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）
第　２回	１０月１３日（金）	１講時（田邉）
第　３回	１０月２０日（金）	１講時（田邉）
第　４回	１０月２７日（金）	１講時（佐藤）
第　５回	１１月１０日（金）	１講時（小澤）
第　６回	１１月１７日（金）	１講時（吉川）
第　７回	１１月２４日（金）	１講時（試験）

Oct. 6 Oyama

Oct.13 Tanabe：Photonic Device-Basic

Oct. 20 Tanabe：-Application

Oct. 27 Sato

Nov.10 Kozawa

Nov.17 Yoshikawa

Nov.24 Examination

Quiz -Photonic Device-

1. What photonic devices do you know? (1～2 devices)

2. Explain the device (structure, function, feature,,, anything OK!)

3. What materials are used in the device?

Student ID: Name:

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

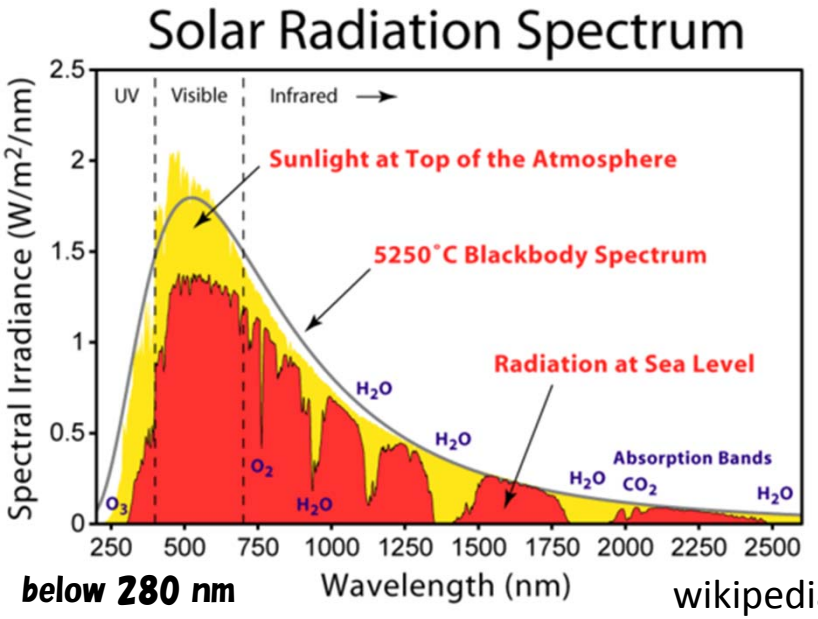
(1) INTRODUCTION

What is LIGHT?

- electric wave~light (electromagnetic wave)
- invisible/visible
- straight propagation
- solar-blind
  - due to ozone absorbance of sunlight

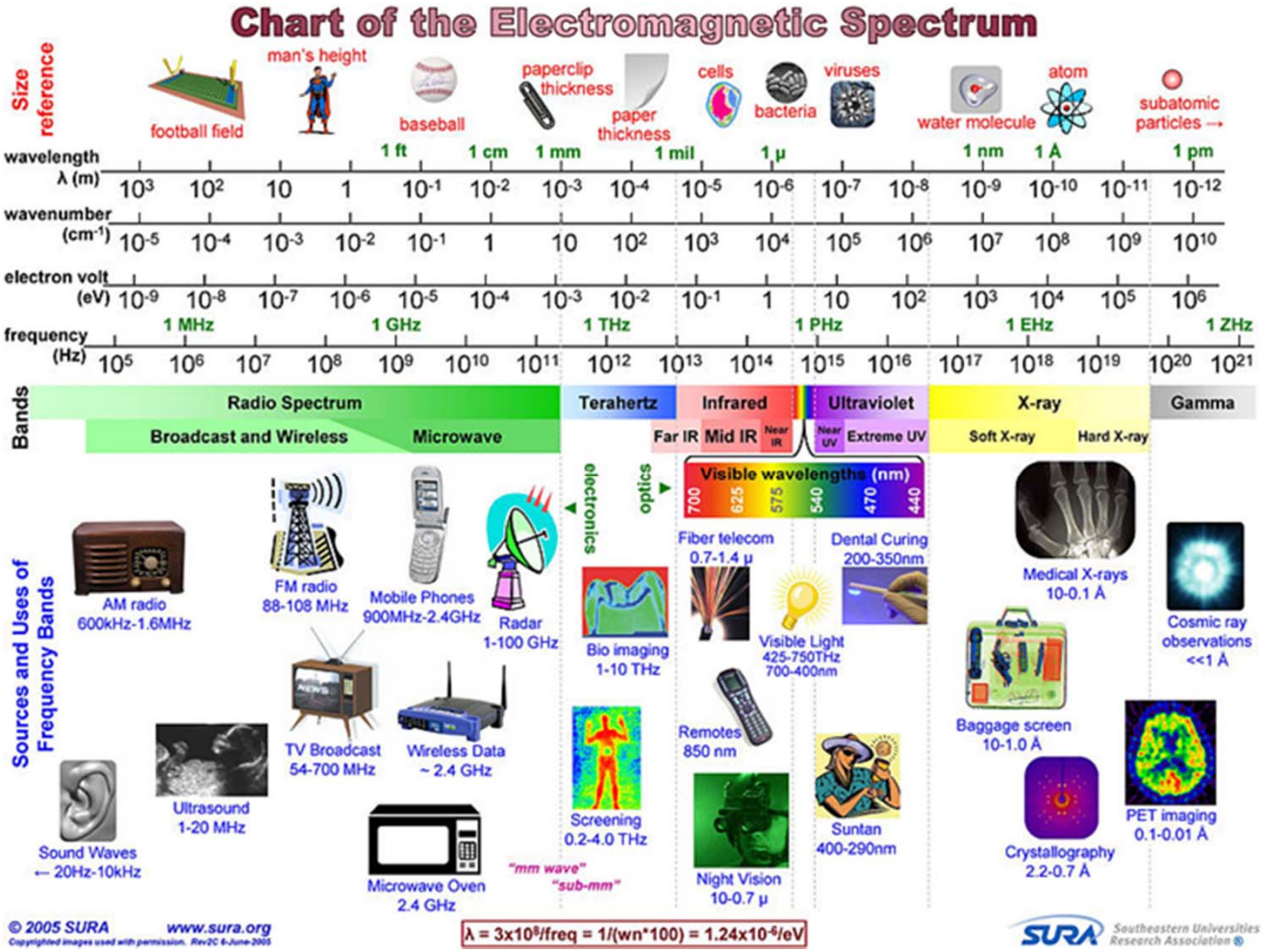
Laser

- single-frequency
- coherent(coordinate phase)
- high energy density



below 280 nm

wikipedia.org



(1) INTRODUCTION

What is LIGHT?

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Laser

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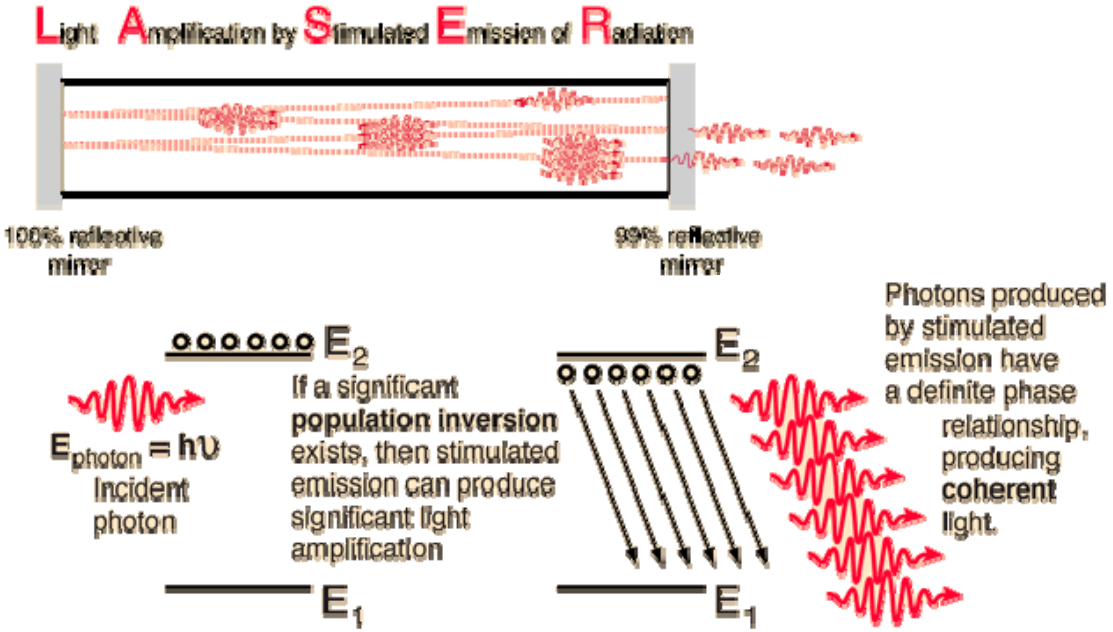
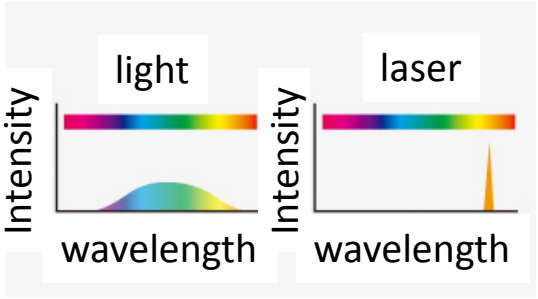
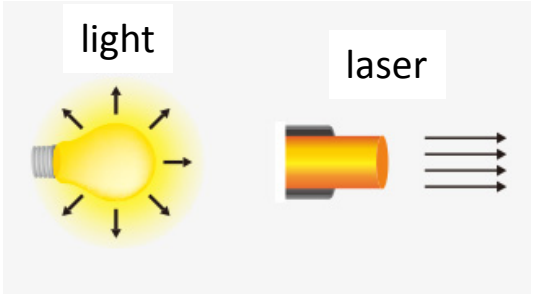
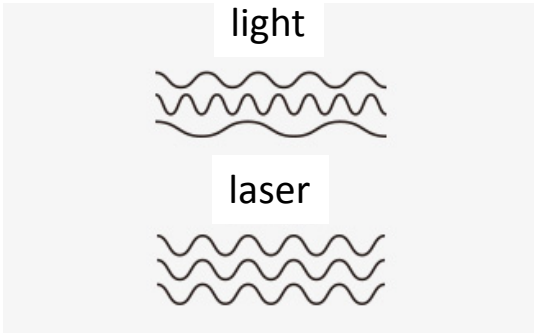


hyperphysics.phy-astr.gsu.edu







laserfront.jp

Application of light(photonic device) to our life

- lighting
- photographing
- energy production
- communication
- non-destructive inspection
- medical diagnosis/treatment

digitaljournal.com

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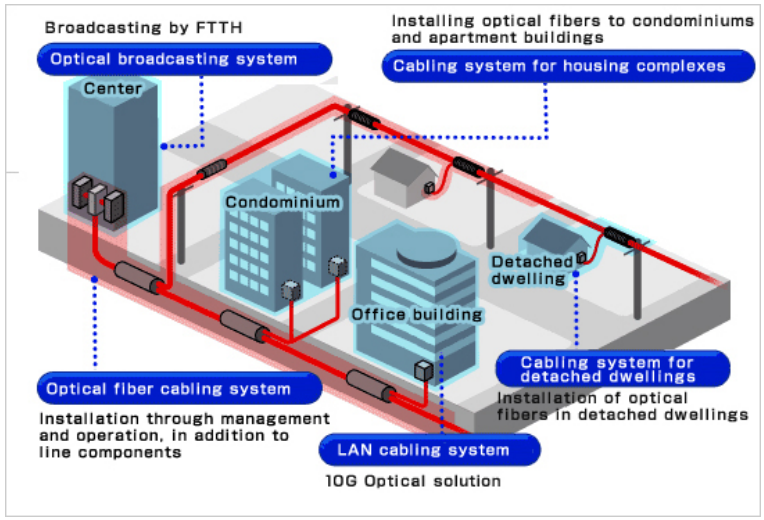
mitsubishielectric.co.jp



furukawa.co.jp

itmedia.co.jp

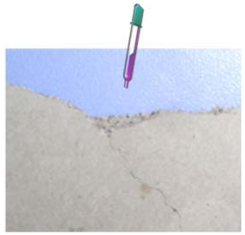
oneslidephotography.com

nonin.com

THz Applications: non-destructive inspection

defects in the construction

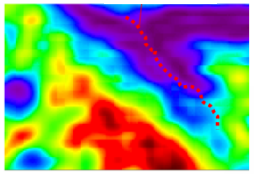
water diffusion
to cracks in the concrete



Concrete

(**10mm thickness**)

crack



THz image

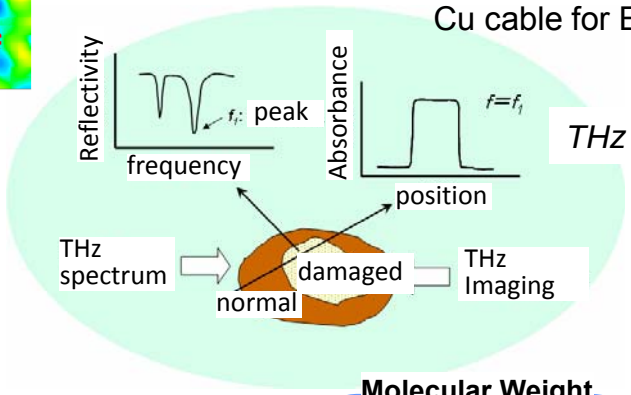
Terahertz＝Safety＋non-destructive

non-destructive：non-ionized、high-transparency

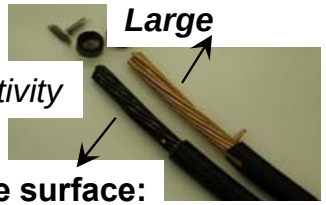
safety：applicable to practical fields

Evaluation for insulator covered metal surface

Cu cable for Electric power



THz Reflectivity



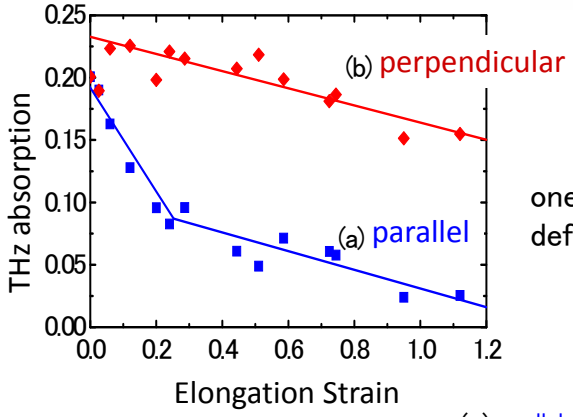
non oxide surface: ***Large***

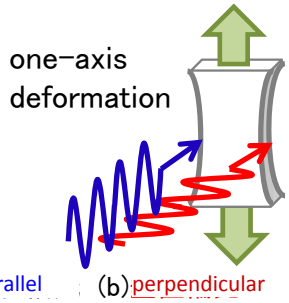
oxide surface: ***Small***

insulators

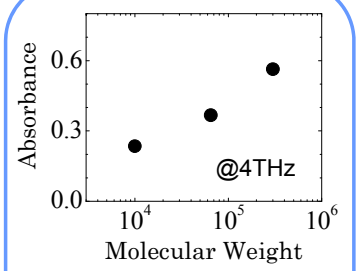
THz transperence ：high

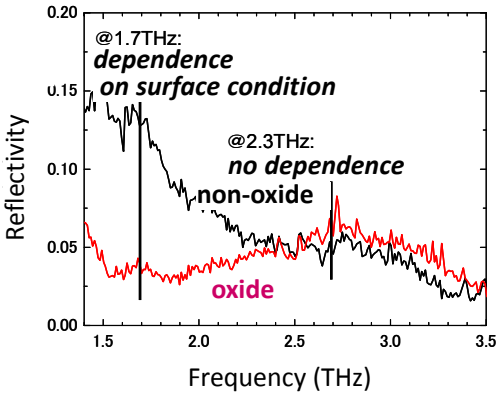
deformed Polyethylene





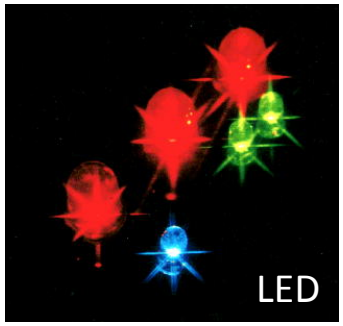
Molecular Weight



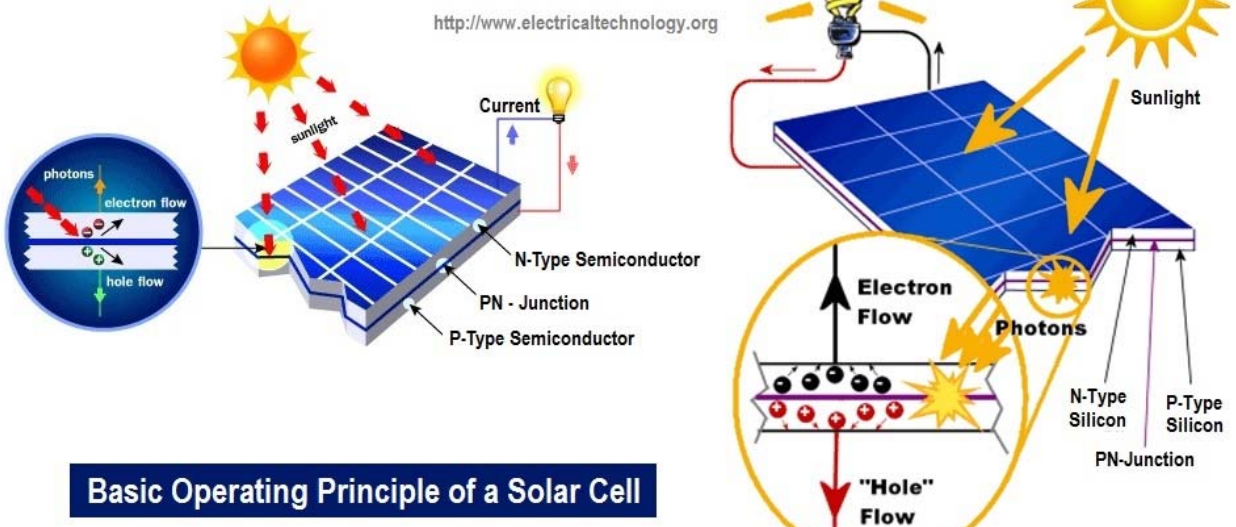


Application of light(photonic device) to our life

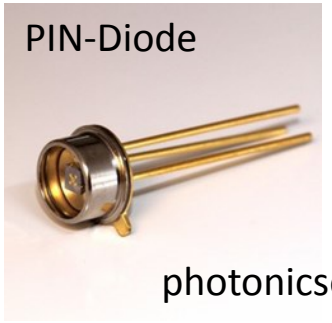
- lighting: Lamp, LED
- photographing: CCD, CMOS
- energy production: Solar Cell
- communication: LD, PIN-Diode
- non-destructive inspection: Infrared-THZ
- medical diagnosis/treatment: LED/Laser



kaden.watch.impress.co.jp



Basic Operating Principle of a Solar Cell



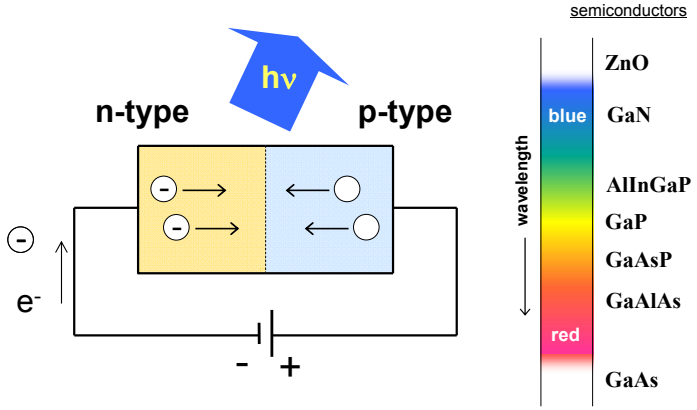
photonicsonline.com

CCD CMOS

oneslidephotography.com

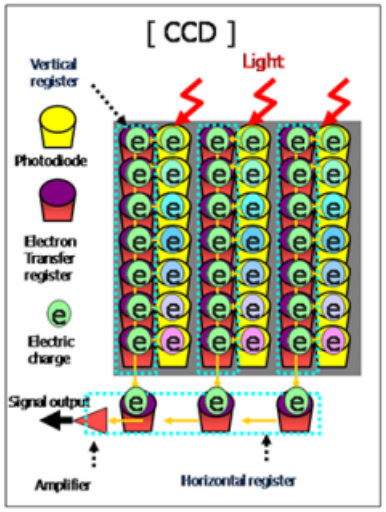
Relation between light and materials

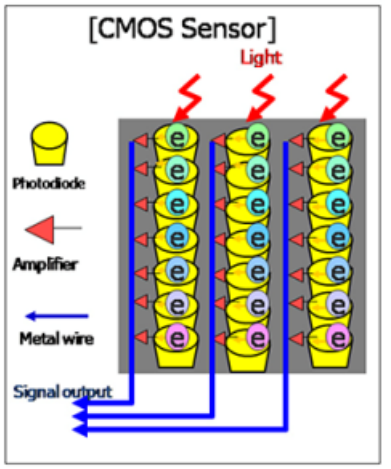
- lighting: Lamp, LED: GaAsP, GaN
- photographing: CCD, CMOS: Si
- energy production: Solar Cell: Si, GaAs
- communication: LD, PIN-Diode: InP
- non-destructive inspection: THZ: GaP, GaSe
- medical diagnosis/treatment: LED/Laser: GaAs, CO_2



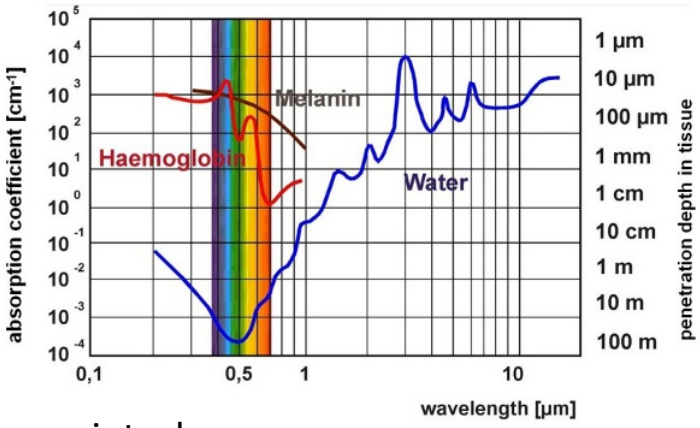
素材	GaAsP系	GaP系	GaAlAs系	AlGaInP系	InGaN系
発光色	黄色～赤色	黄緑色	赤色	黄色～赤色	青色～緑色 (YAGと組み合わせ白)
構造	P-GaAsP / n-GaAsP / n-GaP sub	P-GaP / n-GaP / n-GaP sub	n-GaAlAs / P-GaAlAs / P-GaAs	P-GaAlAs / AlGaInP / n-GaAlAs / n-GaAs	P-GaN / InGaN / n-GaN / n-SiC; P-GaN / InGaN / n-GaN / Al_2O_3
発光効率	0.2 ～ 1.0 (lm/W)	2.0 ～ 3.0 (lm/W)	6 ～ 12 (lm/W)	15 ～ 40 (lm/W)	10 ～ 50 (lm/W)

led.or.jp



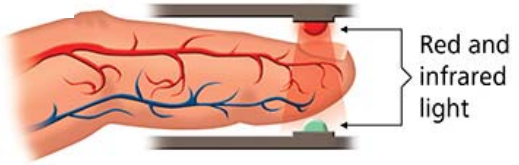


sonyalpharumors.com



intechopen.com

novuslight.com



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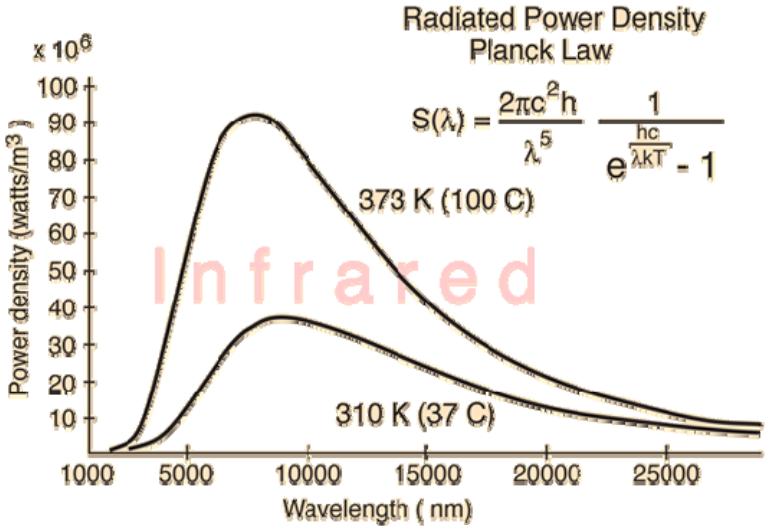
(2) Handling of LIGHT

Generation

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



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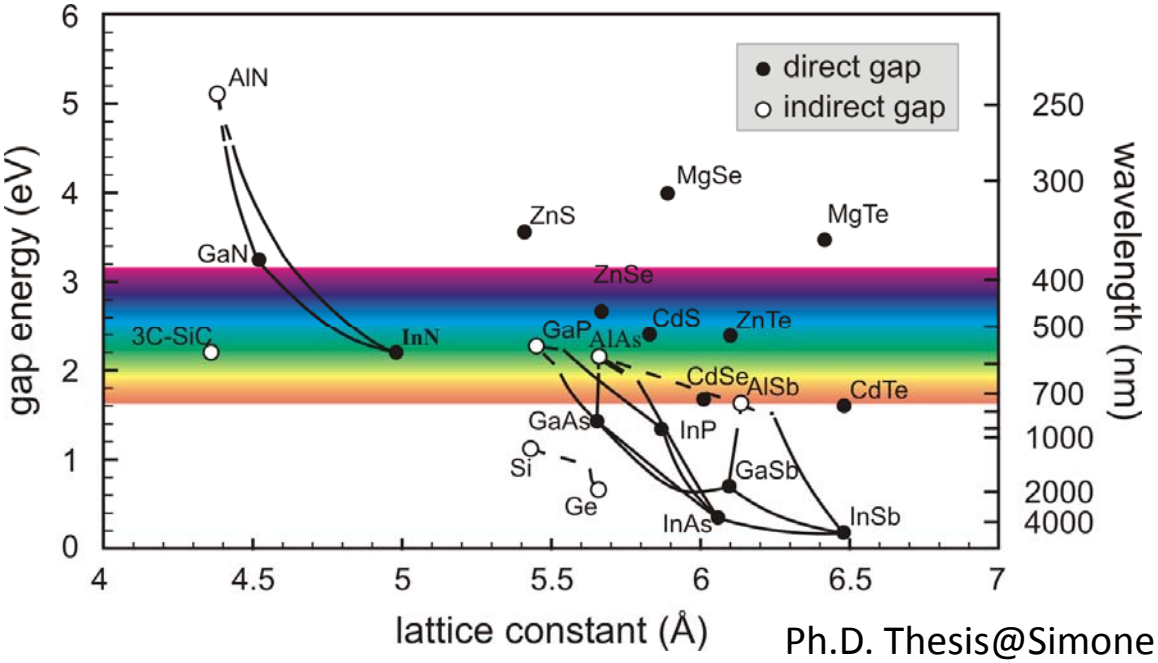
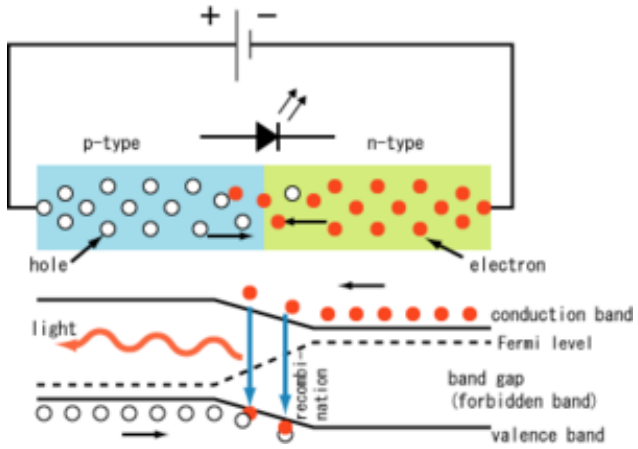


Ph.D. Thesis@Simone Montanari



Electro Luminescence

todayifoundout.com

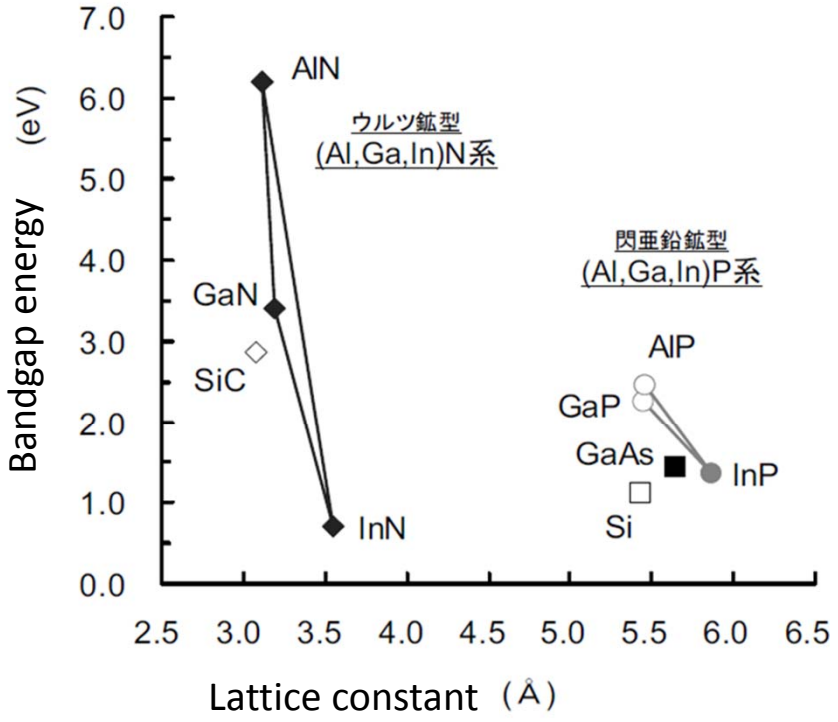
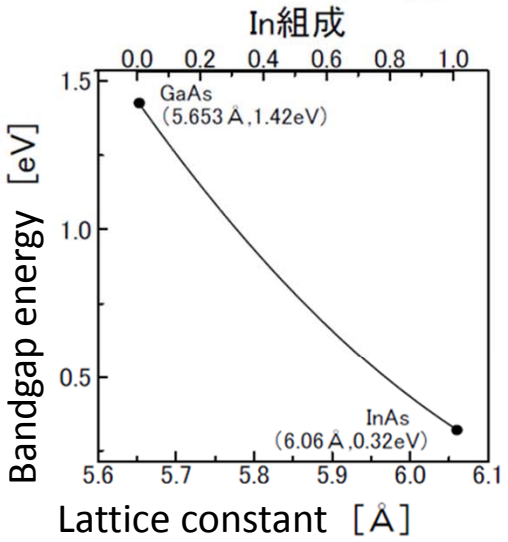


図5　Ⅲ－Ⅴ族半導体／(Al, Ga, In)N系, (Al, Ga, In)P
の格子定数とバンドギャップエネルギーの関係

表面技術 61 (2010)
板東 完治

InGaAs ・・・ 正確には $In_xGa_{1-x}As$ $(0 \leqq x \leqq 1)$ x : In組成

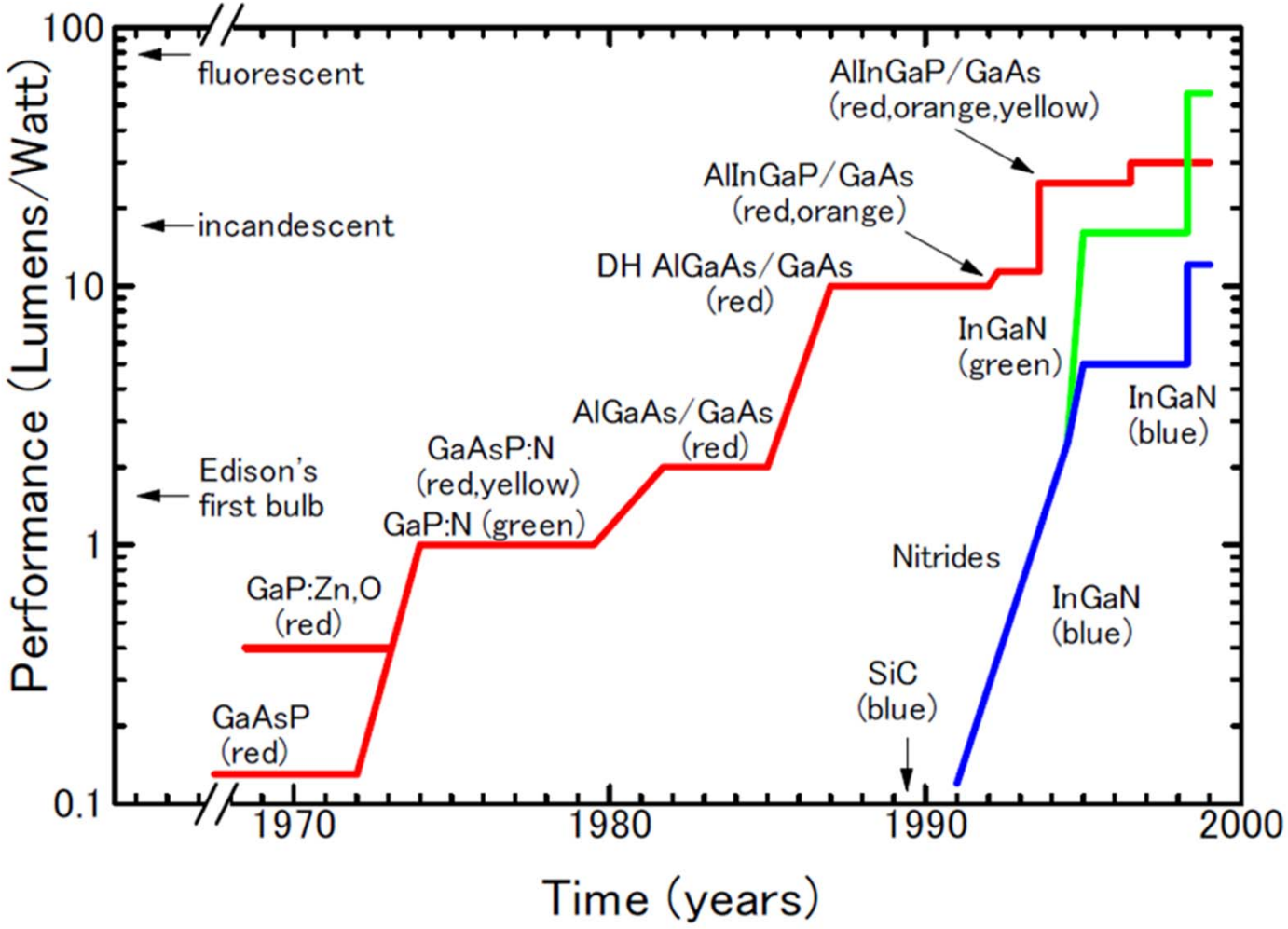


In組成によってバンドギャップと格子定数を連続的に制御できる

$III_xIII_{1-x}V$, $III_xIII_yIII_{1-x-y}V$, $IIIV_yV_{1-y}$, $III_xIII_{1-}V_yV_{1-y}$, ・・・

InGaAs, AlGaInP, GaAsP, InGaAsP, ・・・

鍋谷暢一先生の資料



T. Mukai *et al*, Jpn. J. Appl. Phys., **38**, p.3976 (1999)

(2) Handling of LIGHT

Generation

- heating
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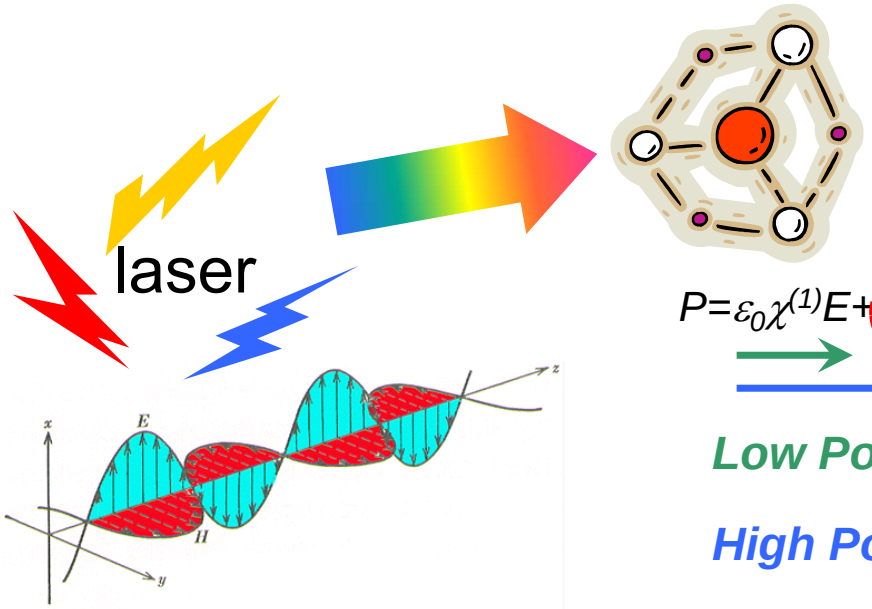
- nonlinear optical process
- (frequency-mixing: DFG, SFG, SHG)

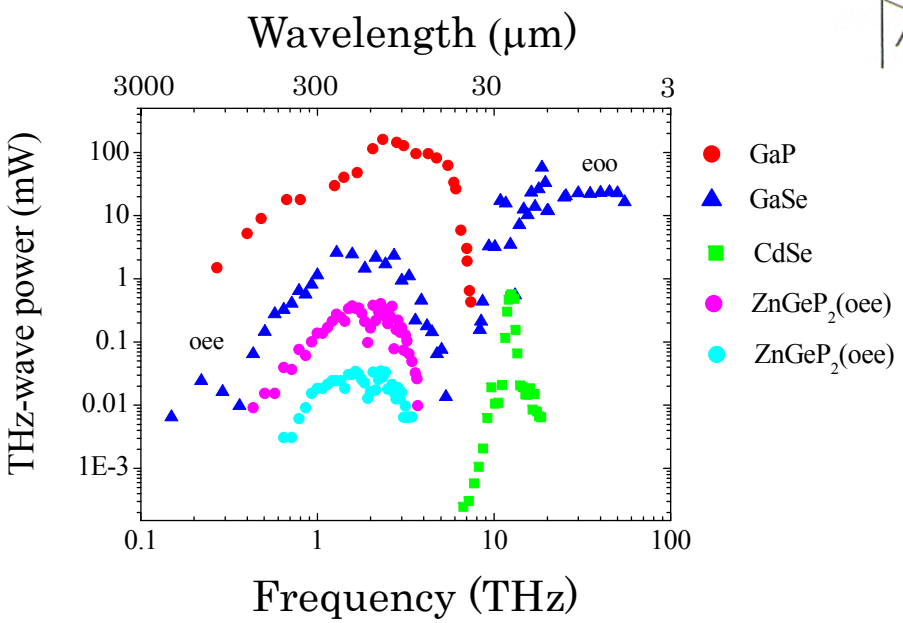


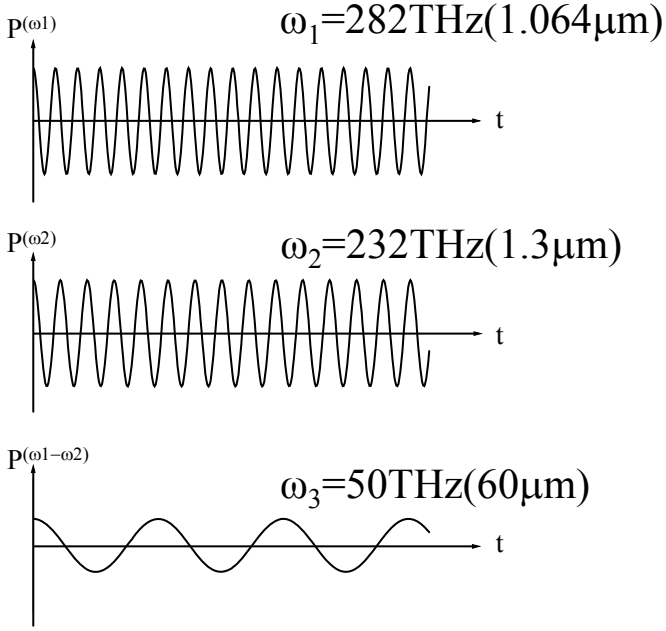
$$P=\varepsilon_0\chi^{(1)}E+\varepsilon_0\chi^{(2)}E^2+\varepsilon_0\chi^{(3)}E^3+\cdots$$

Low Power : Linear

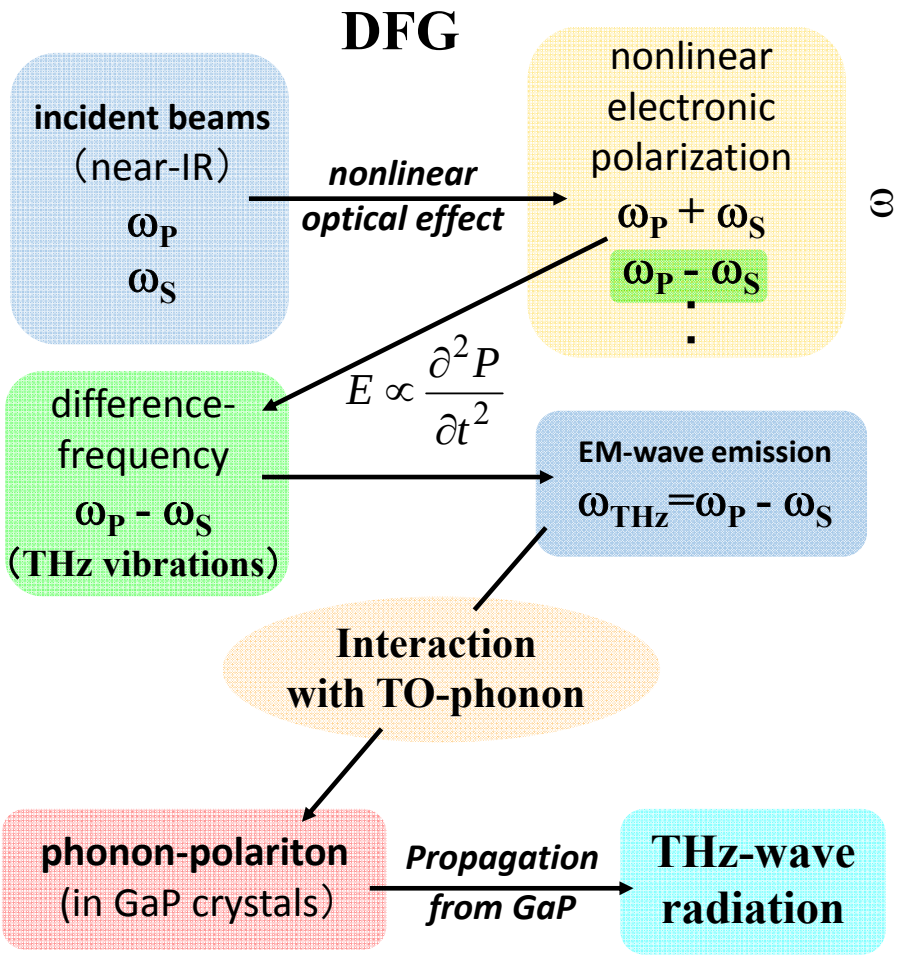
High Power: nonlinear

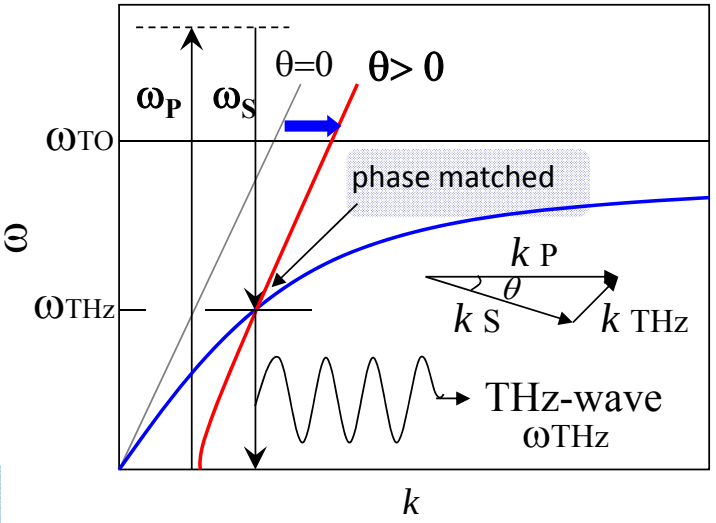
difference-frequency generation (DFG)





THz-wave generation based on non-collinear phase-matched DFG in phonon-polariton of GaP





THz-wave generation
nonlinear phase-matching condition

small angle phase matching

small angle tuning of two incident beams enables to generate tunable THz-wave

(2) Handling of LIGHT

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- heating
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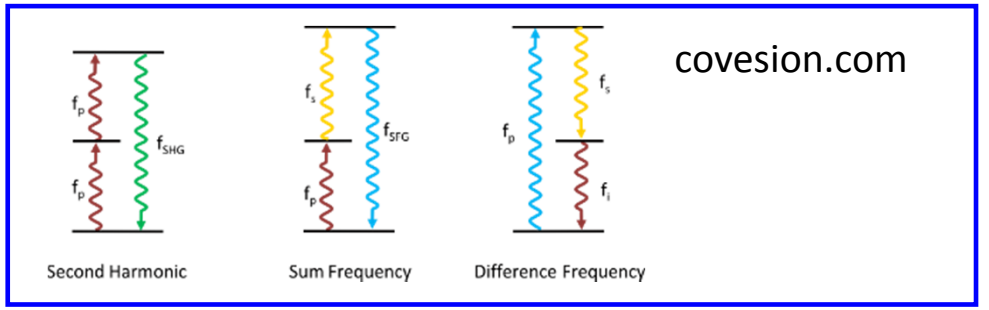
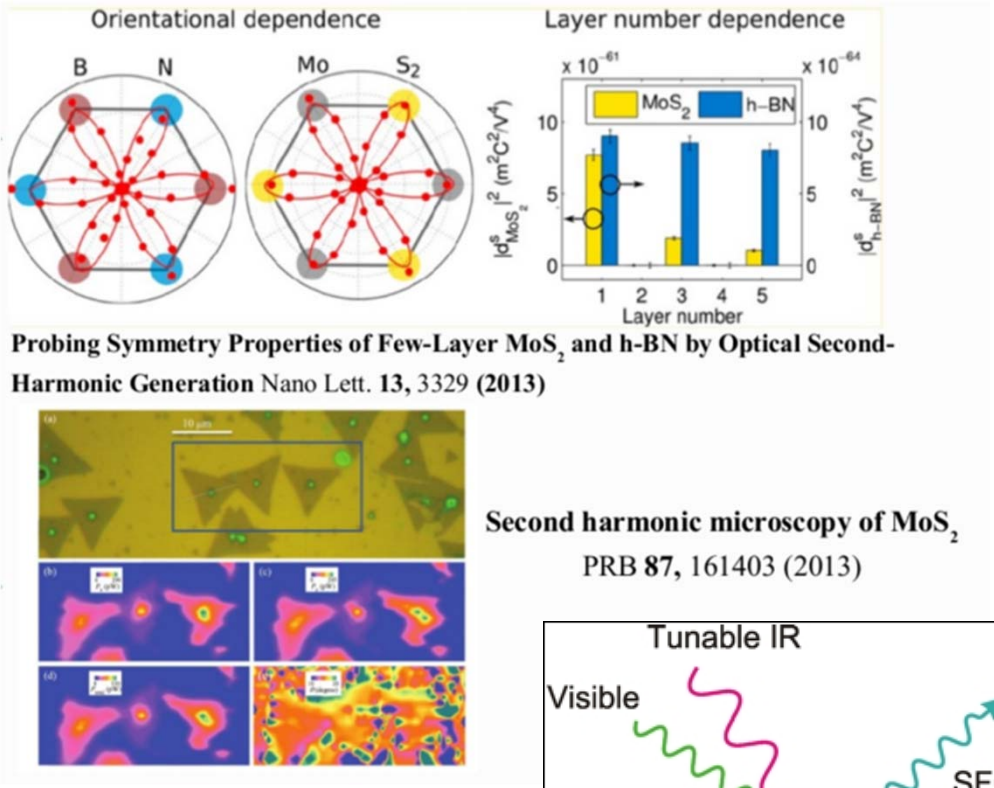


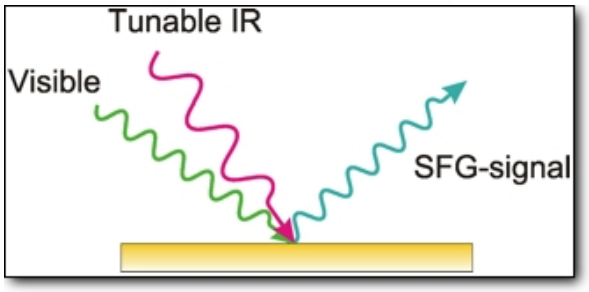
covesion.com



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

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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

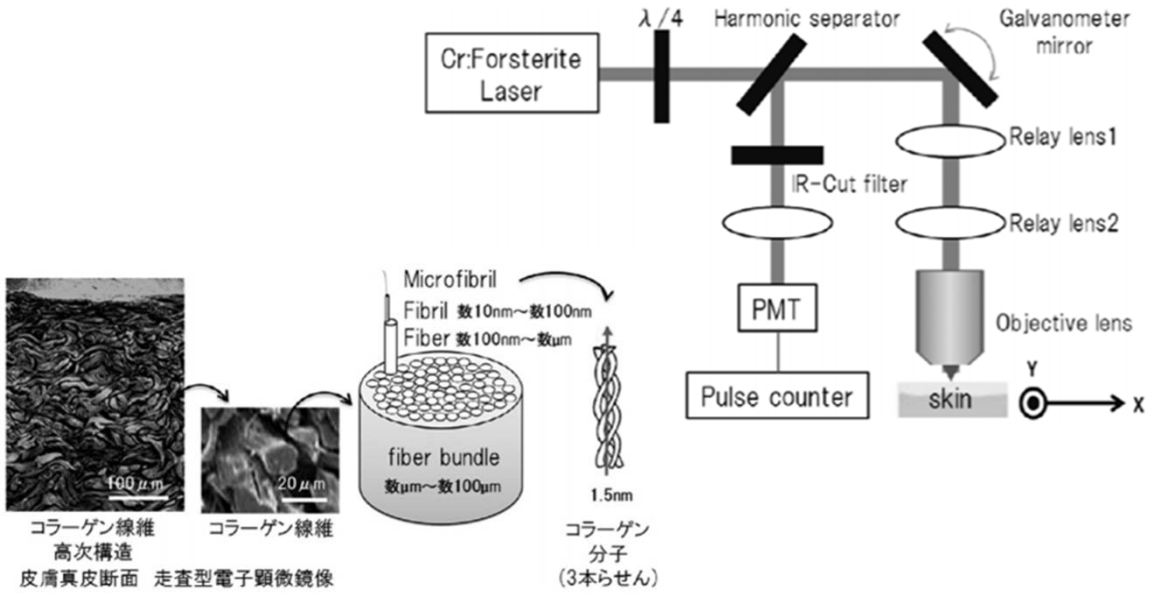


図 1　コラーゲン線維の高次構造.
Fig. 1　Hierarchical structure of collagen fiber.

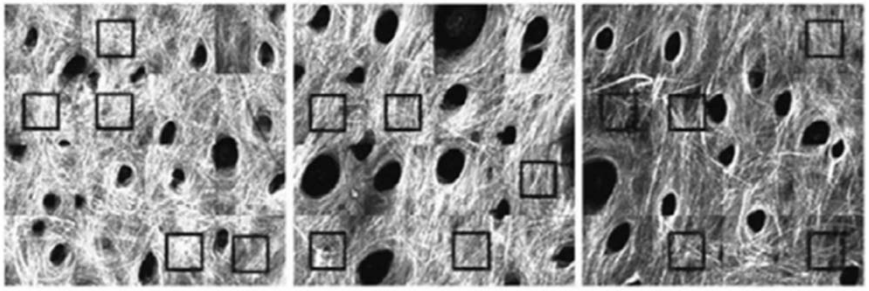


図 6　各年代被験者における頬皮膚の大面積 SHG イメージと画像解析に用いた領域（黒枠）.

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

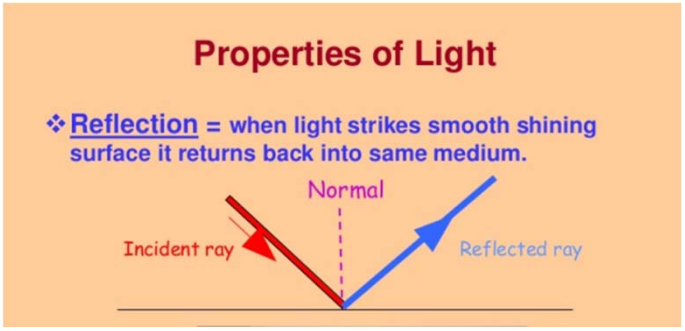
Propagation :absorption

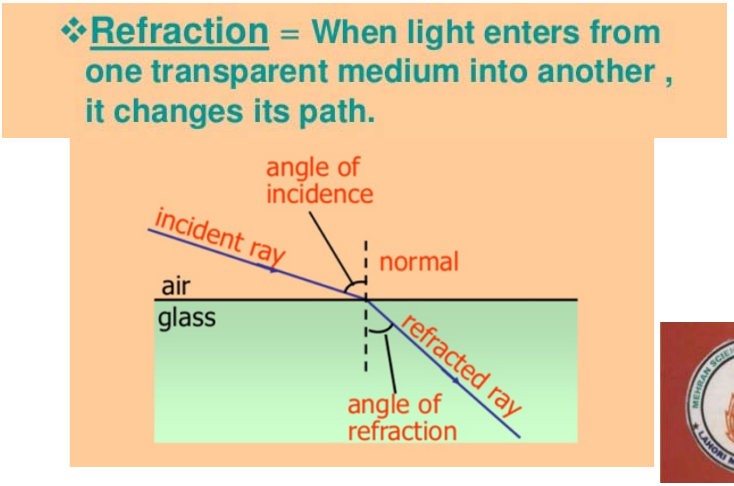
in air, liquid and solid

:reflection, refraction, diffraction, absorption and scattering

waveguide

optical fiber



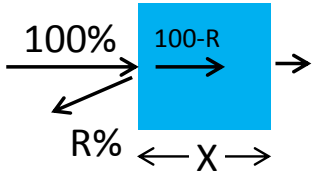


Absorption

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

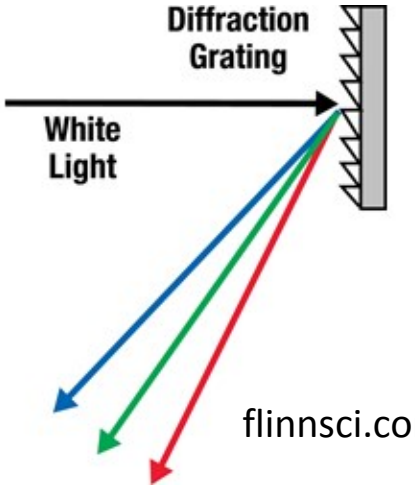
T : Transmittance

X_1, x_2 : Thickness



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

Diffraction



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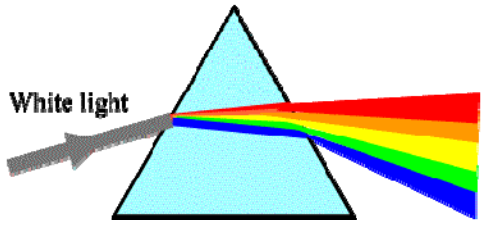

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(2) Handling of LIGHT

Propagation :absorption

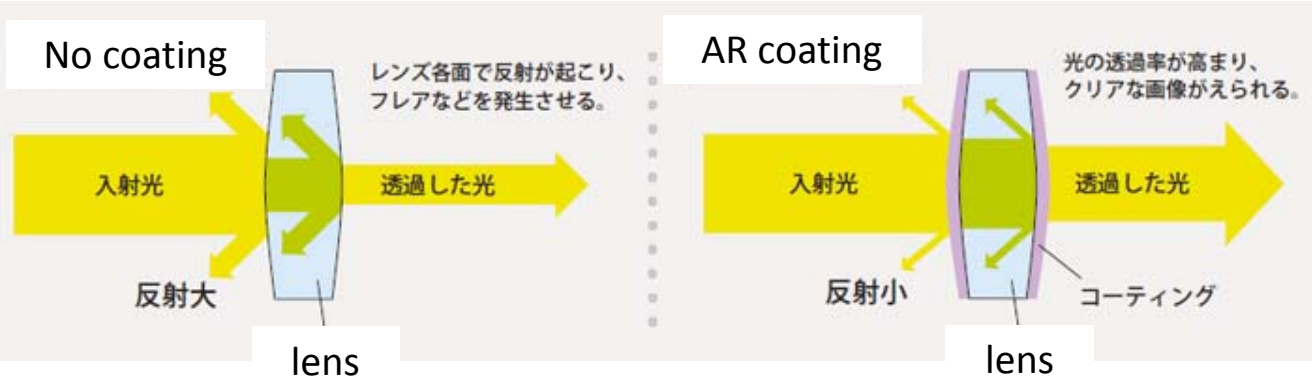
in air, liquid and solid

:reflection, refraction, diffraction, absorption and scattering

waveguide

optical fiber

Anti-Reflection coating



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(2) Handling of LIGHT

Propagation :absorption

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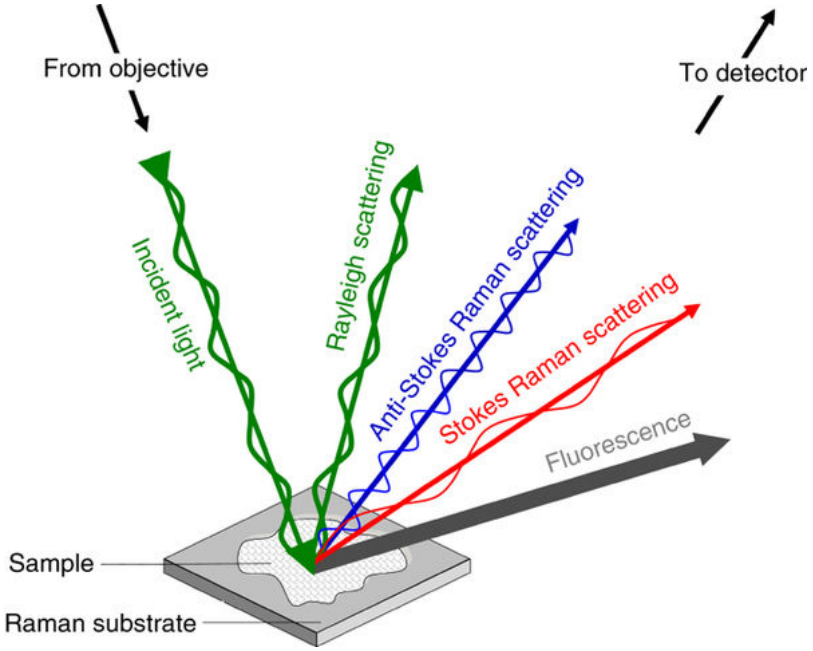
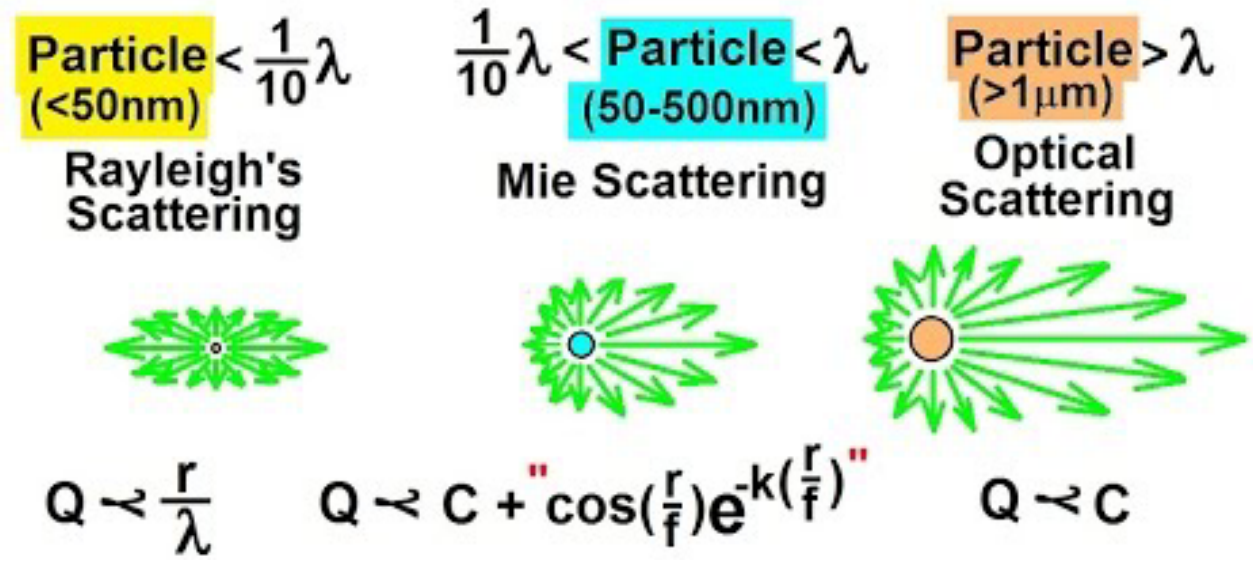
:reflection, refraction, diffraction, absorption and scattering

waveguide

optical fiber



Nature Protocols 11, 664–687 (2016)



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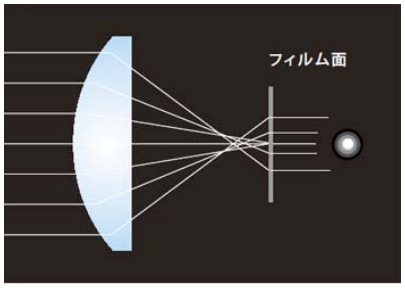
(2) Handling of LIGHT

Condensing(space)

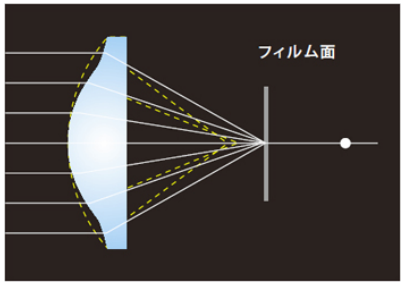
index lens

parabolic mirror

Spherical Lens



Aspherical Lens



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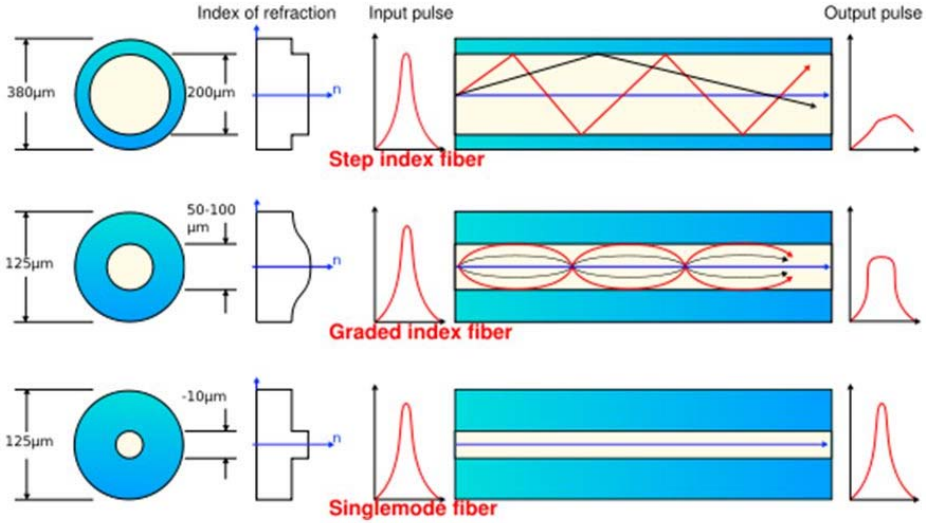


Standardní optická vlákna

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.

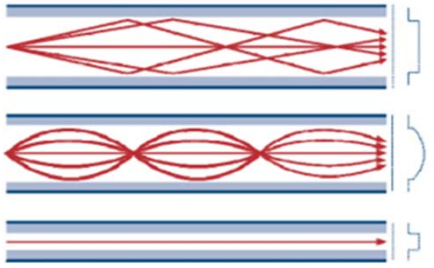
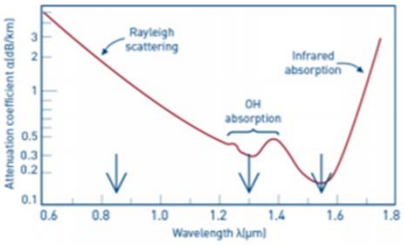


Fig. 2: Different types of fibers, step-index multimode, single mode and gradient index multimode. The propagation of a few rays is also indicated in red, as well as the distribution of the refractive index to the right.

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

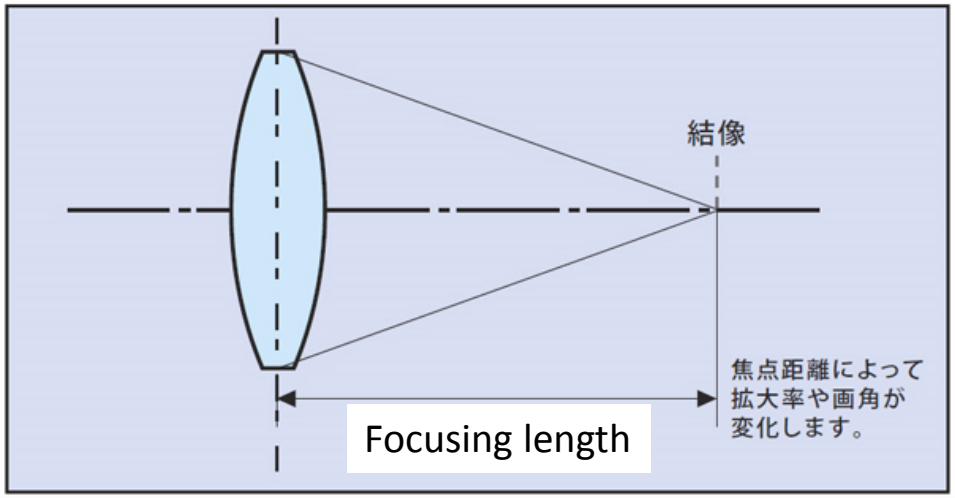


(2) Handling of LIGHT

Condensing(space)

index lens

parabolic mirror



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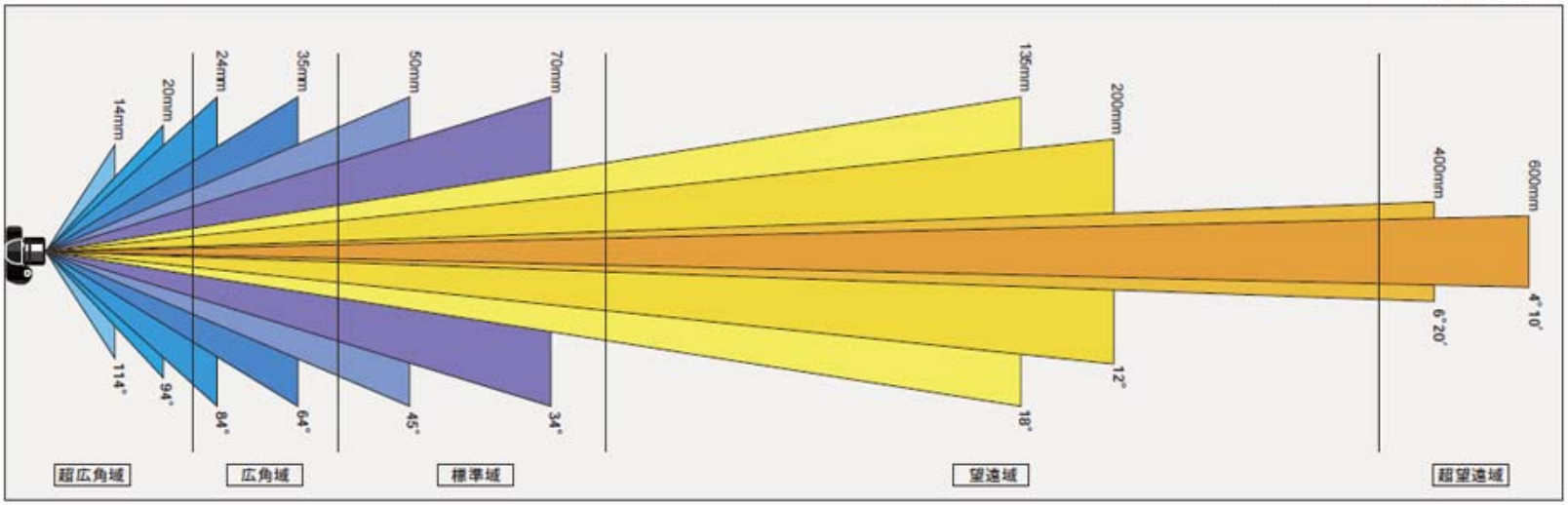
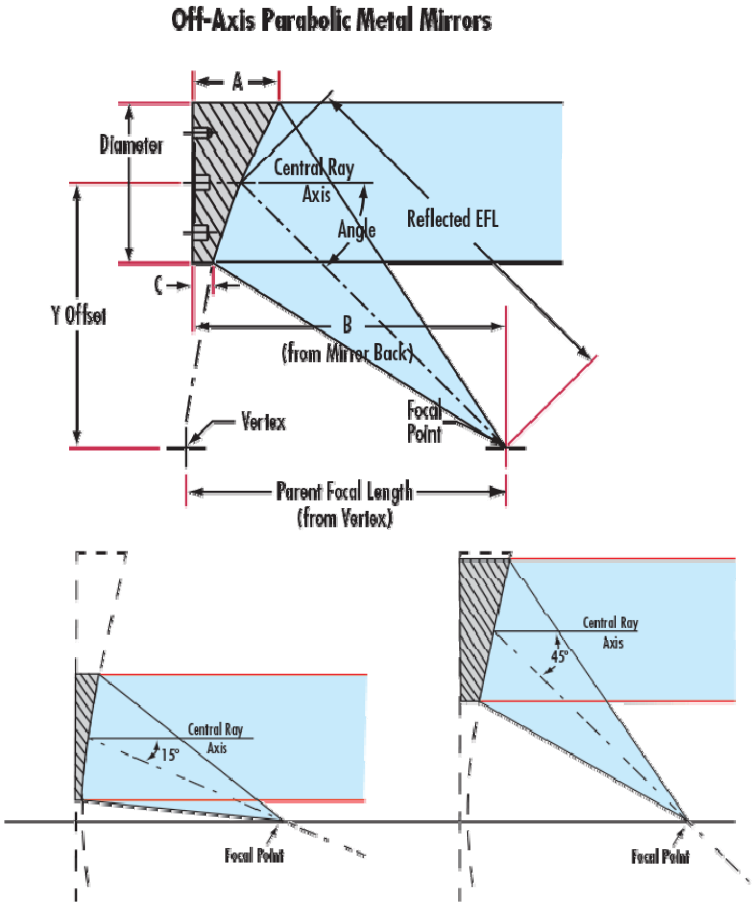


(2) Handling of LIGHT

Condensing(space)

index lens

parabolic mirror



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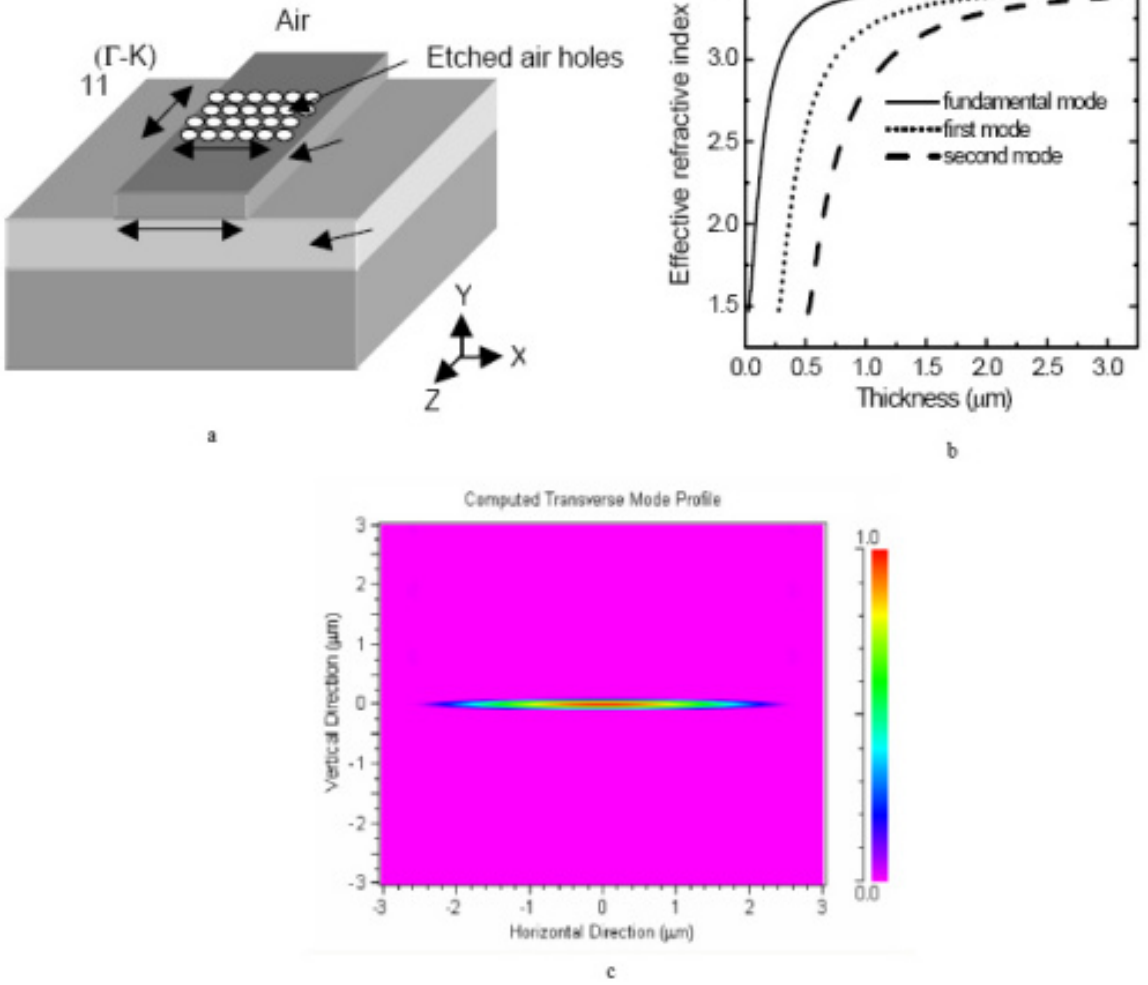
Photonic Crystal



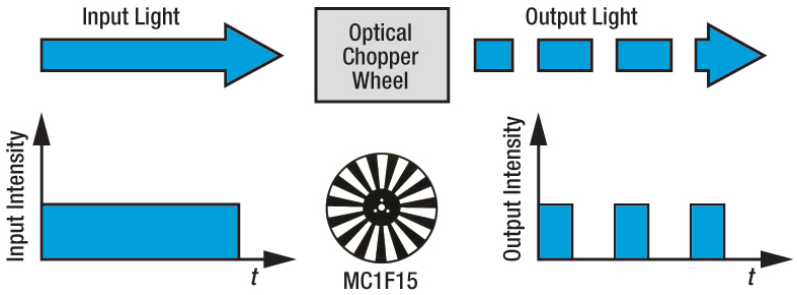
Optics Express Vol. 12, Issue 17, pp. 3934-3939 (2004)

(2) Handling of LIGHT

Condensing(time) / modulating

- shutter
- mode lock
- Q-switching

ms



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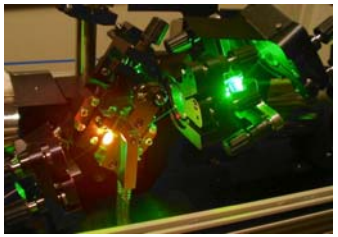

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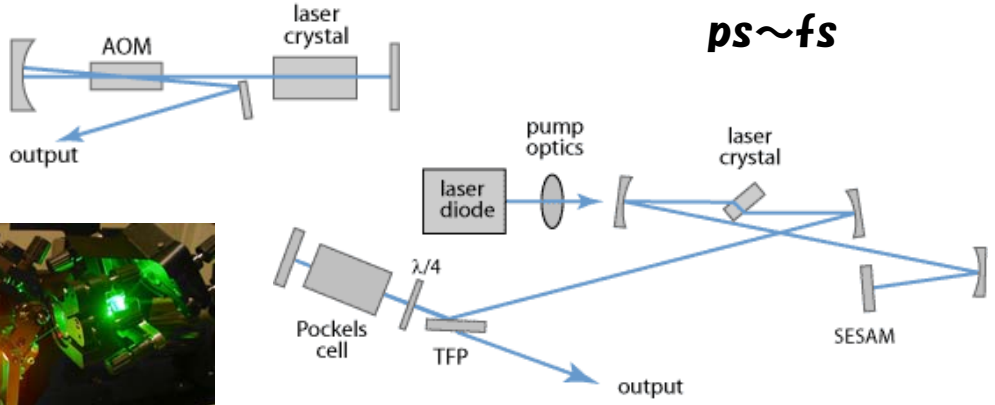

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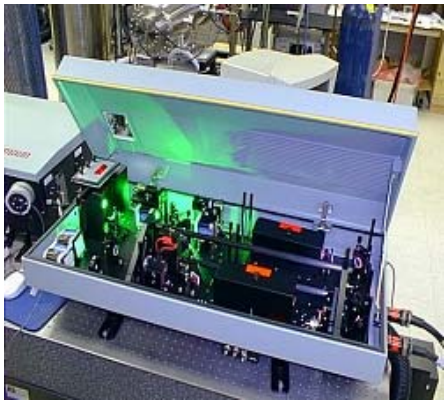

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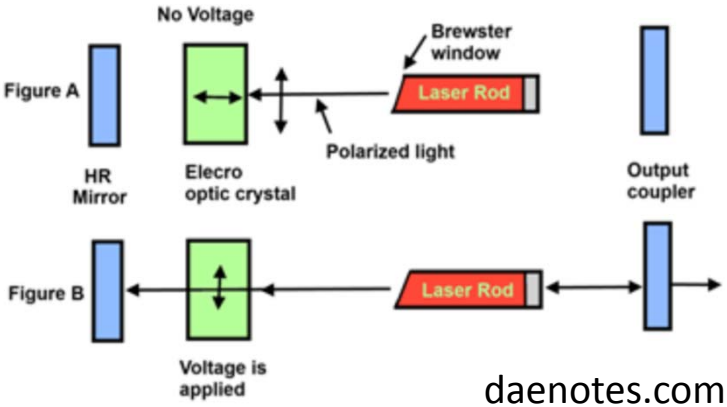

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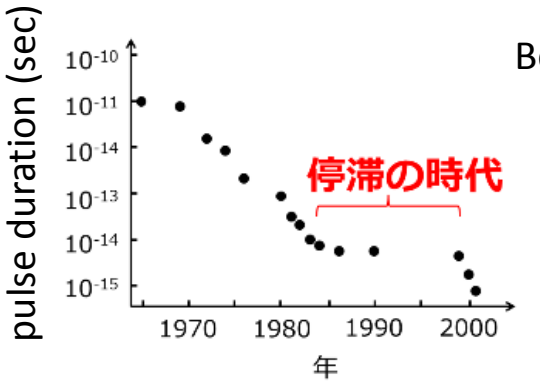
(2) Handling of LIGHT

Condensing(time) / modulating

- shutter
- mode lock
- Q-switching

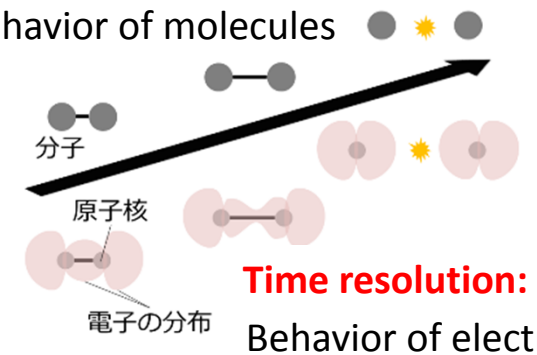
Nobel Prize in Chemistry 1999
Ahmed Zewail

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



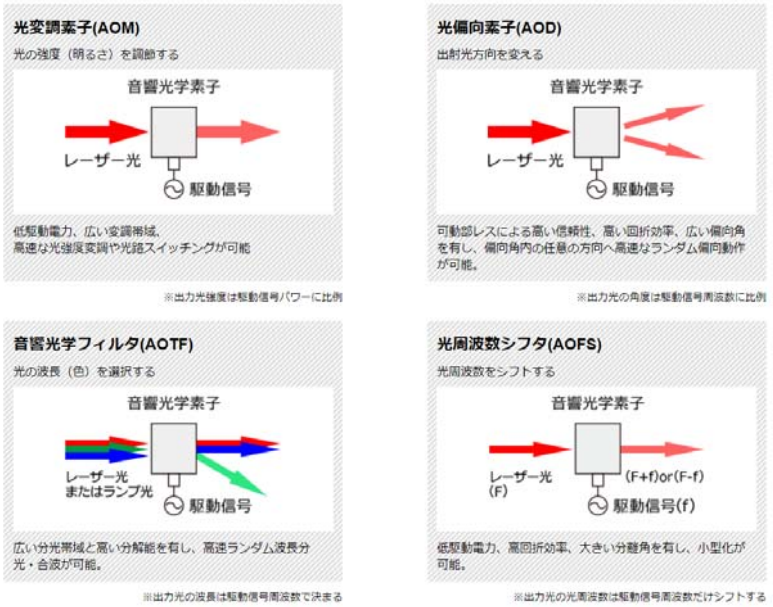
Until now

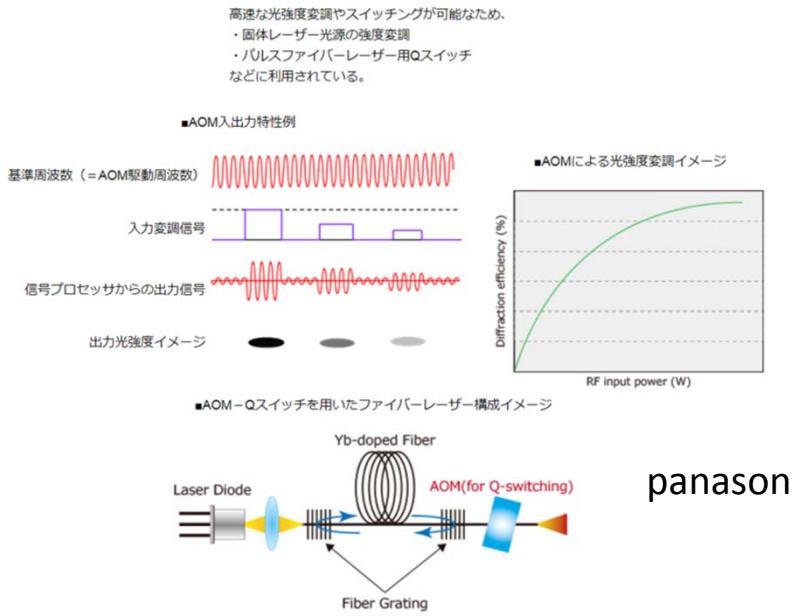
Behavior of molecules



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

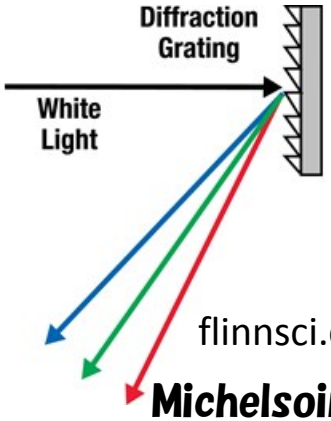
Selecting

filter

grating

interference

Raman effect



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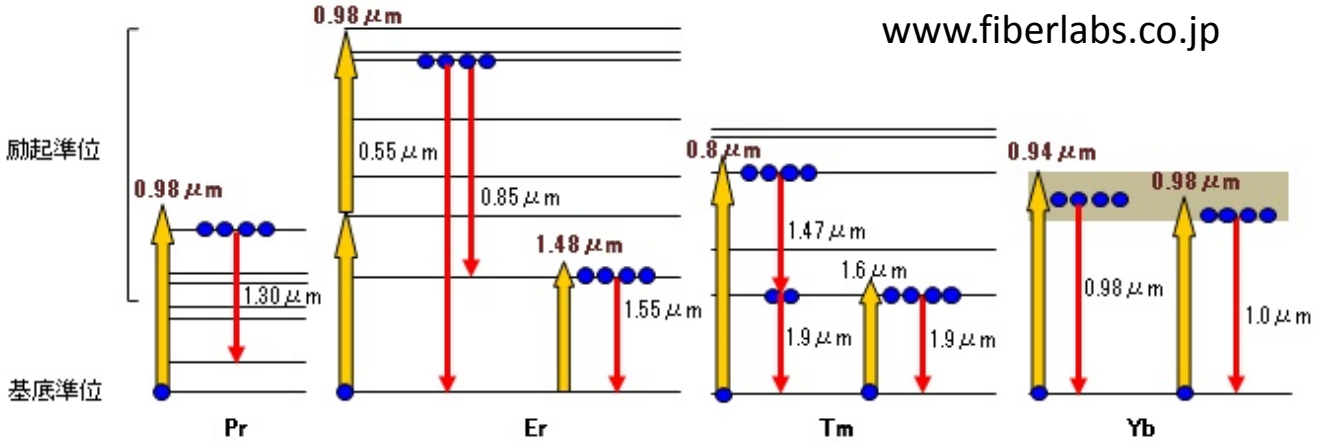
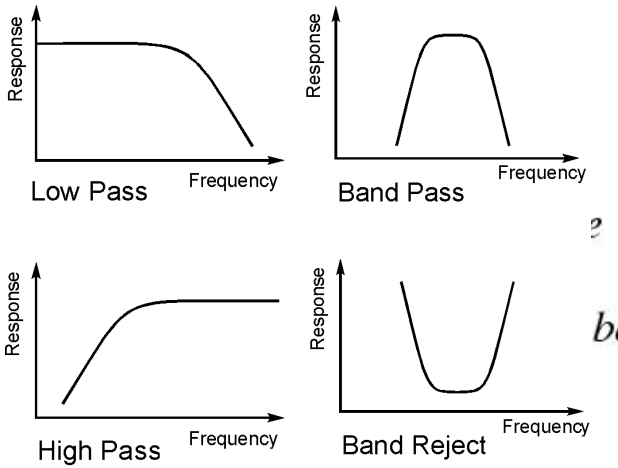


www.fiberlabs.co.jp

Filter



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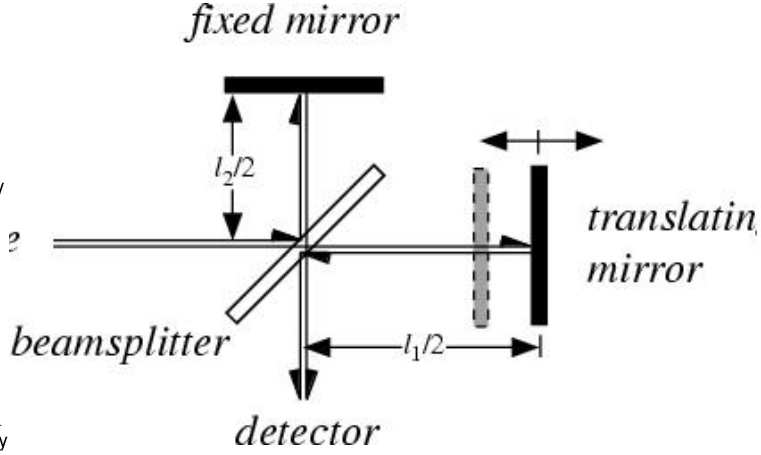
Michelsointerferometer



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Fabry-Perot interferometer

physik.uni-siegen.de

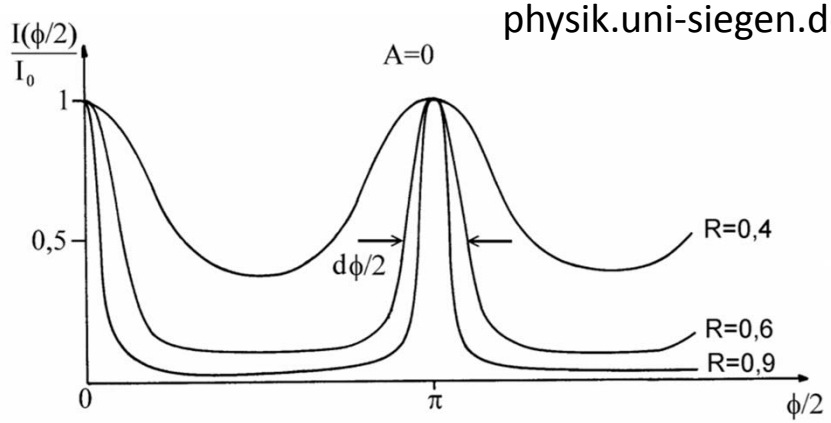
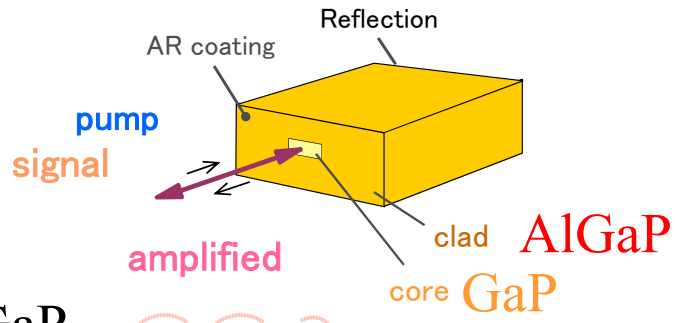


Figure 3: Airy function for different reflection coefficients R

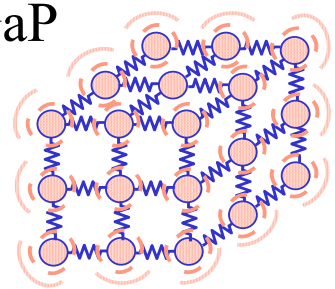
(2) Handling of LIGHT

Amplification
- stimulated emission in fiber
- Raman effect

Selecting
- filter
- grating
- interference
- Raman effect

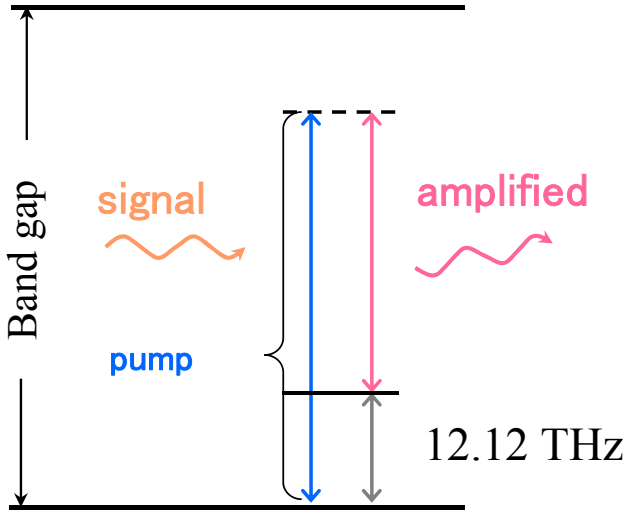


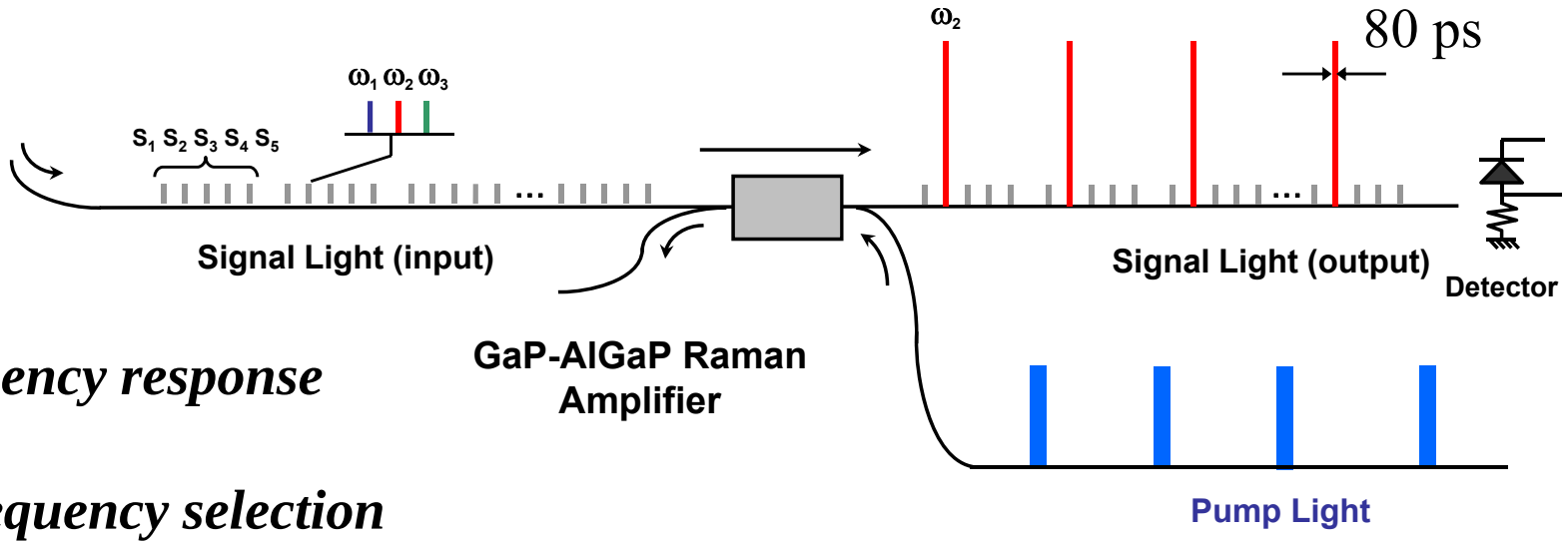
GaP



LO phonon
12.12 THz

▪ Stimulated Raman Amplifier





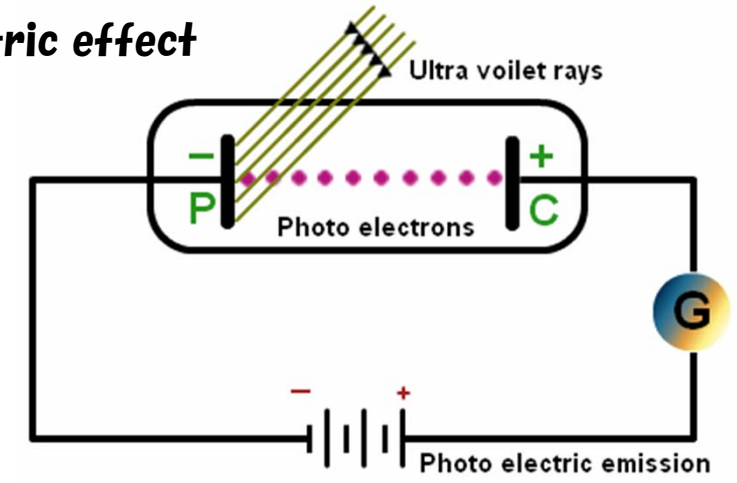
- *high-frequency response*
- *high gain*
- *narrow-frequency selection*

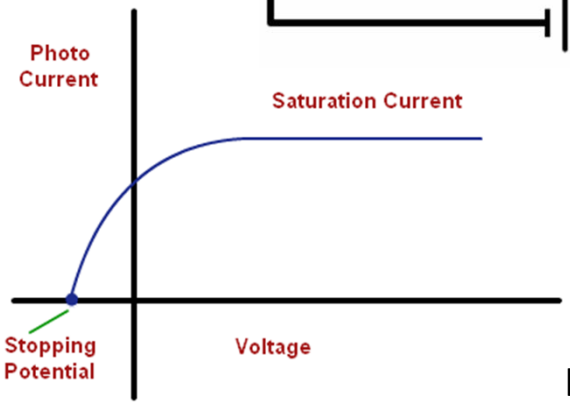
(2) Handling of LIGHT

Detecting

photoelectric effect
energy gap in semiconductor
bolometer / pyroelectric effect

photoelectric effect





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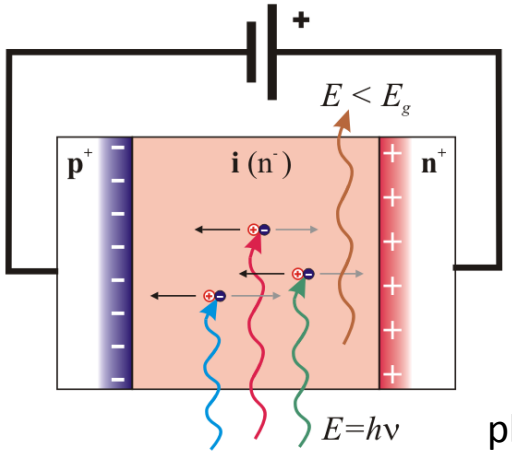
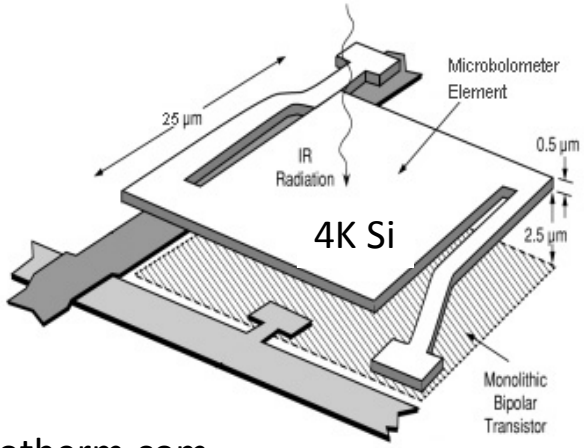
energy gap in semiconductor



physicsopenlab.org

bolometer / pyroelectric effect



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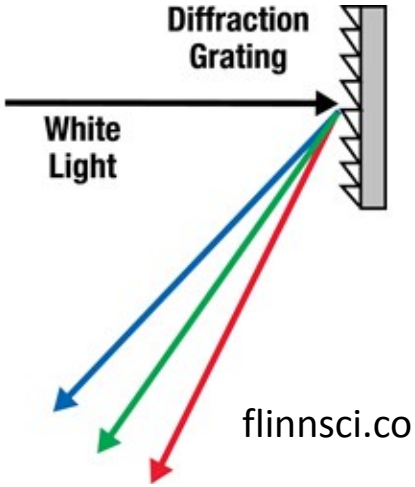
(3) Understanding of LIGHT conditions

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



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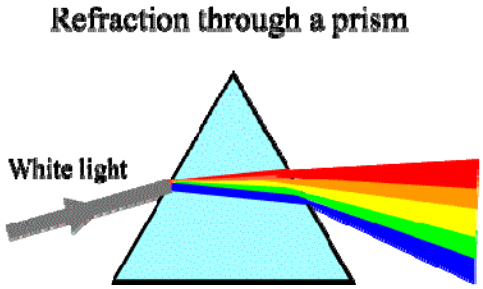

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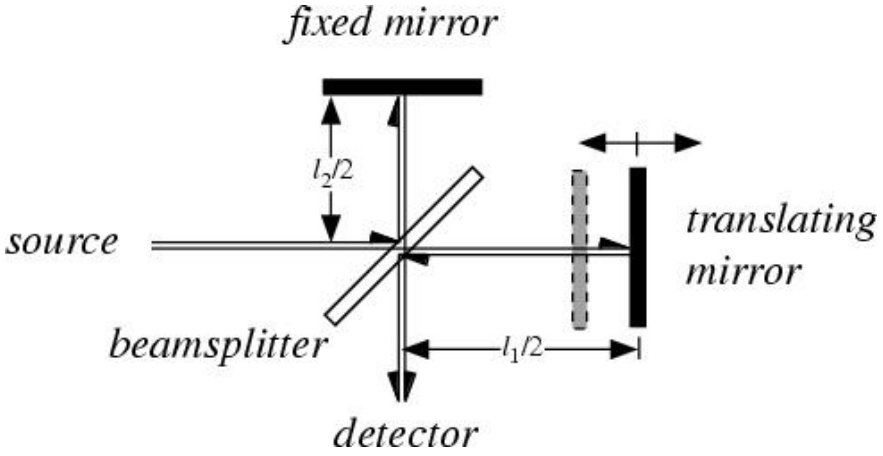
Michelsointerferometer



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Fabry-Perot interferometer

physik.uni-siegen.de

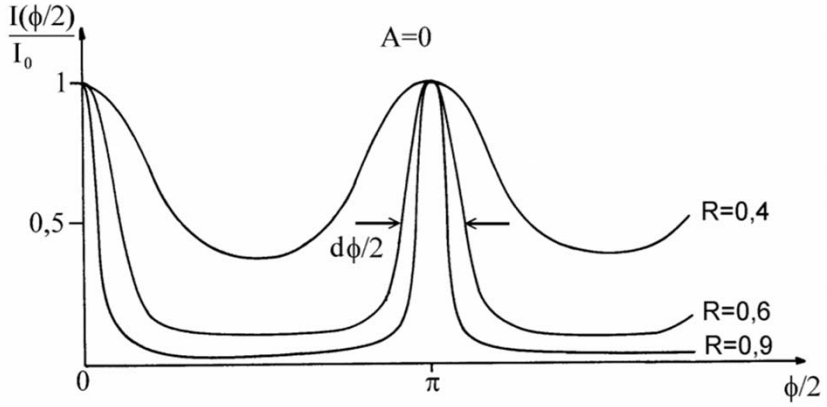
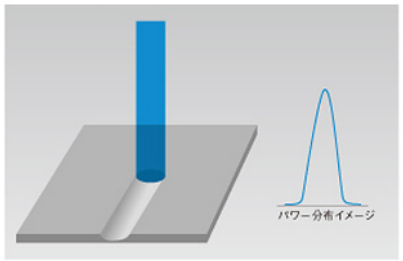


Figure 3: Airy function for different reflection coefficients R

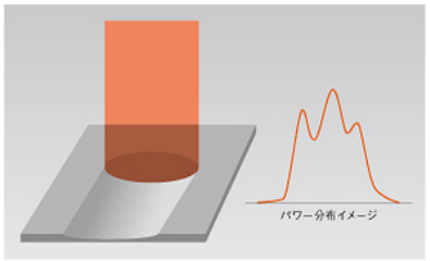
(3) Understanding of LIGHT conditions

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

single mode



multi mode



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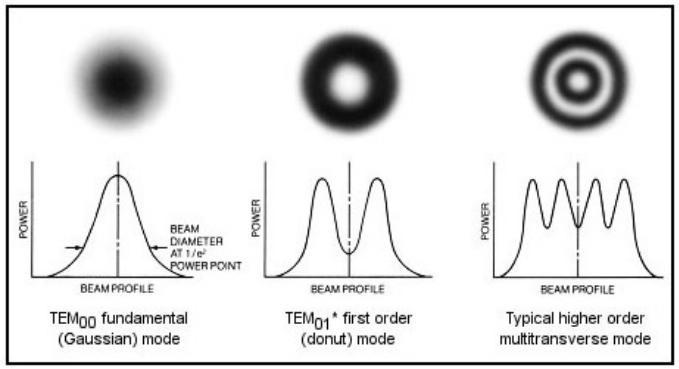

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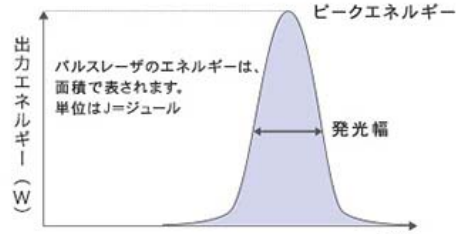
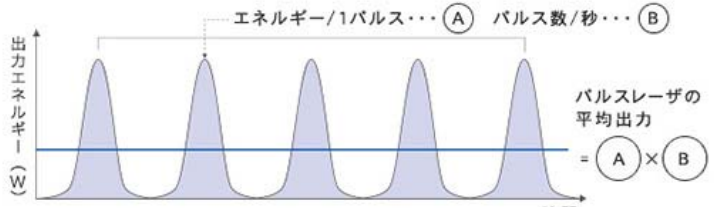
■ peak power



■ average power



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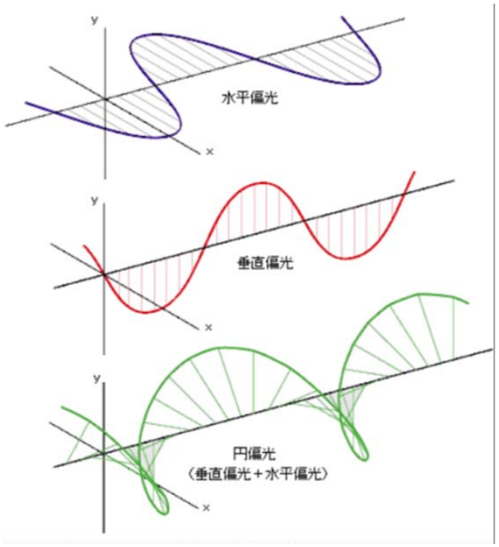

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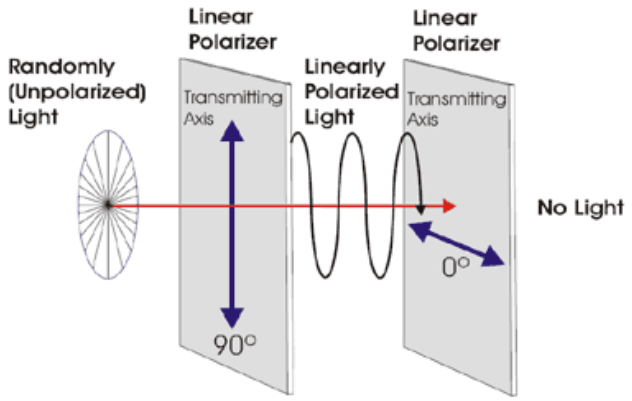

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