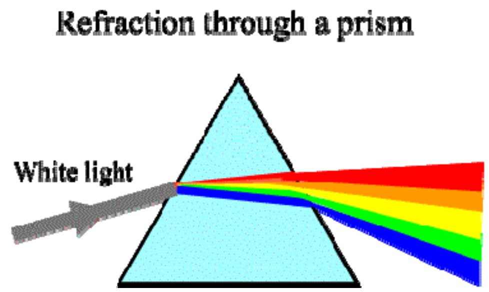
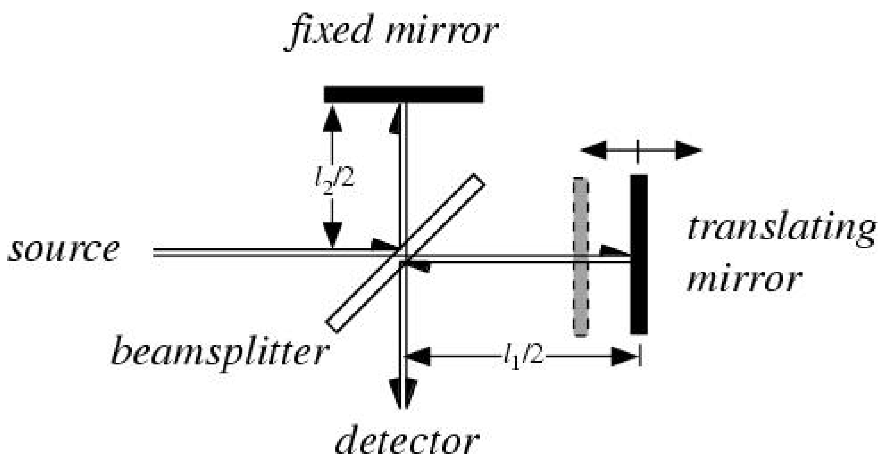


physics.louisville.edu

Michelsointerferometer



http://hank.uoregon.edu

Fabry-Perot interferometer

physik.uni-siegen.de

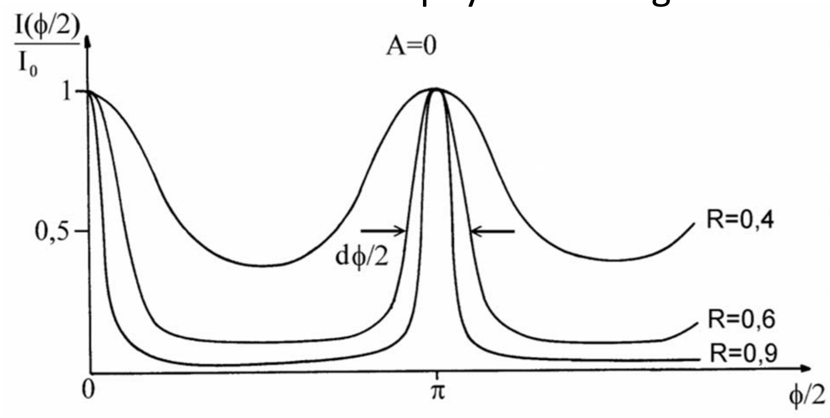
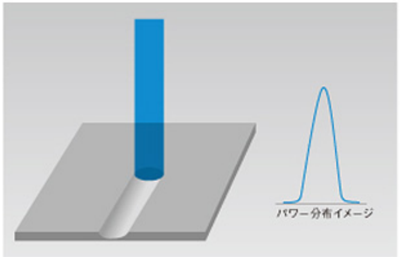


Figure 3: Airy function for different reflection coefficients R

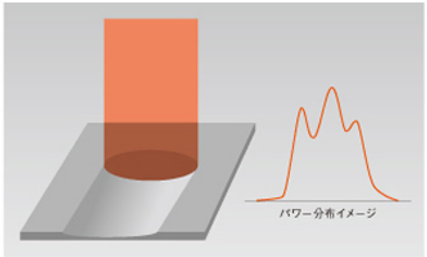
(3) Understanding of LIGHT conditions

wavelength / frequency
linewidth
pulse duration
beam mode
polarization
***power density** :beam diameter*

single mode



multi mode



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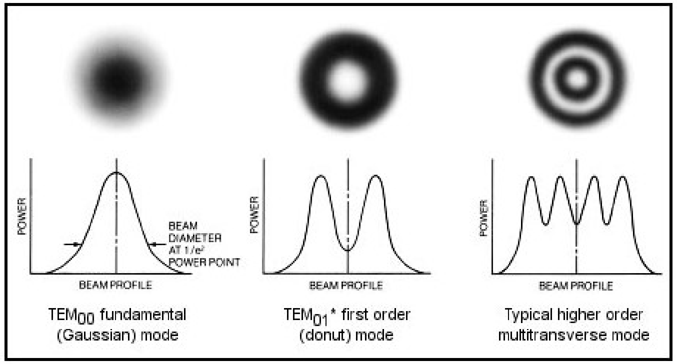
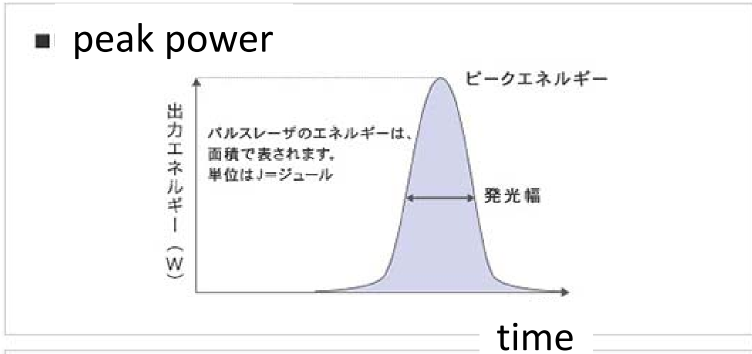
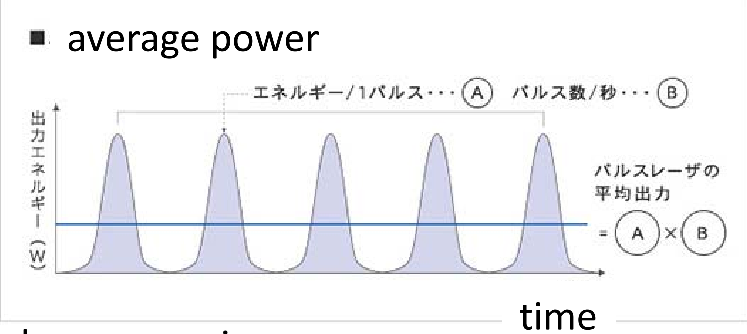
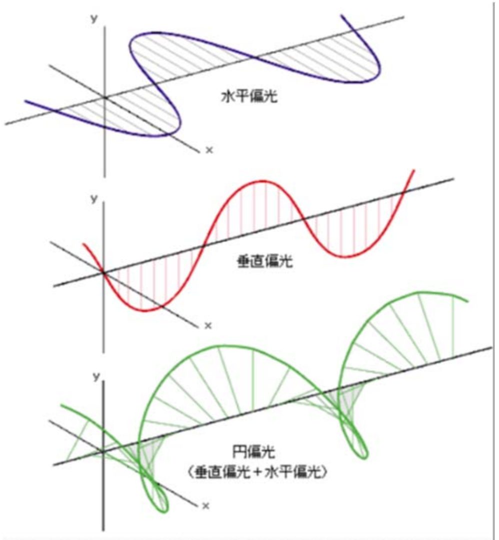


jp.laserto.com





keyence.co.jp



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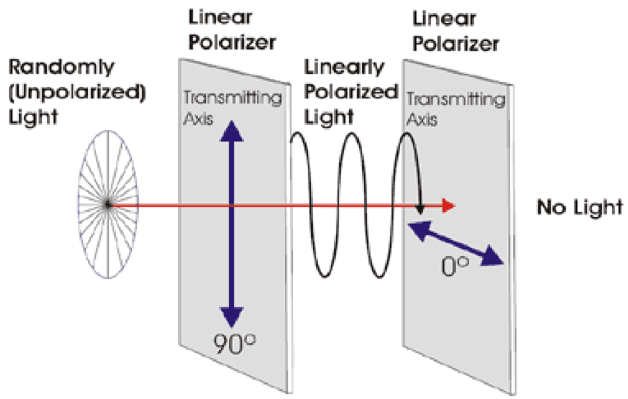
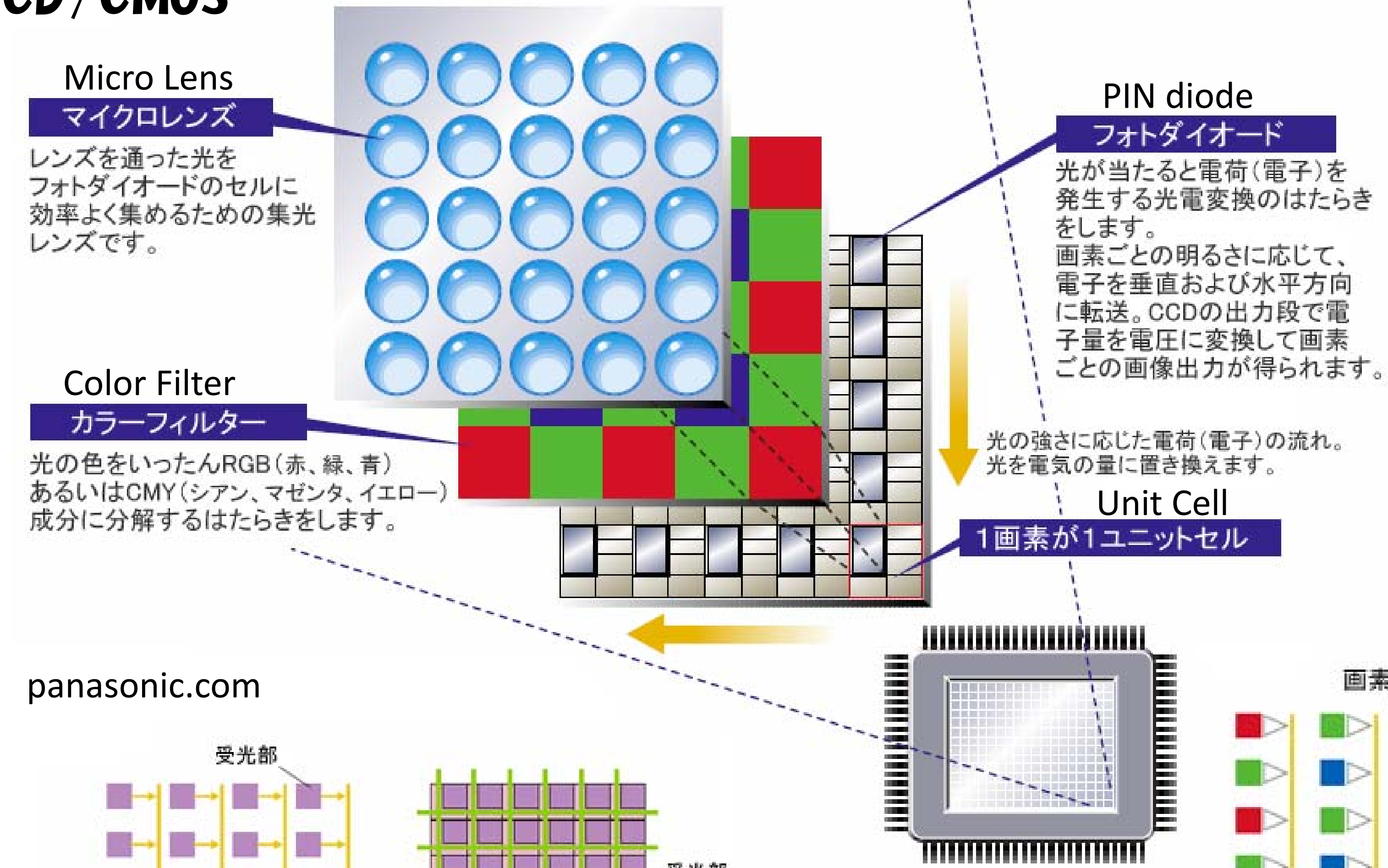
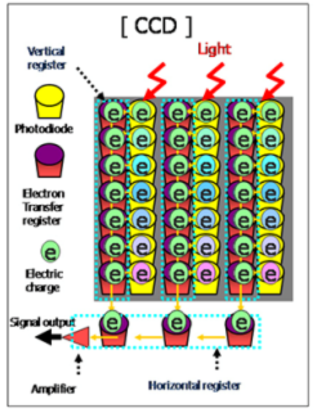
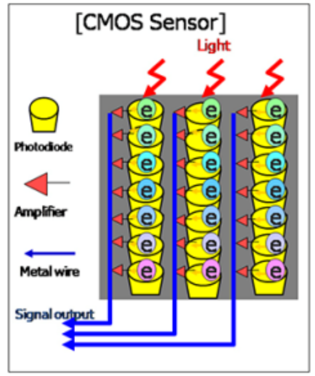


apioptics.com

CCD / CMOS







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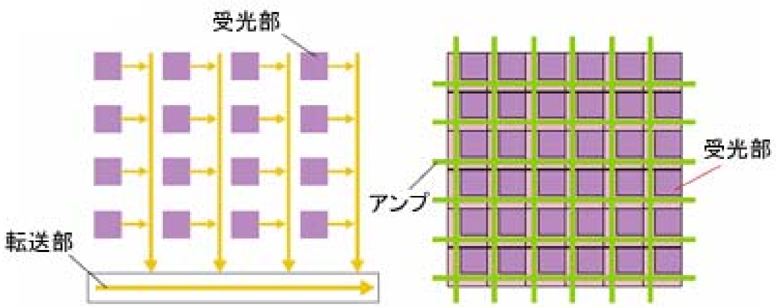
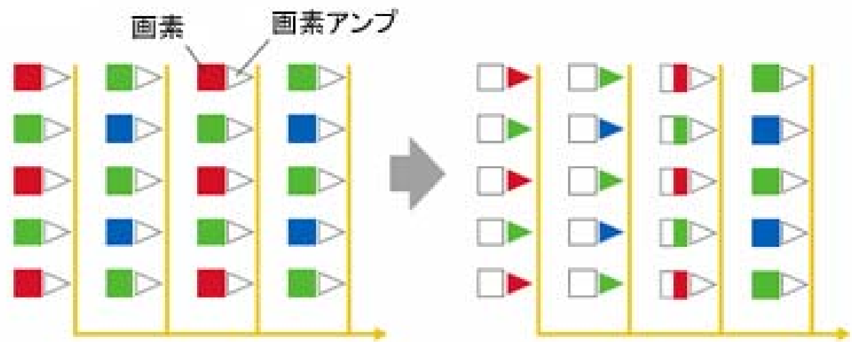
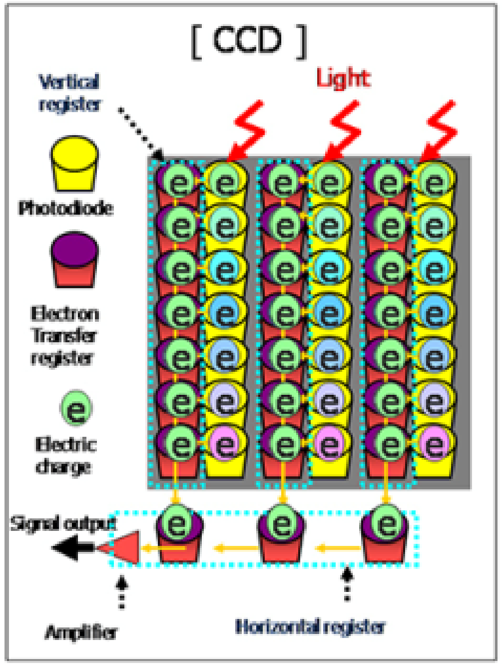
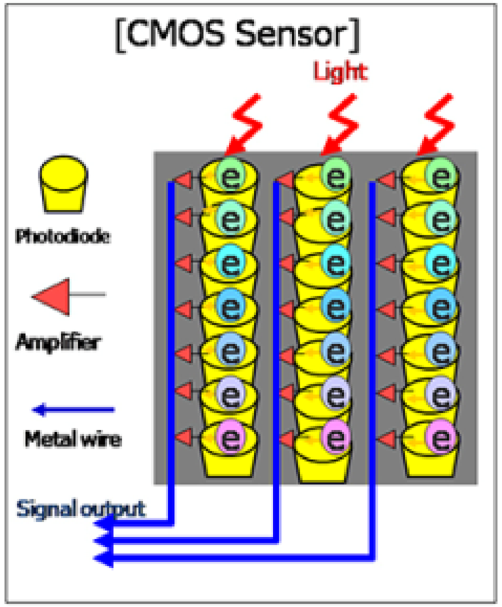


Charge Coupled Device



Complementary Metal Oxide Semiconductor





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