Materials Science of Electronic and Optoelectronic Devices

Tadao Tanabe

Nov. 16 : Photonic Device-Basic

Nov. 23 : Photonic Device-Basic, Application

Nov.30 Examination

Basic of Photonic devices (Tanabe)

2018/11/23

(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

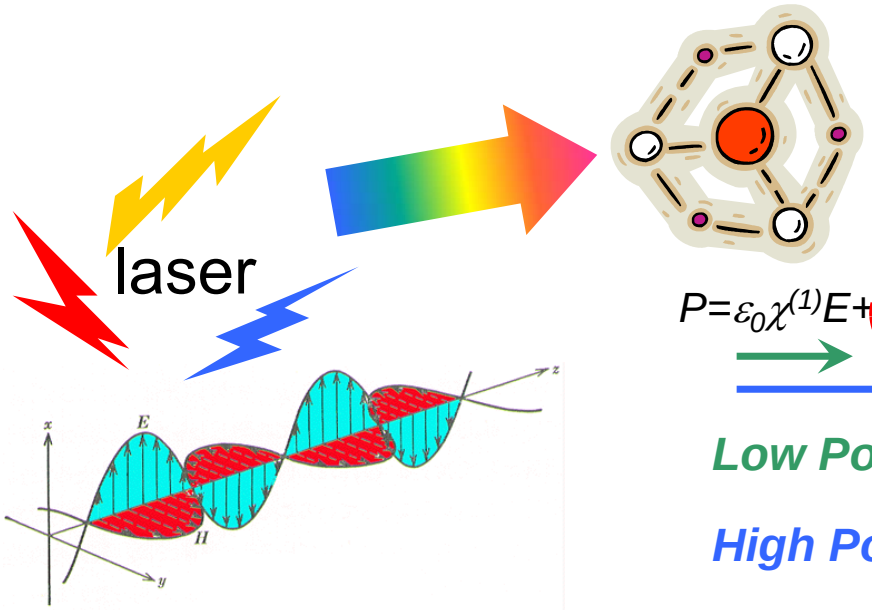
(4) Photonic Technology

(5) Applications

(2) Handling of LIGHT

Generation

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

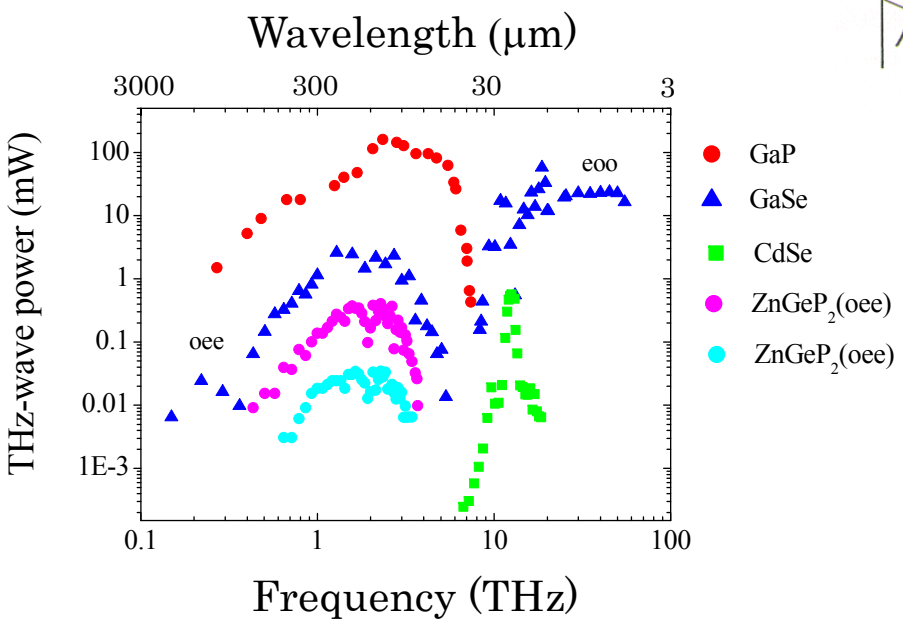


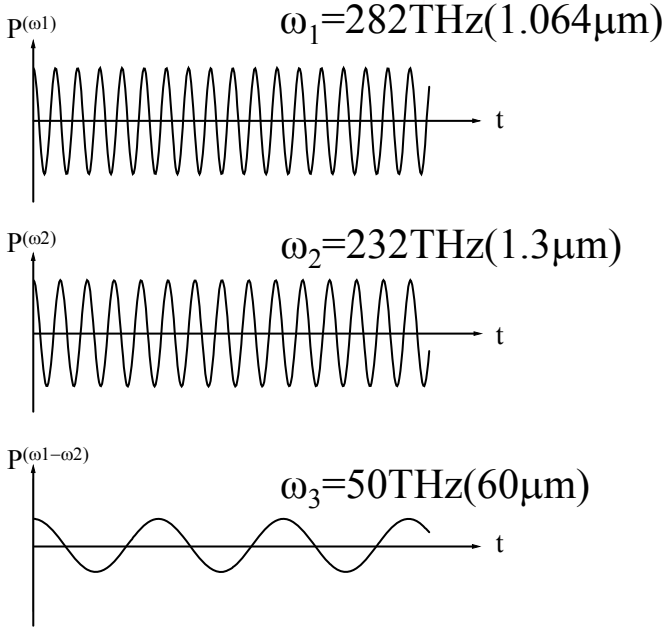
$$P=\varepsilon_0\chi^{(1)}E+\varepsilon_0\chi^{(2)}E^2+\varepsilon_0\chi^{(3)}E^3+\cdots$$

Low Power : Linear

High Power: nonlinear

difference-frequency generation (DFG)





(2) Handling of LIGHT

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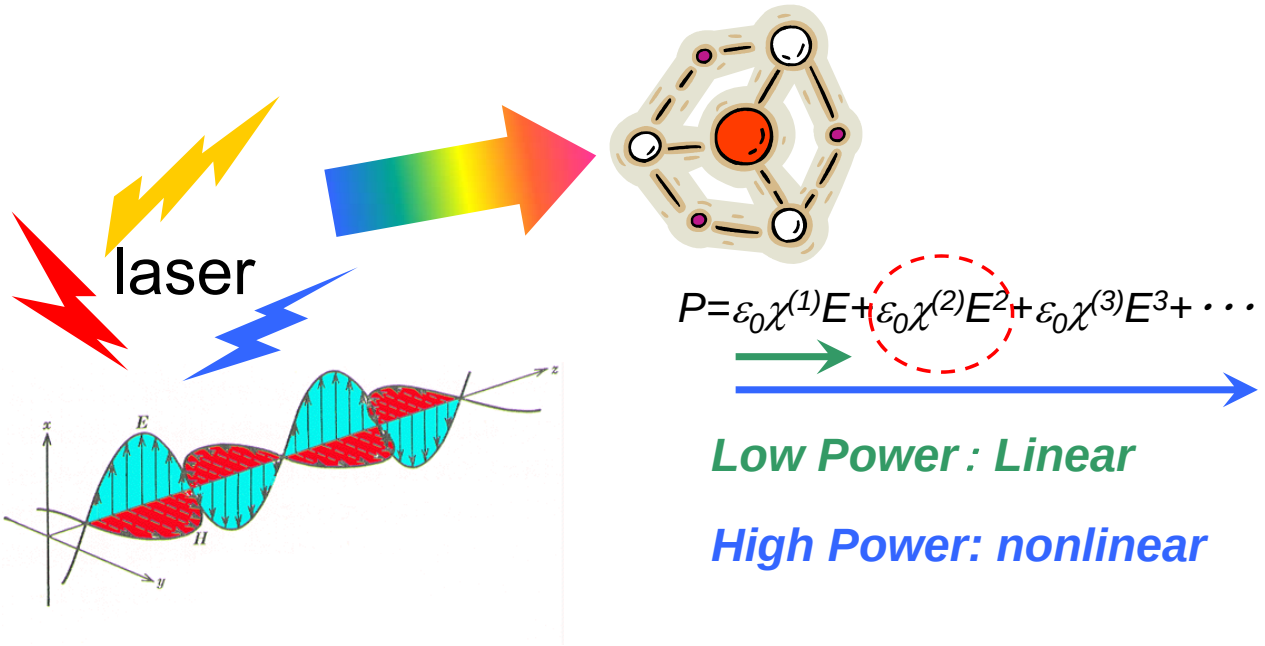
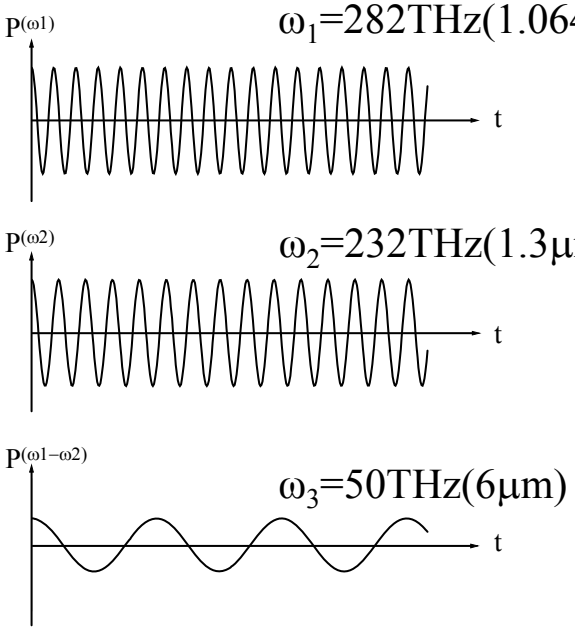


difference-frequency generation (DFG)



DFG ω_3=50THz(6μm)

SFG ω_3=514THz(0.584μm)

THG:846THz(0.354μm)

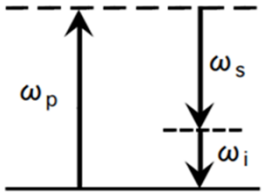
SHG1 ω_3=564THz(0.532μm)

FHG:1128THz(0.266μm)

SHG2 ω_3=464THz(0.647μm)

SHG@1961

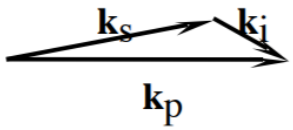
Michigan Univ. P.A. Franken、A.E. Hill、C.W. Peters, G. Weinreich



energy conservation law

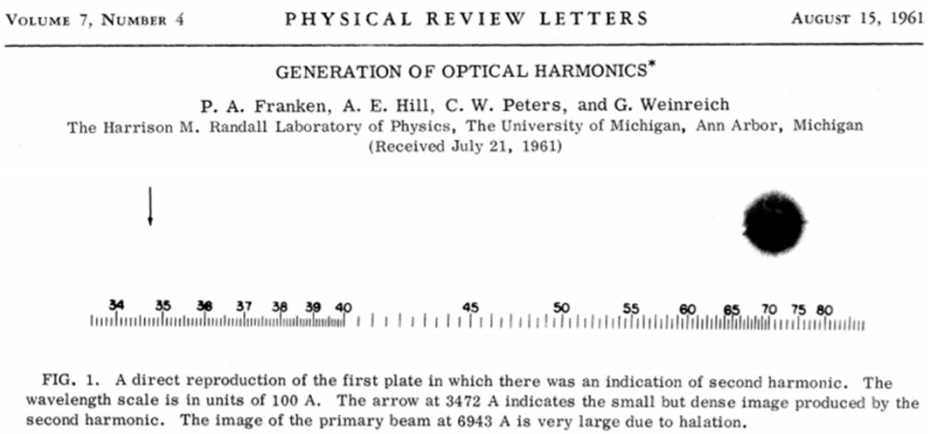
$\omega_p = \omega_s + \omega_i$

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



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 (3×10^8m/s)

λ: wavelength

(2) Handling of LIGHT

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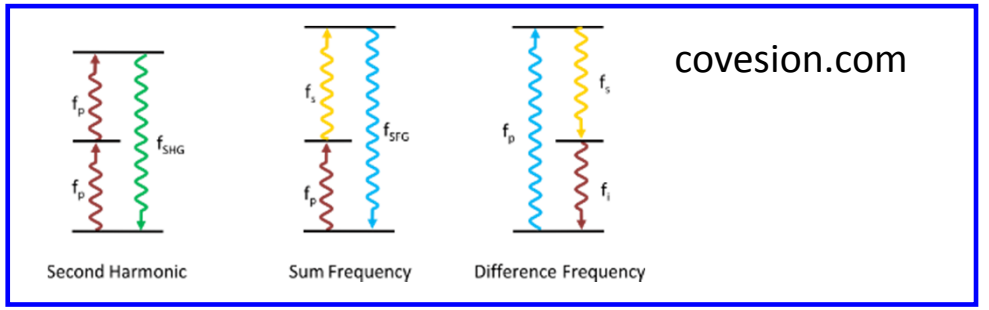
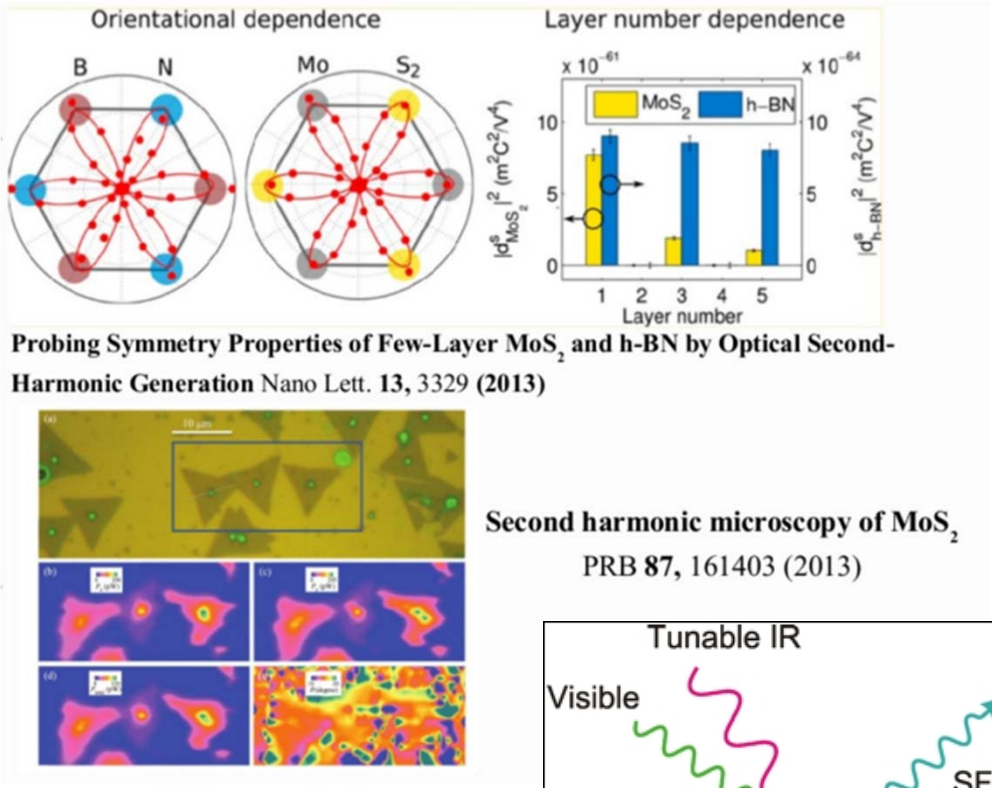


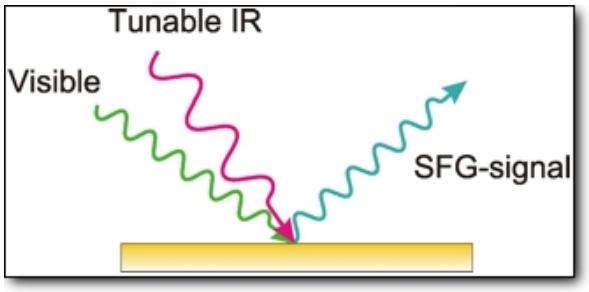
covesion.com



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)



Claudio Attaccalite, CNRS researcher at Neel Institute Grenoble

nb.uw.edu

(2) Handling of LIGHT

Generation

- heating
- energy gap in semiconductor
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  (frequency-mixing: DFG, SFG, SHG)

Transactions of Japanese Society for Medical and Biological Engineering
Vol. 55 (2017) No. 2 p. 91-96

Quantitative Evaluation of Collagen Fiber Structure in Human Dermis Based on Two-Dimensional Auto-Correlation Analysis of SHG (Second Harmonic Generation) Image

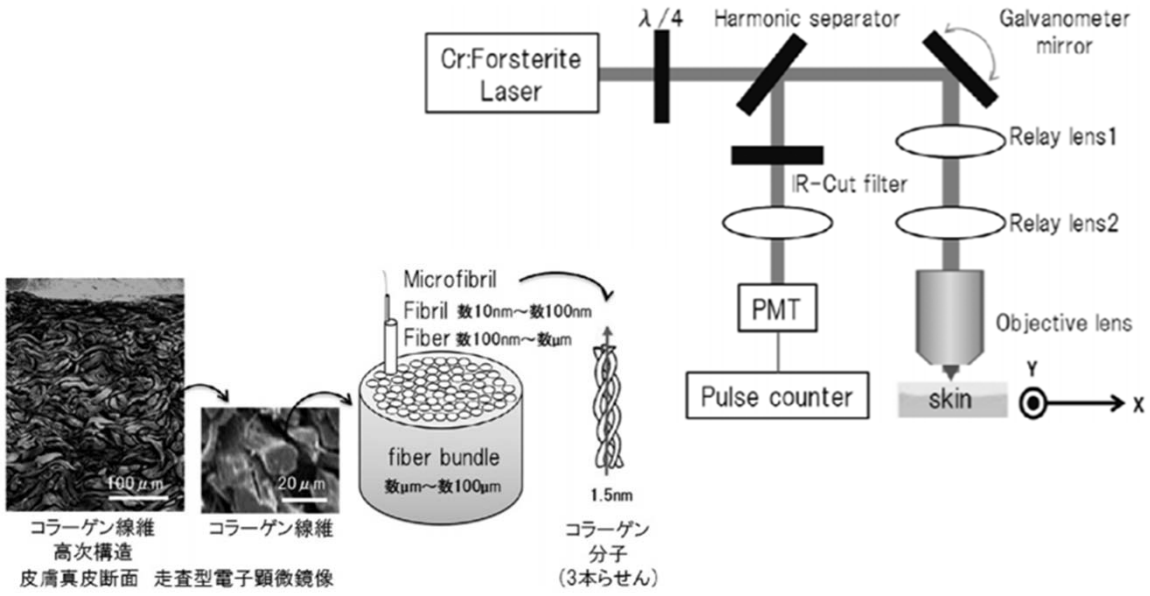


図 1　コラーゲン線維の高次構造.
Fig. 1　Hierarchical structure of collagen fiber.

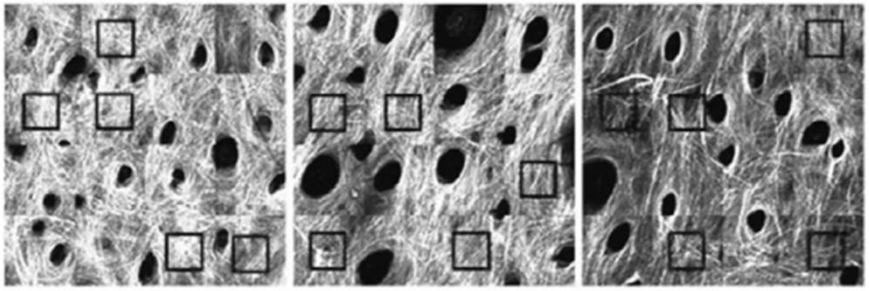


図 6　各年代被験者における頬皮膚の大面積 SHG イメージと画像解析に用いた領域（黒枠）.

Fig. 6　Large-area SHG images (image size = 1.6 mm × 1.6 mm, pixel size = 512 pixel × 512 pixel), probing depth (= 70–100 μm from epidermis) of subjects in their 20s, 40s, and 60s. Black holes indicate appendages (including hair follicles)

(2) Handling of LIGHT

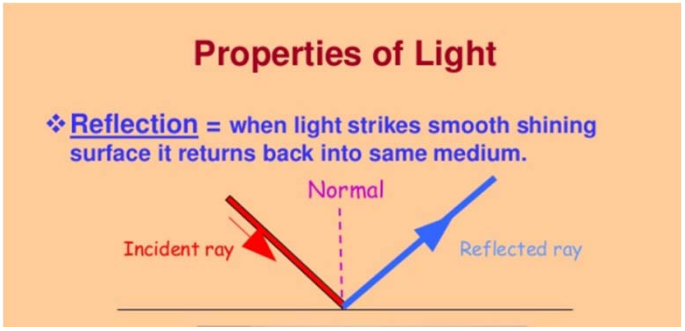
Propagation :absorption

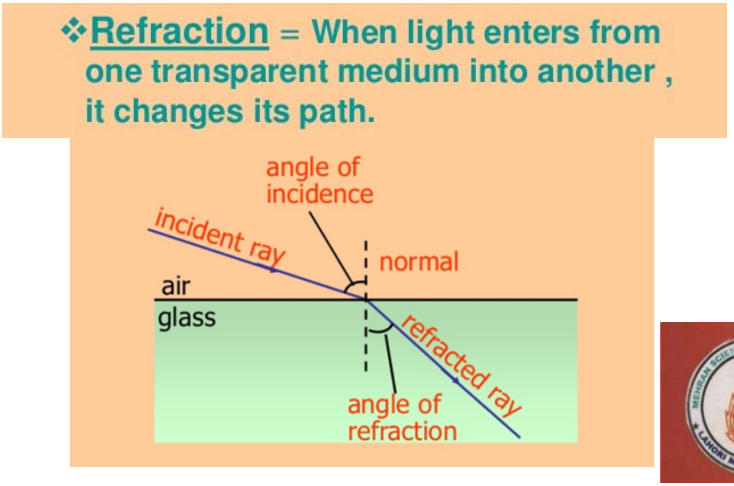
in air, liquid and solid

:reflection, refraction, diffraction, absorption and scattering

waveguide

optical fiber



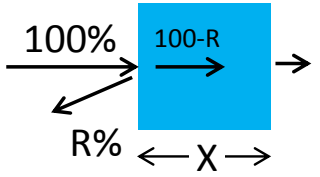


Absorption

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

T : Transmittance

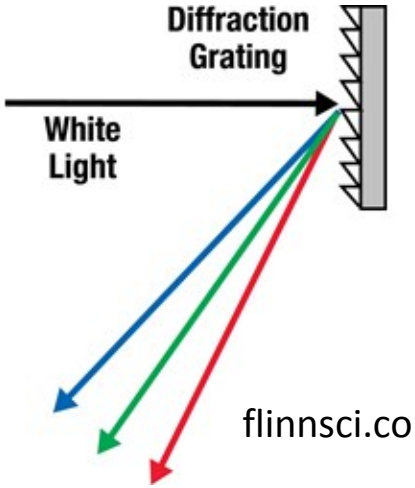
X_1, x_2 : Thickness



T%（measurement）

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

Diffraction



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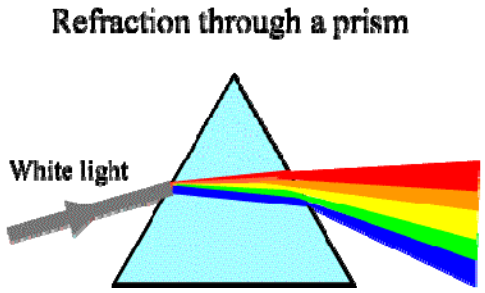


physics.louisville.edu

(2) Handling of LIGHT

Propagation :absorption

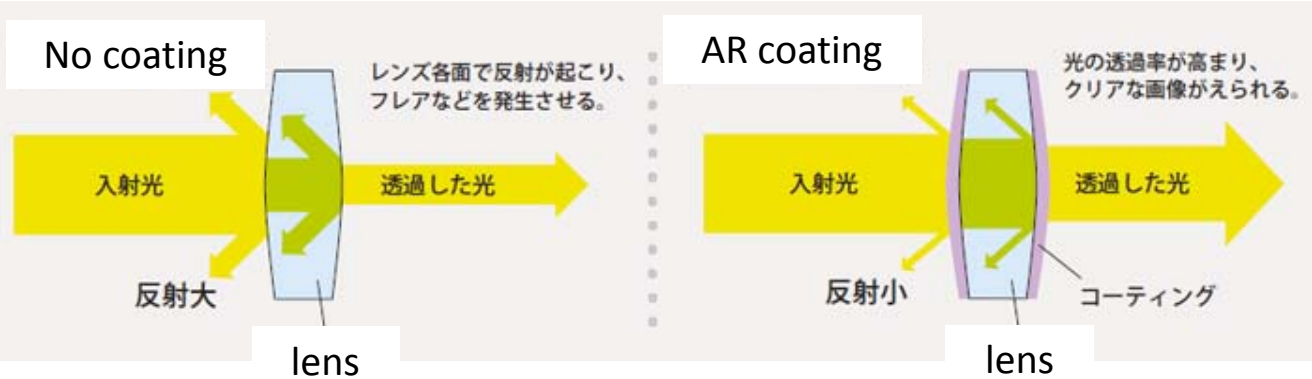
in air, liquid and solid

:reflection, refraction, diffraction, absorption and scattering

waveguide

optical fiber

Anti-Reflection coating



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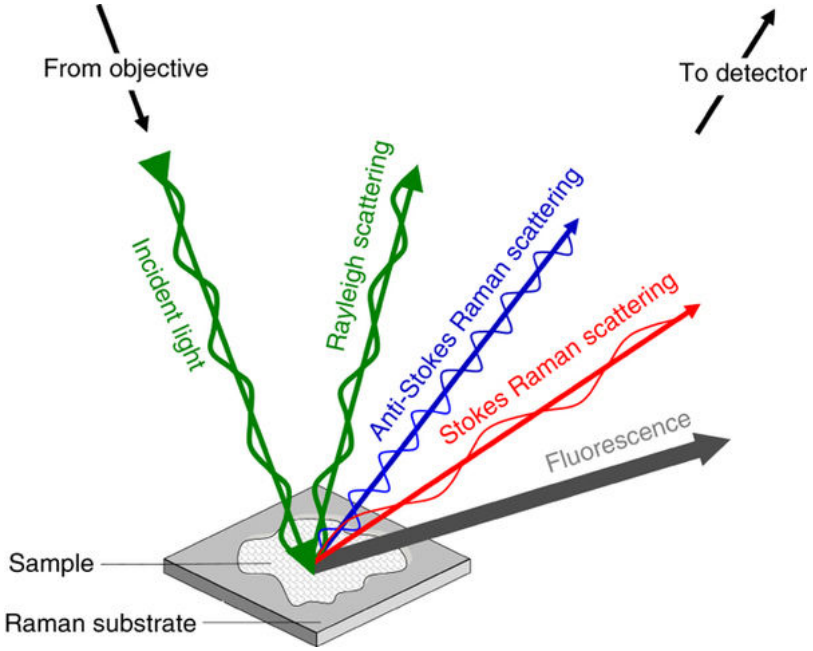
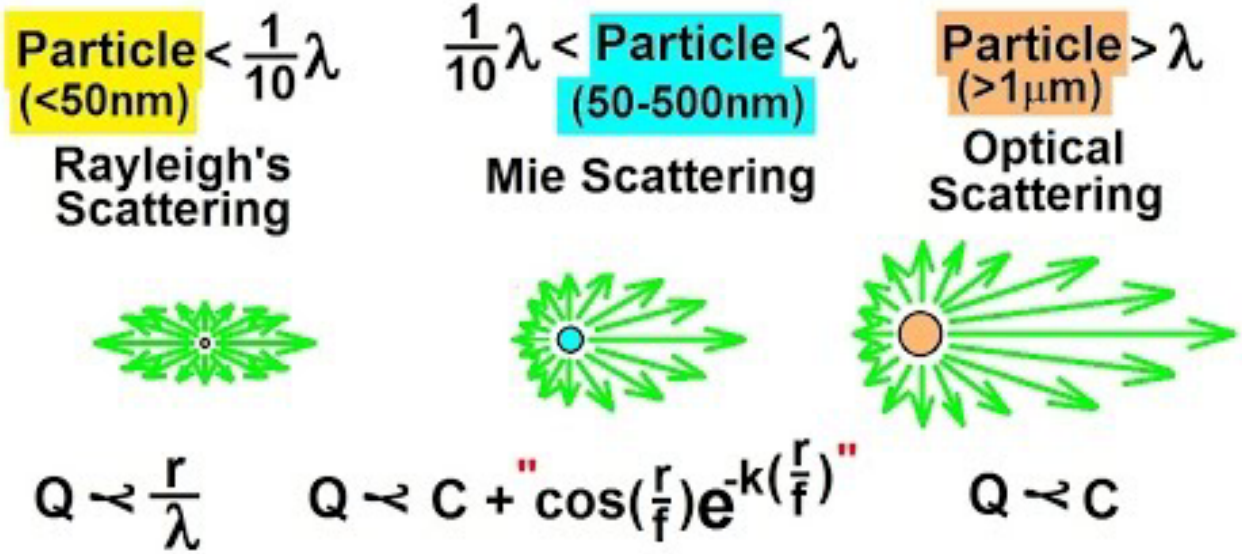


Nature Protocols 11, 664–687 (2016)



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SUNSET

white clouds

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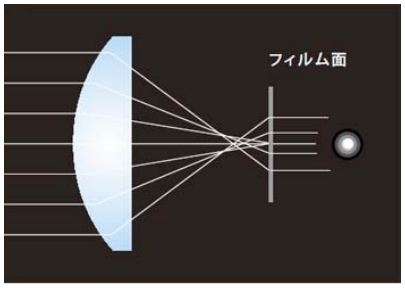
(2) Handling of LIGHT

Condensing(space)

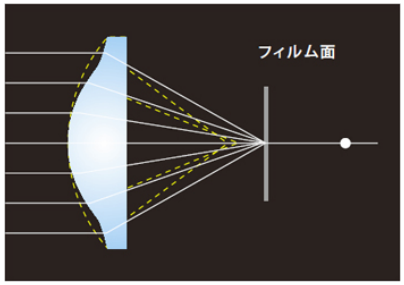
index lens

parabolic mirror

Spherical Lens



Aspherical Lens



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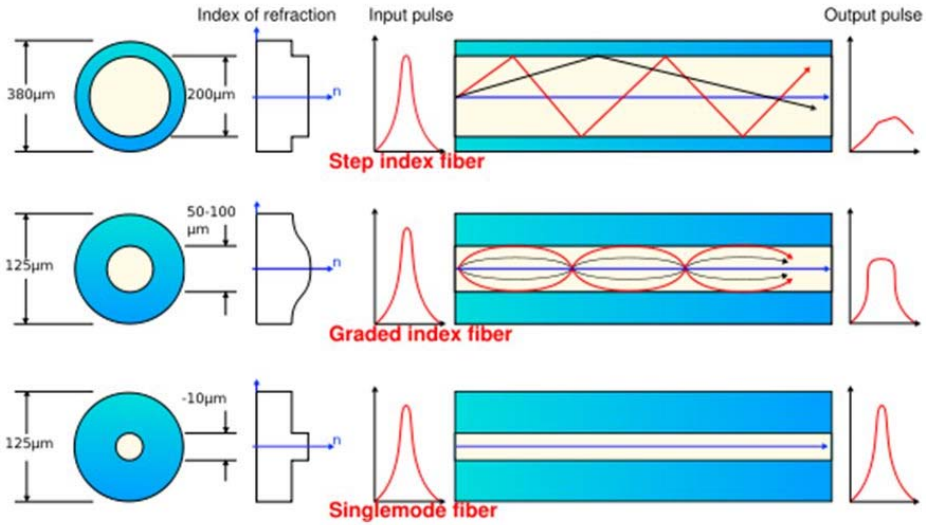


Standardní optická vlákna

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.

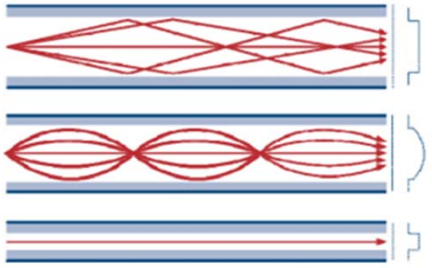
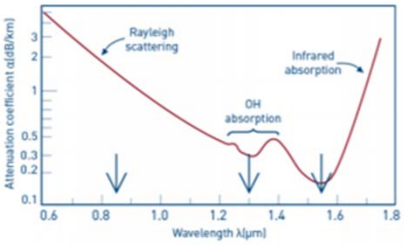


Fig. 2: Different types of fibers, step-index multimode, single mode and gradient index multimode. The propagation of a few rays is also indicated in red, as well as the distribution of the refractive index to the right.

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

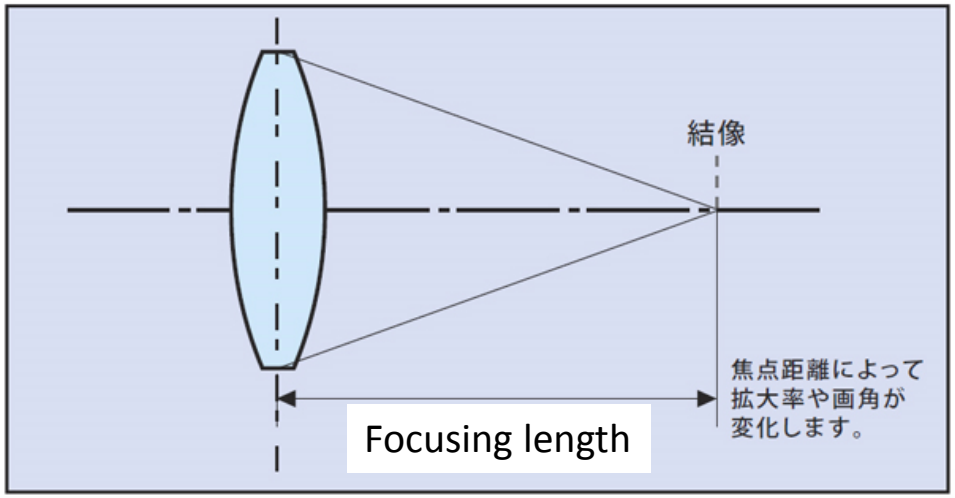


(2) Handling of LIGHT

Condensing(space)

index lens

parabolic mirror



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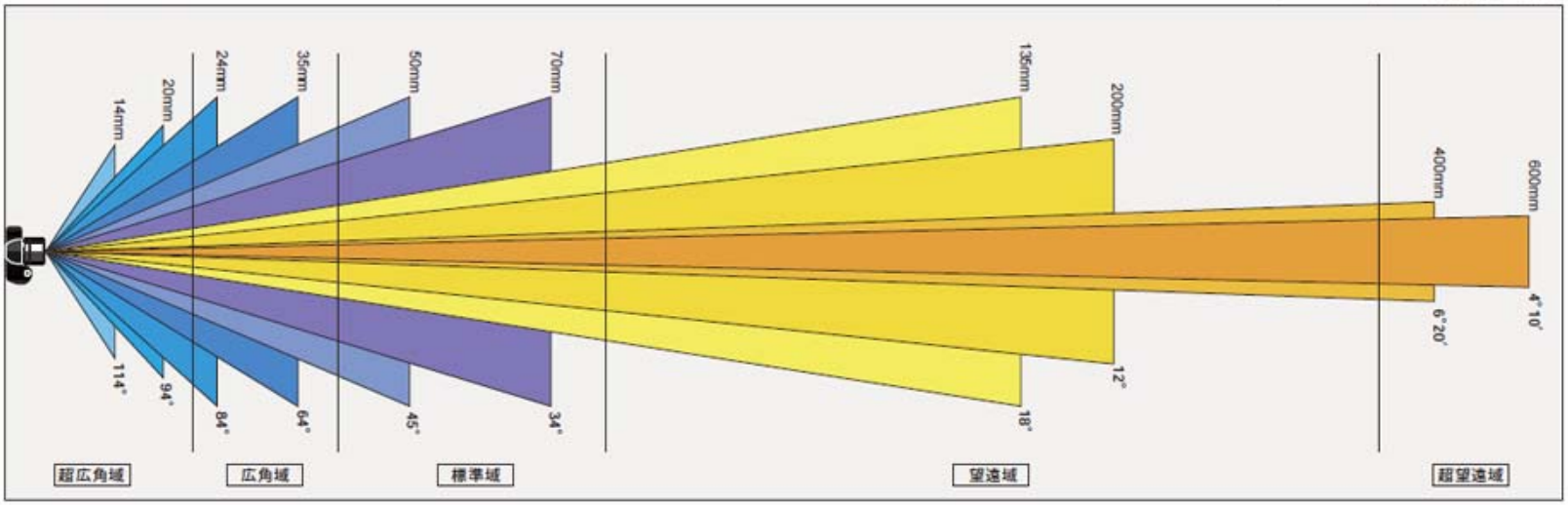
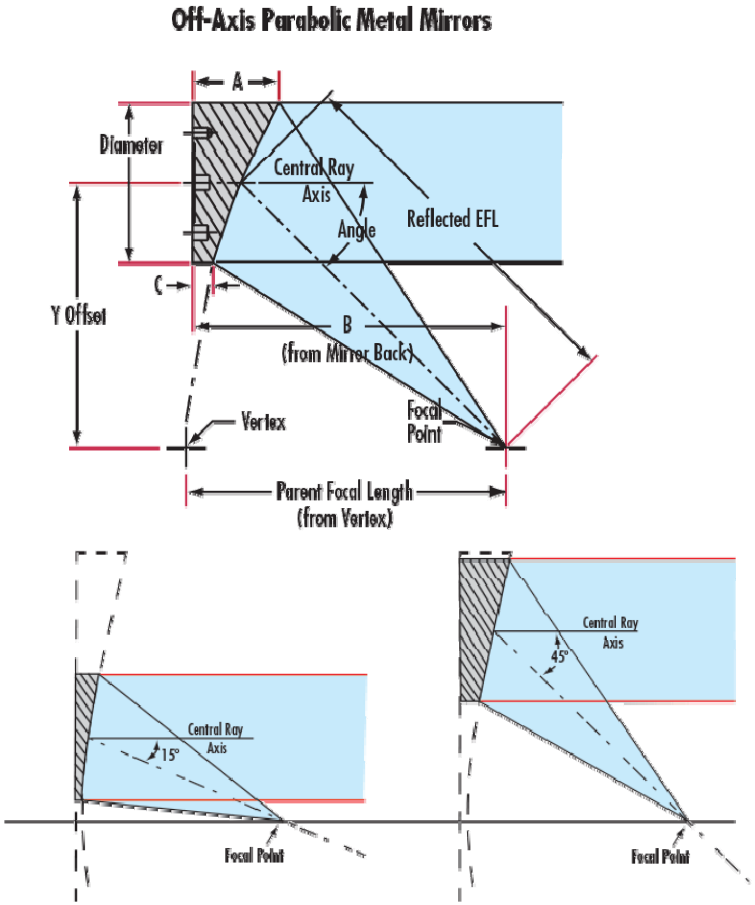


(2) Handling of LIGHT

Condensing(space)

- index lens
- parabolic mirror



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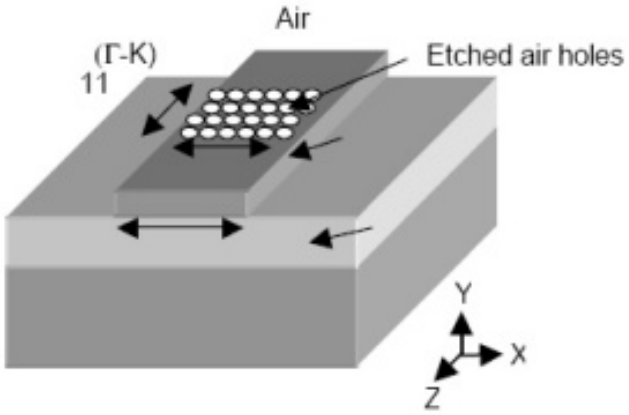
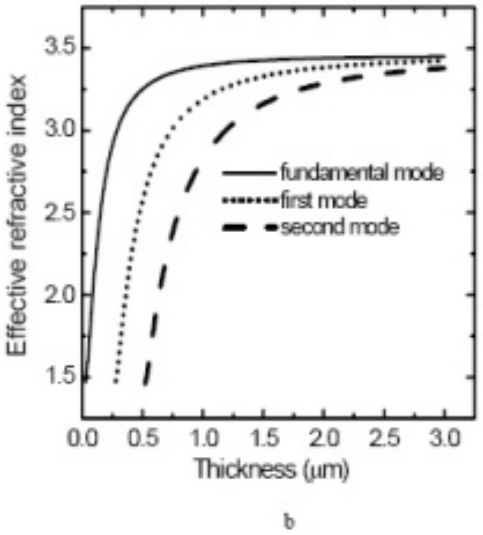
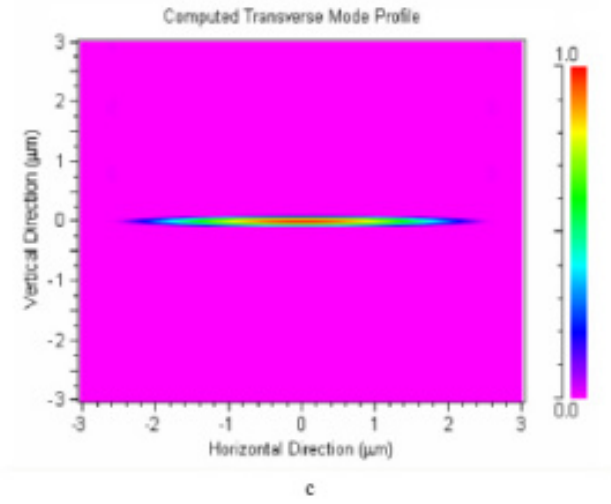
Photonic Crystal







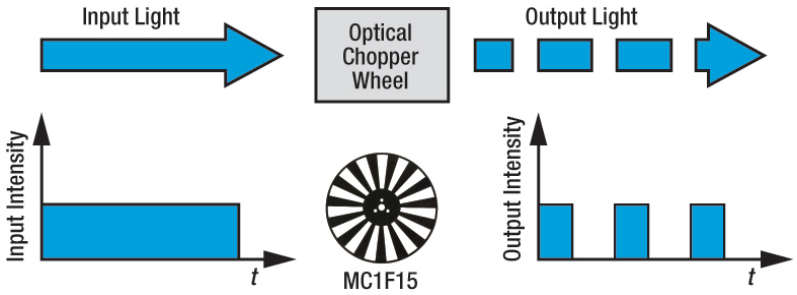
Optics Express Vol. 12, Issue 17, pp. 3934-3939 (2004)

(2) Handling of LIGHT

Condensing(time) / modulating

- shutter
- mode lock
- Q-switching

ms



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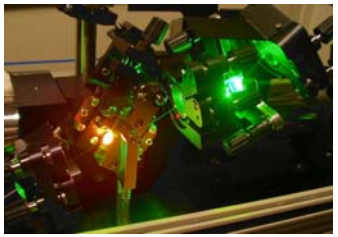

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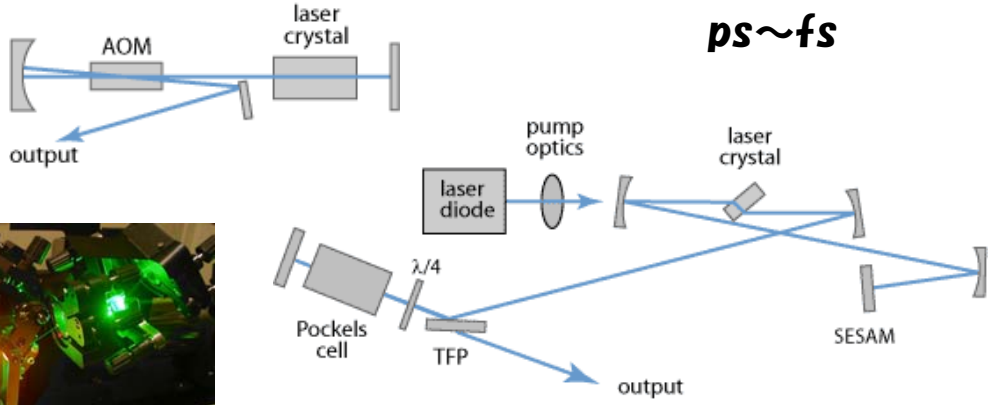

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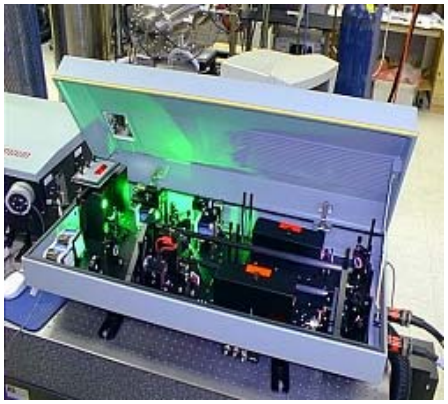

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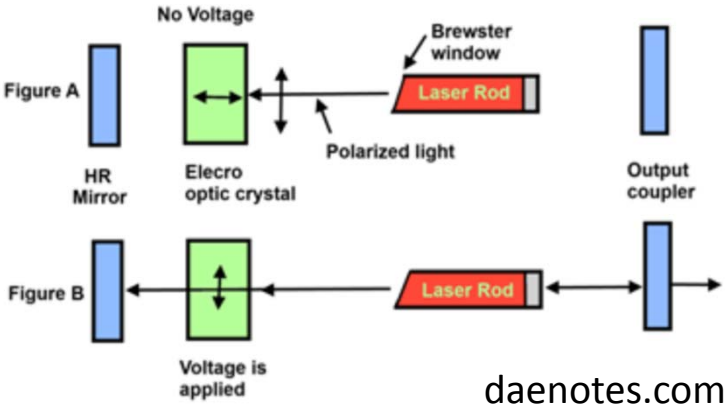


daenotes.com

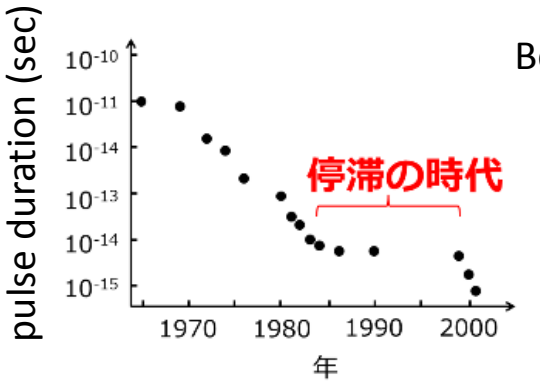
(2) Handling of LIGHT

Condensing(time) / modulating

- shutter
- mode lock
- Q-switching

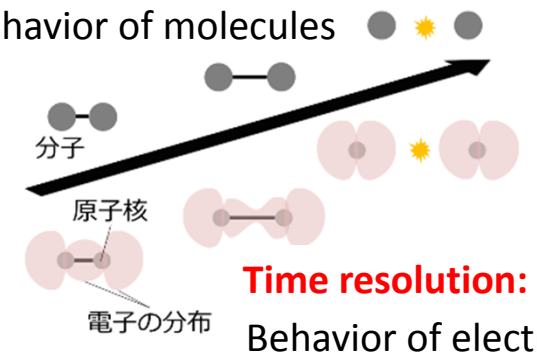
Nobel Prize in Chemistry 1999
Ahmed Zewail

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



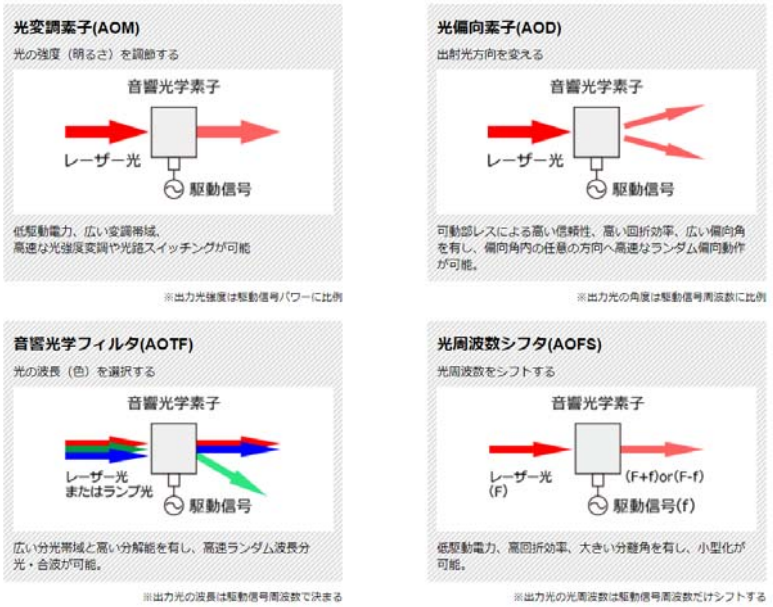
Until now

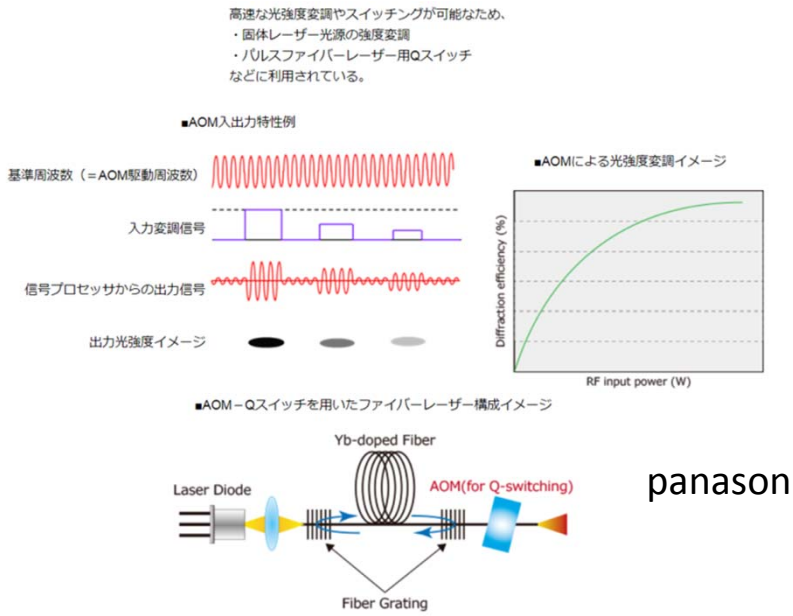
Behavior of molecules



Time resolution: 10^{18}sec

Behavior of electrons at(10^{-18}) second





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(2) Handling of LIGHT

Amplification

stimulated emission in fiber

Raman effect

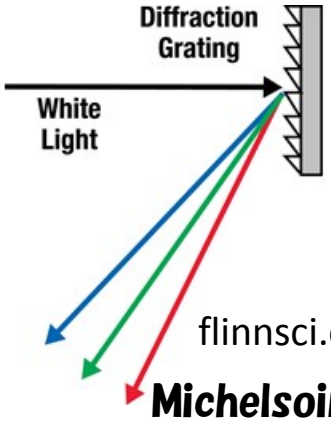
Selecting

filter

grating

interference

Raman effect



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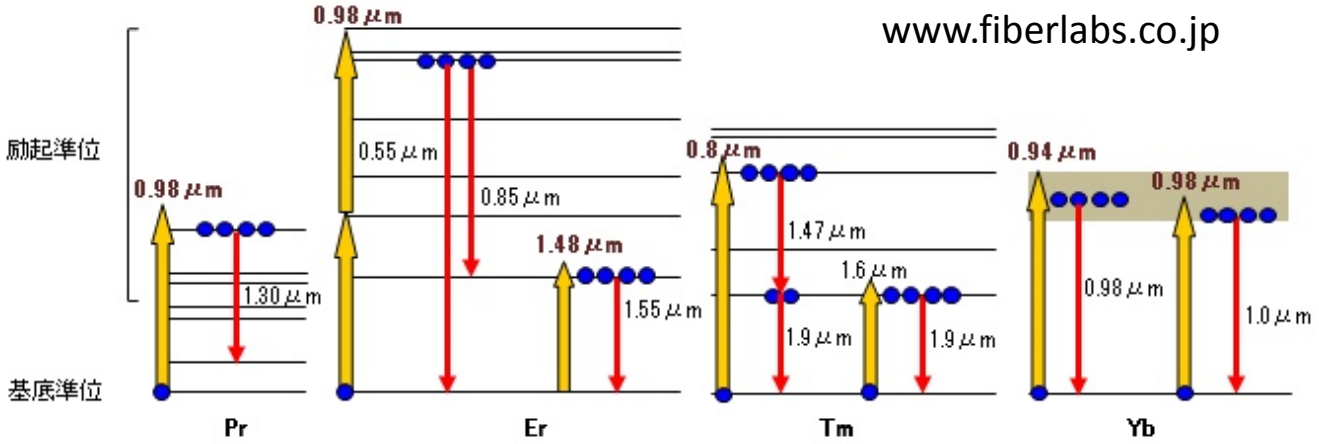

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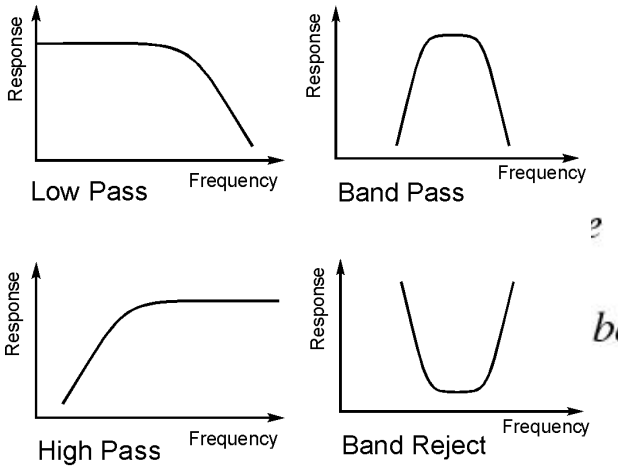
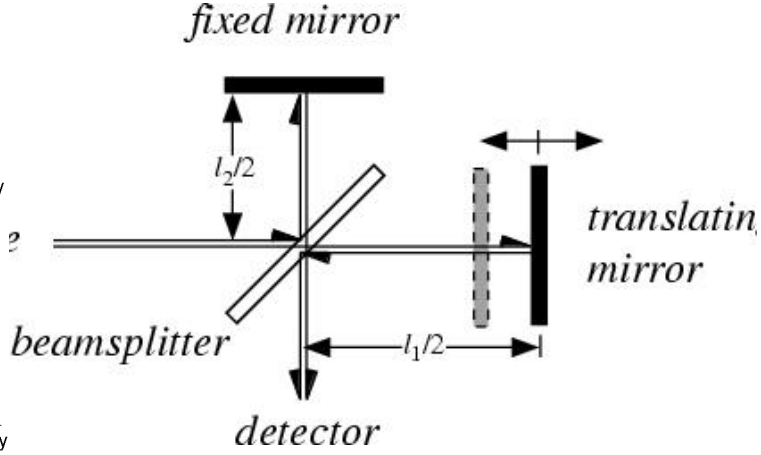
Filter



physics.tutorvista.com

Michelsointerferometer



http://hank.uoregon.ed

Fabry-Perot interferometer

physik.uni-siegen.de

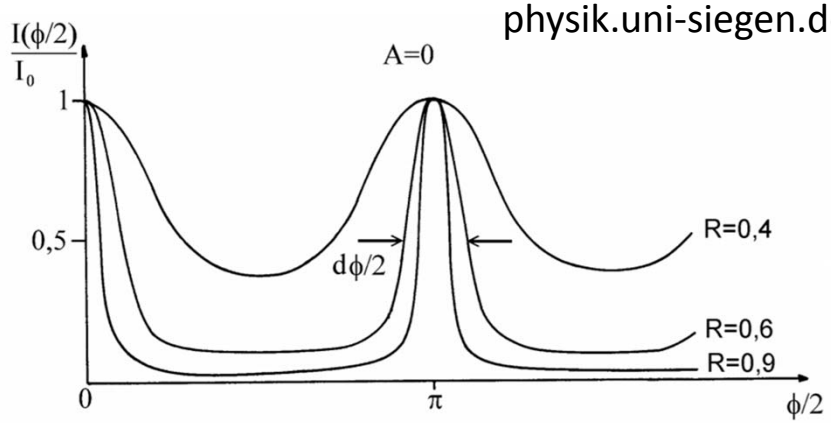
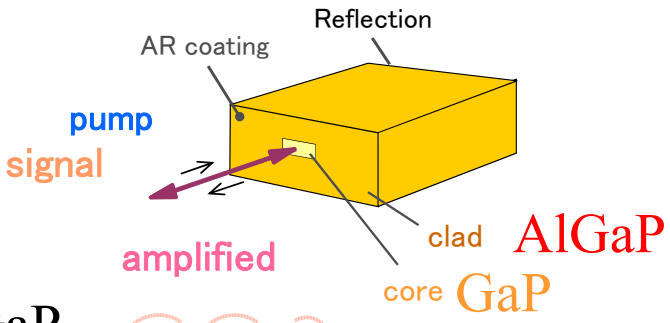


Figure 3: Airy function for different reflection coefficients R

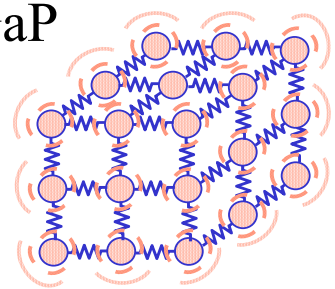
(2) Handling of LIGHT

Amplification
- stimulated emission in fiber
- Raman effect

Selecting
- filter
- grating
- interference
- Raman effect

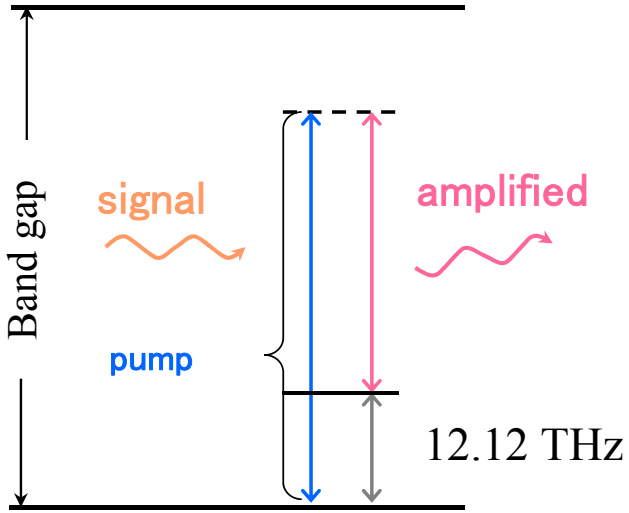


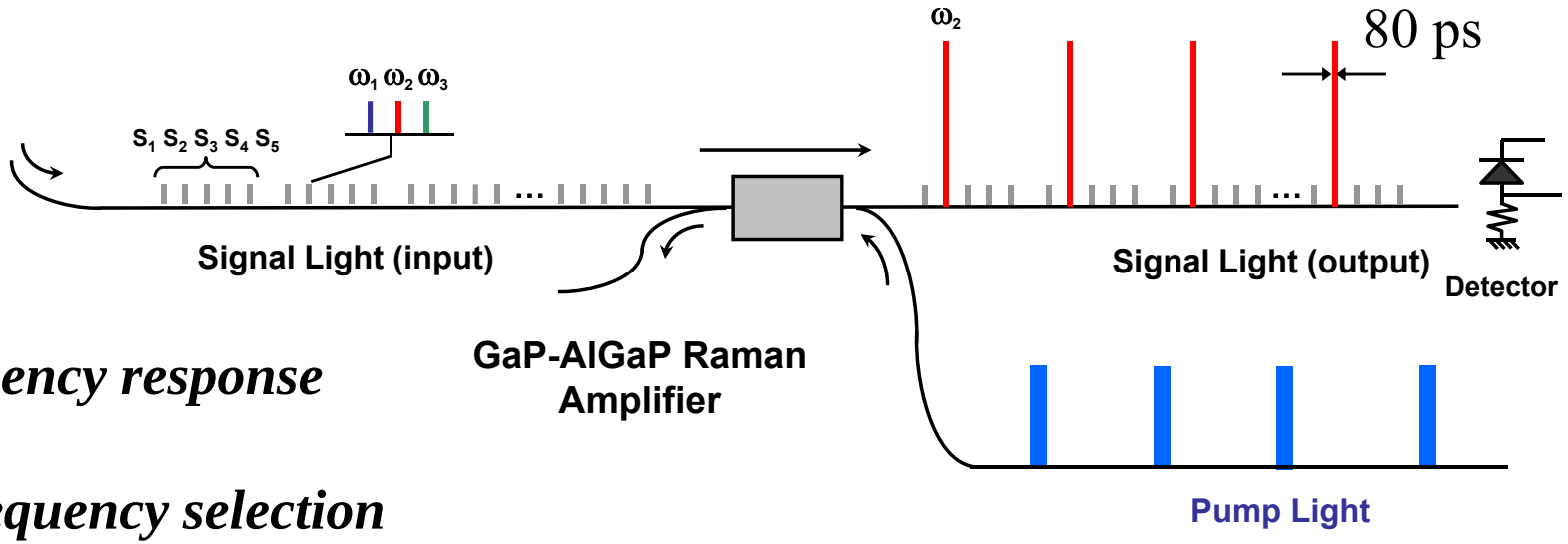
GaP



LO phonon
12.12 THz

▪ Stimulated Raman Amplifier





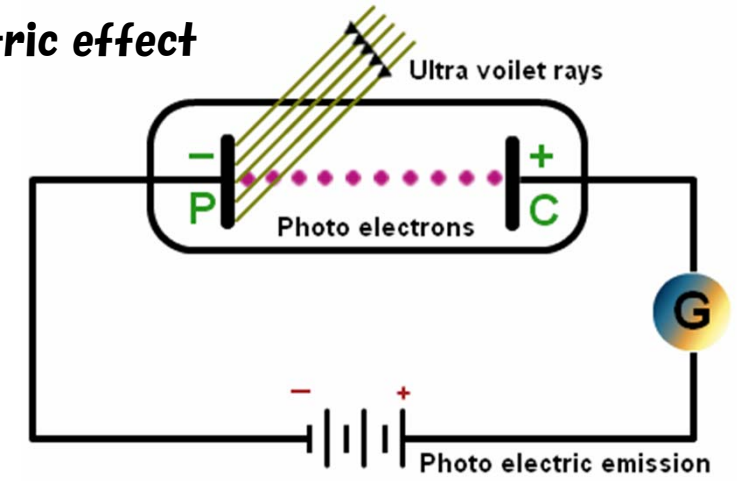
- *high-frequency response*
- *high gain*
- *narrow-frequency selection*

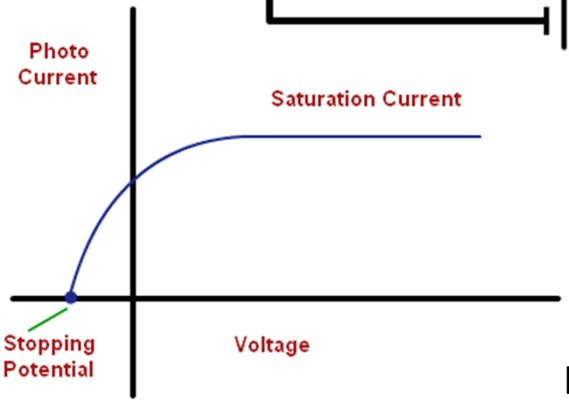
(2) Handling of LIGHT

Detecting

photoelectric effect
energy gap in semiconductor
bolometer / pyroelectric effect

photoelectric effect





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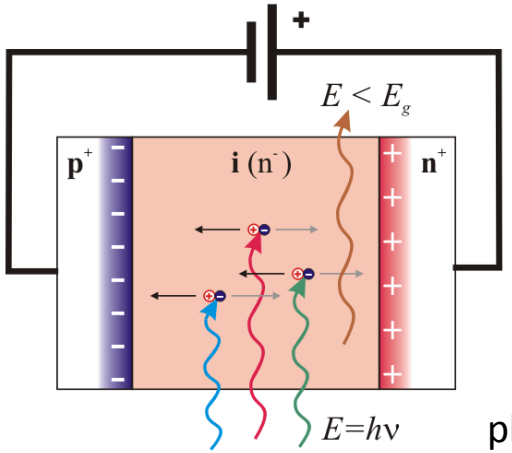
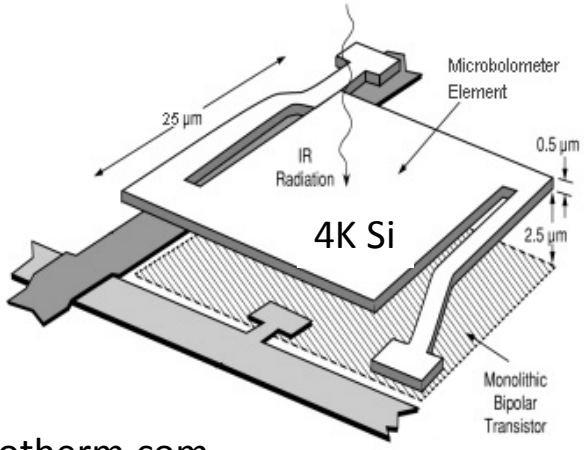
energy gap in semiconductor



physicsopenlab.org

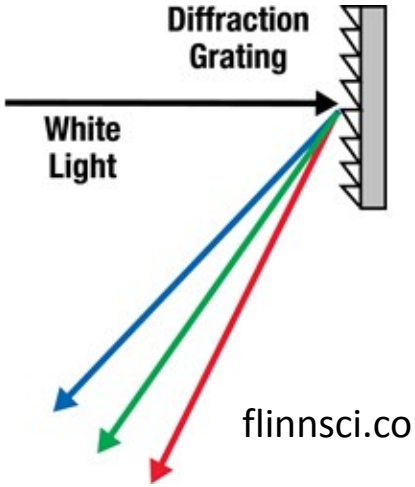
bolometer / pyroelectric effect



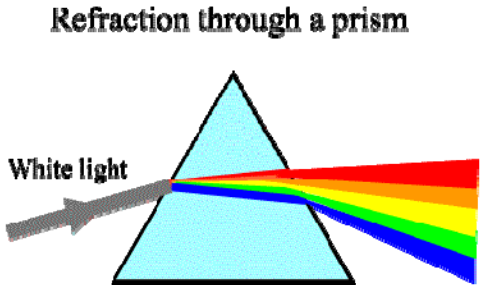
optotherm.com

(3) Understanding of LIGHT conditions

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

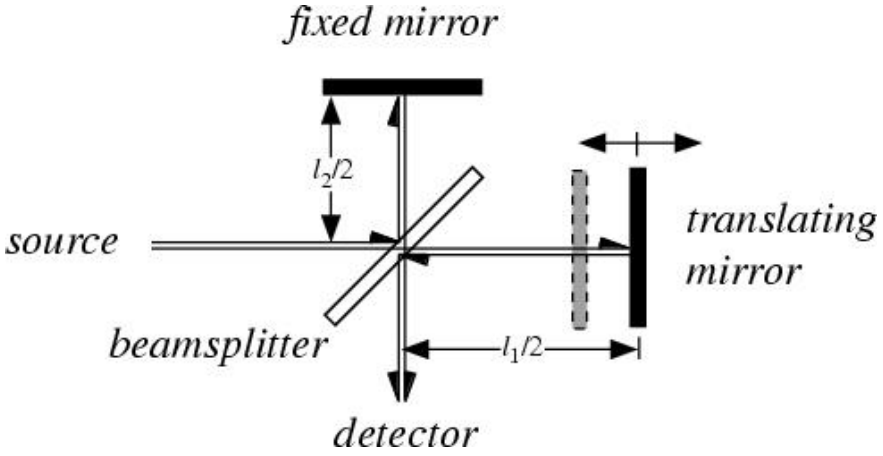


flinnsci.com



physics.louisville.edu

Michelsointerferometer



http://hank.uoregon.edu

Fabry-Perot interferometer

physik.uni-siegen.de

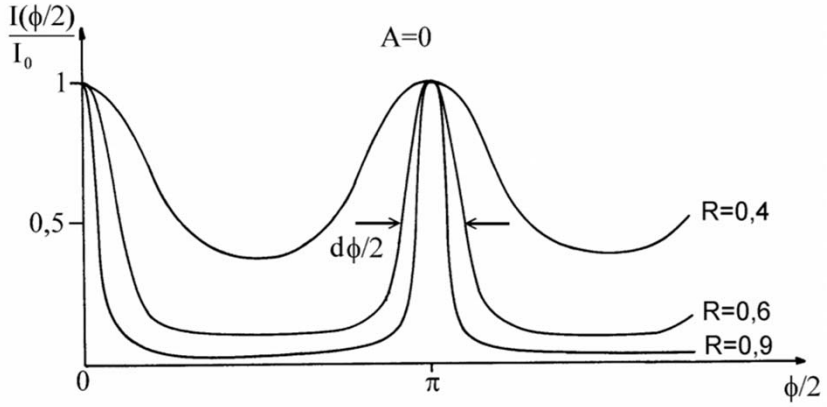
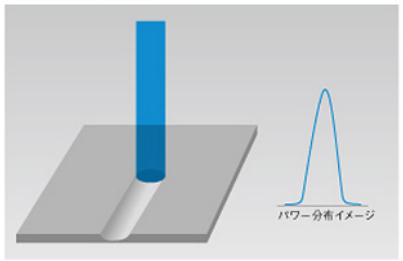


Figure 3: Airy function for different reflection coefficients R

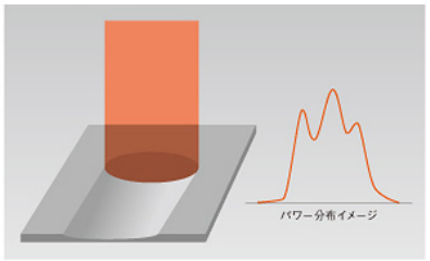
(3) Understanding of LIGHT conditions

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

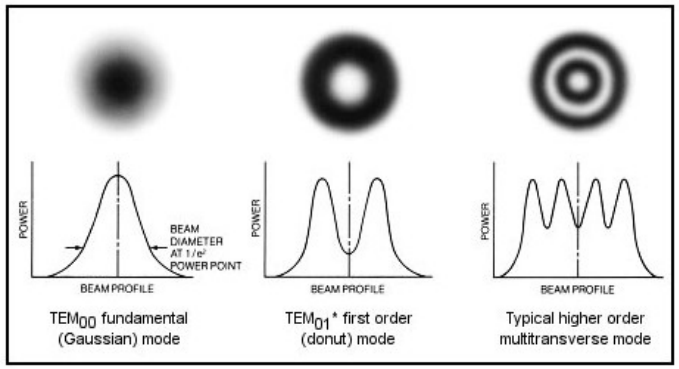
single mode



multi mode

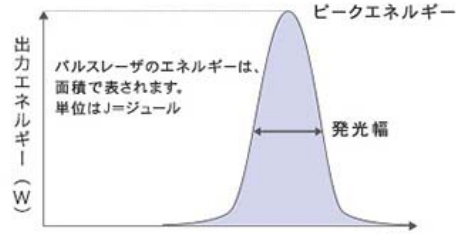


omron.co.jp

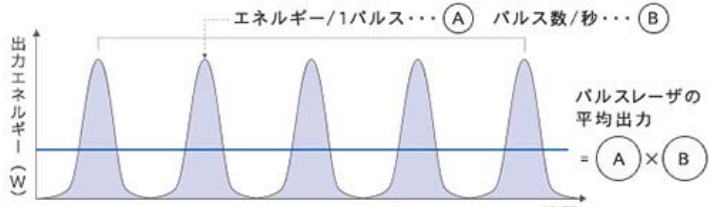


jp.laserto.com

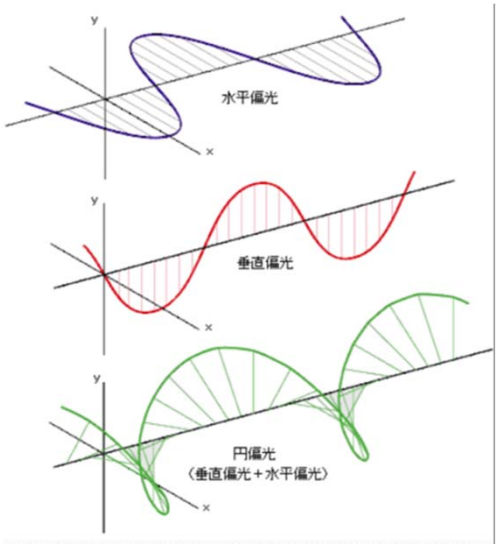
■ peak power



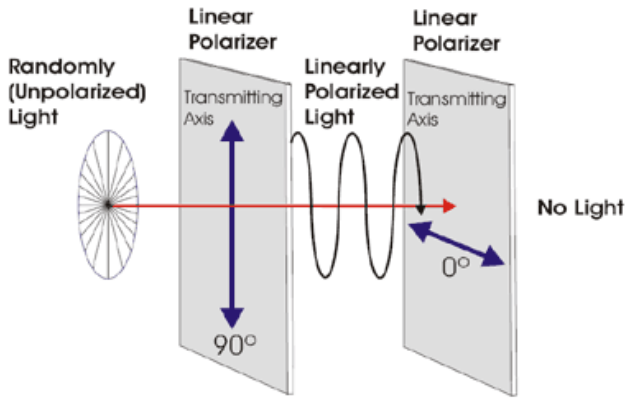
■ average power



keyence.co.jp



狩野覚先生資料より



apioptics.com

CCD / CMOS

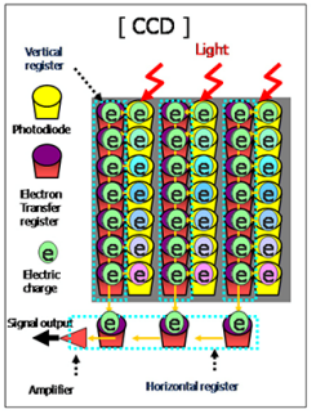
Micro Lens
マイクロレンズ
レンズを通った光を
フォトダイオードのセルに
効率よく集めるための集光
レンズです。

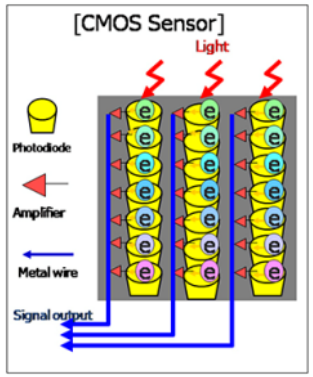
Color Filter
カラーフィルター
光の色をいったんRGB（赤、緑、青）
あるいはCMY（シアン、マゼンタ、イエロー）
成分に分解するはたらきをします。

PIN diode
フォトダイオード
光が当たると電荷（電子）を
発生する光電変換のはたらき
をします。
画素ごとの明るさに応じて、
電子を垂直および水平方向
に転送。CCDの出力段で電
子量を電圧に変換して画素
ごとの画像出力が得られます。

光の強さに応じた電荷（電子）の流れ。
光を電気の量に置き換えます。

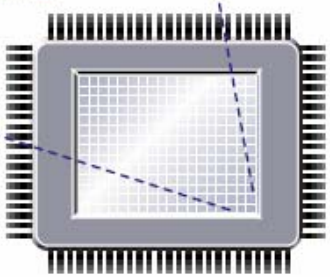
Unit Cell
1画素が1ユニットセル

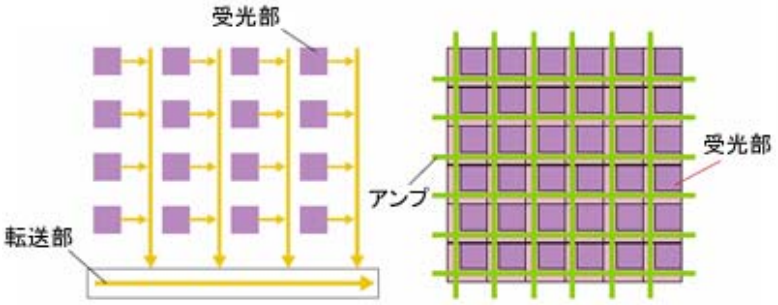




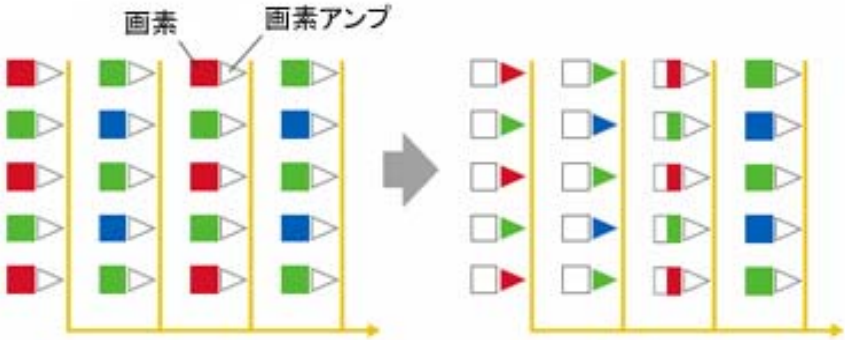
sonyalpharumors.com

panasonic.com

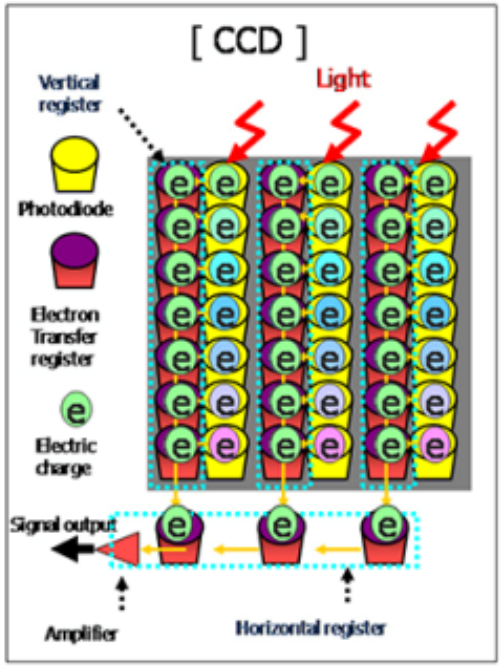


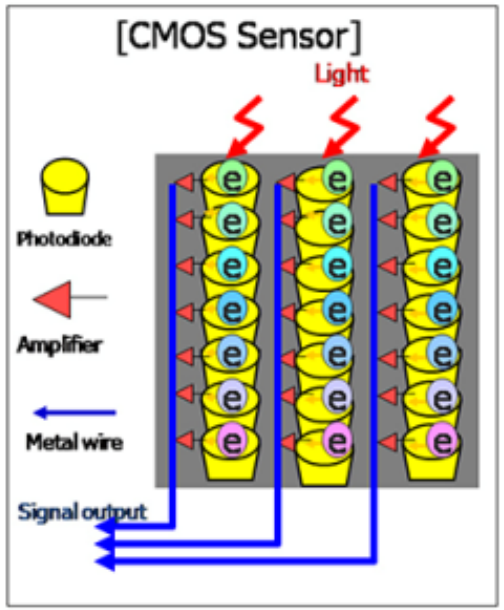


Charge Coupled Device



Complementary Metal Oxide Semiconductor





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