Nonlinear Photonics Group

Hattori-Kano-You Group

Graduate school:
Subprogram in Applied Physics, Program in Engineering Sciences,

Program in Humanics (Kano)

Undergraduate course:
Applied Physics, College of Engineering Sciences,

Bachelor's Program in Interdisciplinary Engineering (Hattori)

http://www.bk.tsukuba.ac.jp/~thz/

What is “Nonlinear Photonics”

- Optical phenomena induced by intense laser light, such as new-wavelength-light generation or creation of novel states of matters, are called “Nonlinear optical phenomena.” We use nonlinear optics for various application.

Research subjects

- Terahertz spectroscopy of biological tissues and materials for the understanding of water molecule dynamics
- Sensing using terahertz waveguides
- Development of new measurement techniques using terahertz waves

- Development of new pathological diagnosis using nonlinear Raman imaging
- Visualization of the reprograming process of iPS cells
- Study of lipid metabolism in brown adipocytes

Current status of the group

- Professor   Toshiaki Hattori （服部 利明）
  hattori@bk.tsukuba.ac.jp, 3F625
- Assistant Professor Borwen You （游 博文）
  you.borwen.gt@u.tsukuba.ac.jp, 3F530
- Associate Professor Hideaki Kano （加納 英明）
  hkano@bk.tsukuba.ac.jp, 3F607
- Students   Master course 12
  PhD course 1
  Undergraduate (4th year) 6
  Research students 5
  （as of October 2019）
- Labs   3G217, 3G411, Natural Science Building D205
- Student rooms   3G216, 3M408
- After graduation

  Hamamatsu Photonics, Tokyo Electron, Ricoh, Panasonic, NTT West, Terumo, SIIX, Aisin AW, Shimadzu, Japanese Bankers Association, Kao, Toshiba Medical, JR East, NHK, Furukawa Electric, Casio, Sanki Engineering, Asahi Glass, Tokyo Electric Power, Toyota Central R&D Labs, Shibaura Mechatronics, Sumitomo Heavy Industries, Japan Electrical Safety & Environment Technology Laboratories, Ruhr-Univ. Bochum, Mitutoyo, Hokkaido Electric Power, Southampton Univ., Fuji Technical Research, Fujitsu, IREP, Sharp, V Technology, Asahi Kasei, Wanbishi Archives, Canon, Toshiba, JR East, Fuji Heavy Industries, Sumitomo Life Insurance, Sumitomo Chemical

Nonlinear optical phenomena

- Sum frequency & difference frequency generation

$$\omega_1, \omega_2 \quad \Rightarrow \quad \omega_3 = \omega_1 + \omega_2$$

$$\omega_1, \omega_2 \quad \Rightarrow \quad \omega_4 = \omega_1 - \omega_2$$

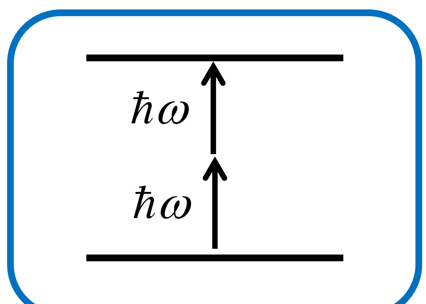
Terahertz wave genaration

- Optical wave mixing

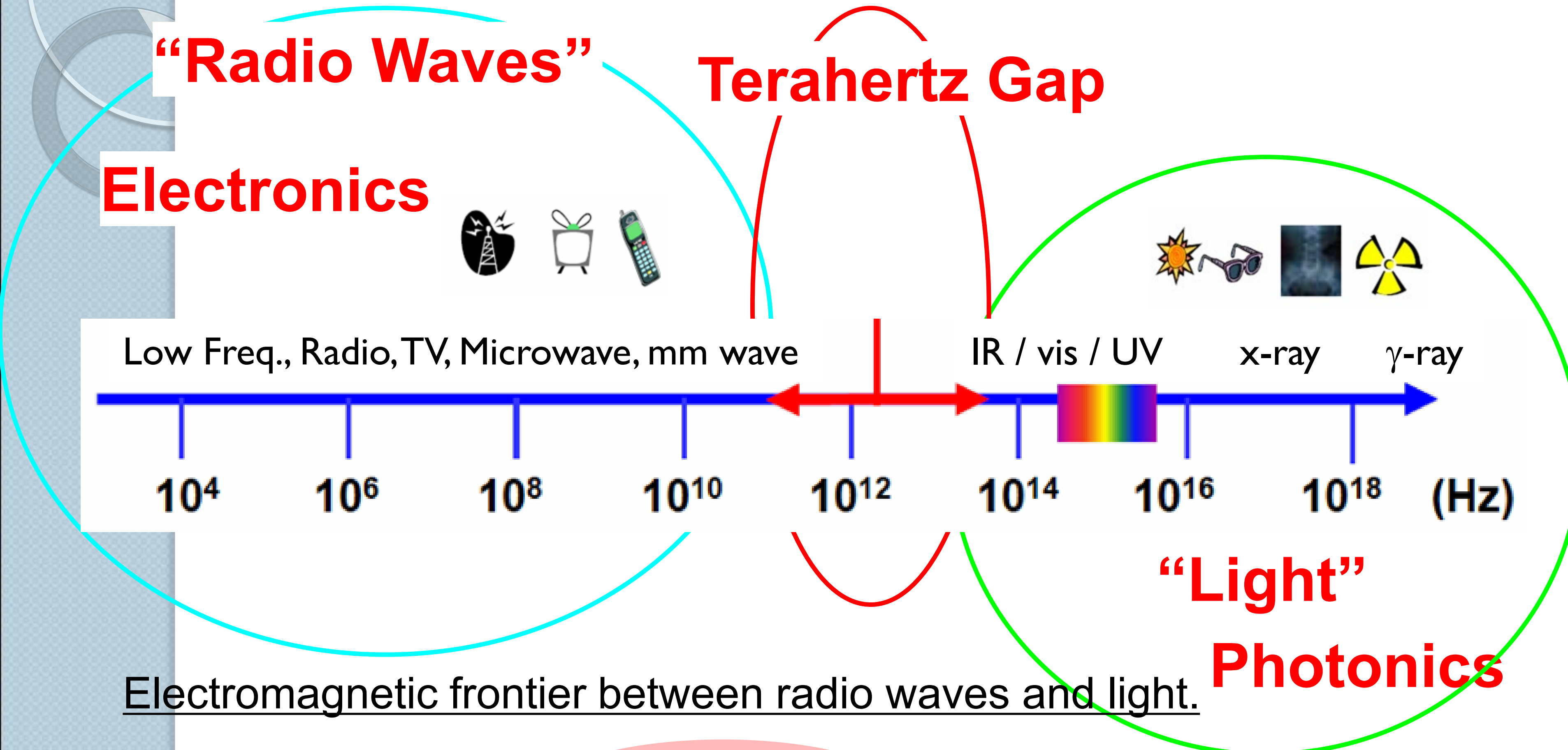
$$\omega_1, \omega_2, \omega_3 \quad \Rightarrow \quad \omega_4 = \omega_1 - \omega_2 + \omega_3$$

Coherent Raman scattering

- Multi-photon absorption & emission



What is "Terahertz Waves."



<u>Electromagnetic frontier between radio waves and light.</u>

Radio wave ⟷ Terahertz waves 0.03 - 12 THz ⟷ Light

Long wavelength
Low photon energy
Large diffraction

Short wavelength
High photon energy
Propagates straightly

Applications of terahertz waves

- Imaging

  Security inspection, product inspection, medical diagnosis

  Drugs, explosives and combustibles, semiconductors ・・・・

  Transmits through cloth, paper, etc.

  Absorbed by water. / Reflected by metals.

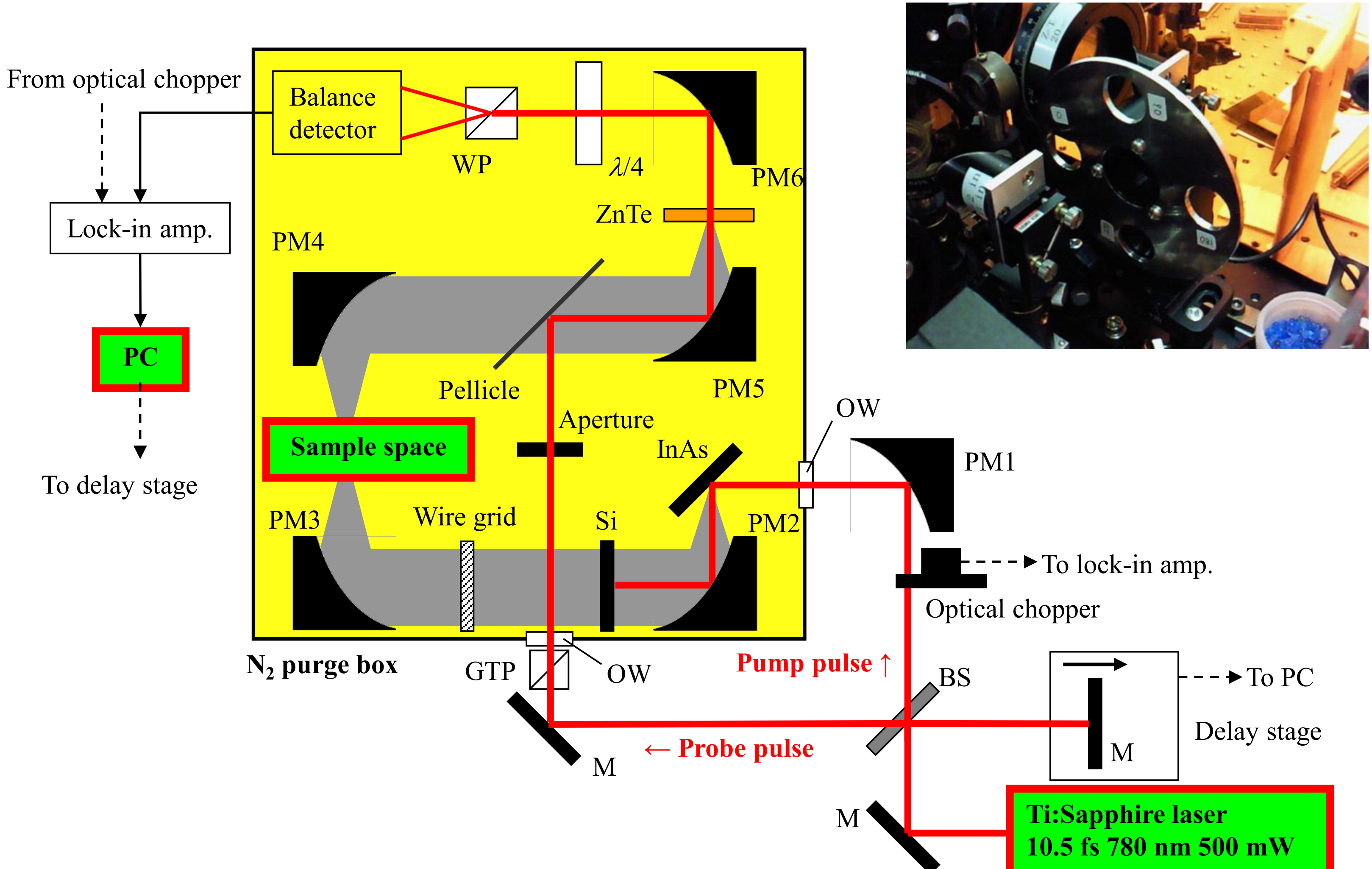
  Bio-safe. Spectroscopy for material identification.

- Spectroscopy

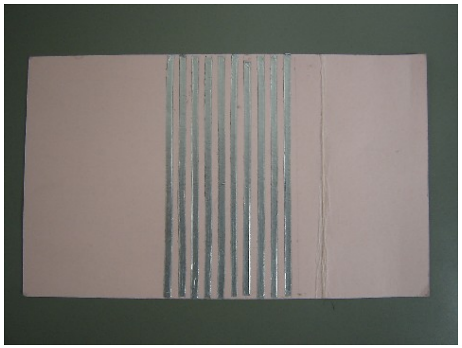
  Bio-materials, semiconductors, space, environment ・・・・

- High-speed communication

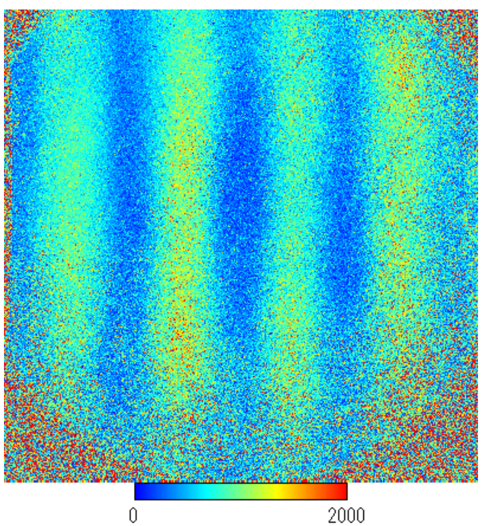
THz spectroscopy apparatus



Terahertz imaging

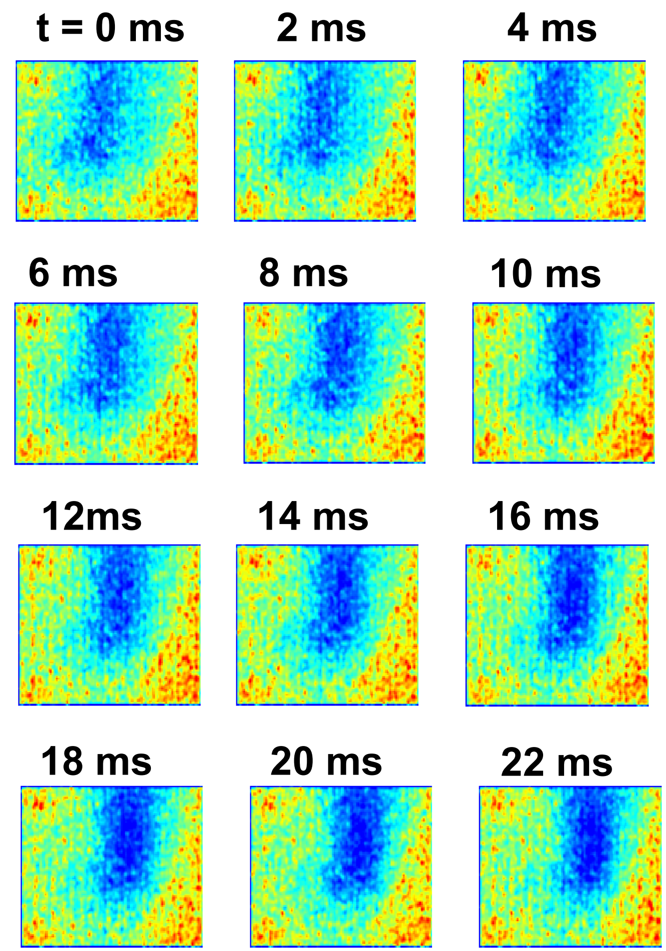


Metal strips

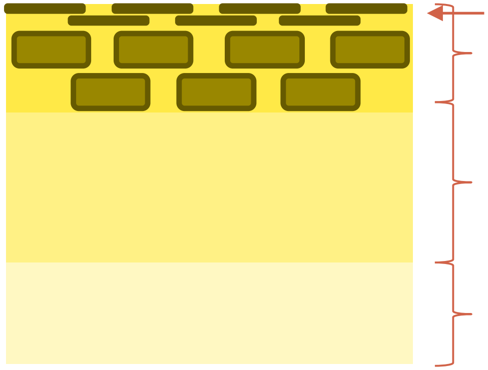


Terahertz image

High-speed THz video



Skin observed using terahertz waves



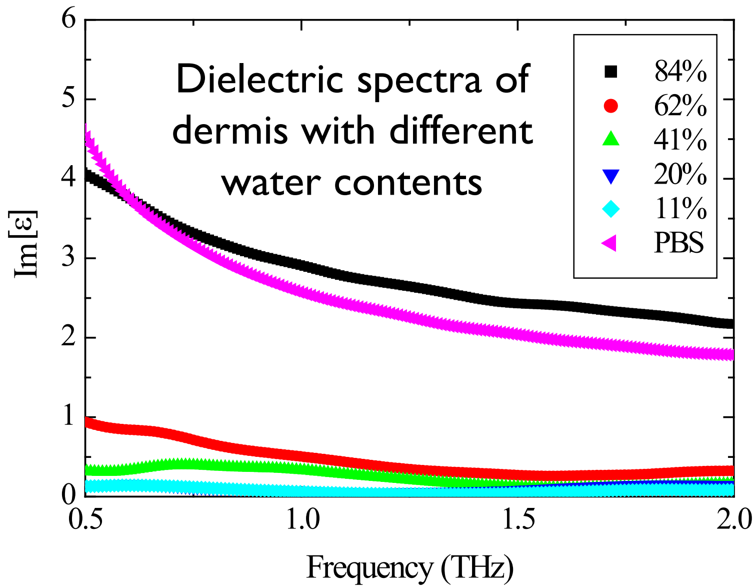
stratum corneum（0.02 mm）
epidermis（0.1～0.3 mm）

dermis（2～3 mm）

Composed of collagen, elastin, etc.

subcutaneous tissue

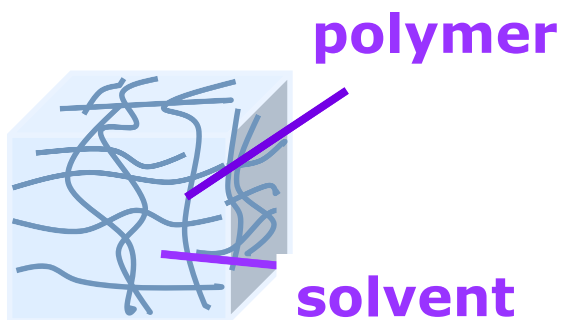
Dermis can affect skin resilience.
How is the relationship of aging with the water characteristi



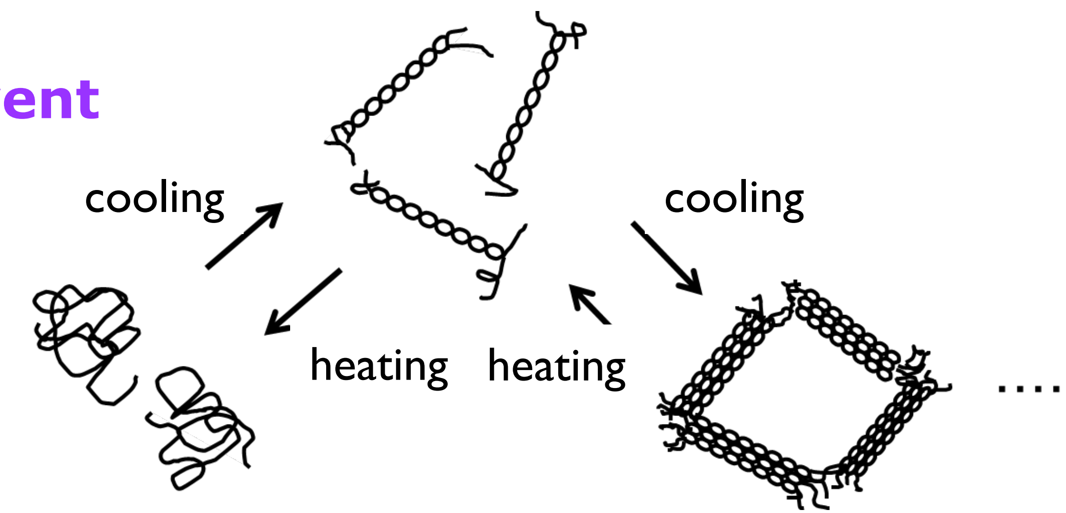
Gels observed using terahertz waves

・Agarose: polysaccharide, principal component of agar
・3-D polymer network contains water in agarose hydrogel.

Agarose gel

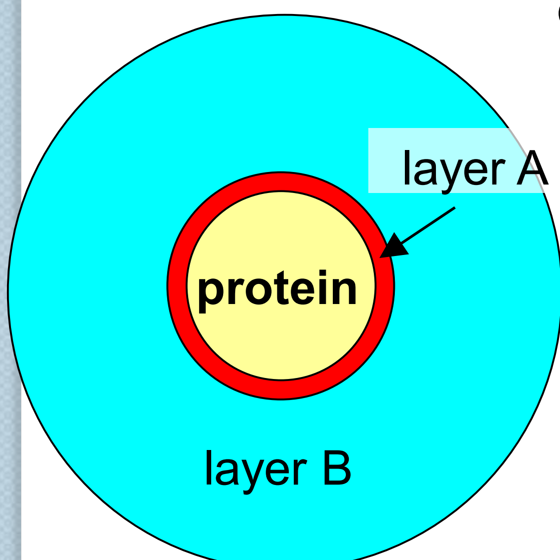


Sol-gel transition of agarose

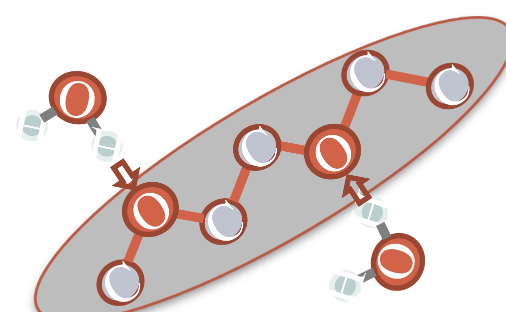


Hydration of various molecules

- Solutes are stabilized by interaction (such as electrostatic, hydrogen bond, etc) with solvents. This is called solvation. (Hydration in aqueous solutions.)
- Water molecules around the solute can have special properties.
- Functions of bio-molecules are enabled under this circumstance.



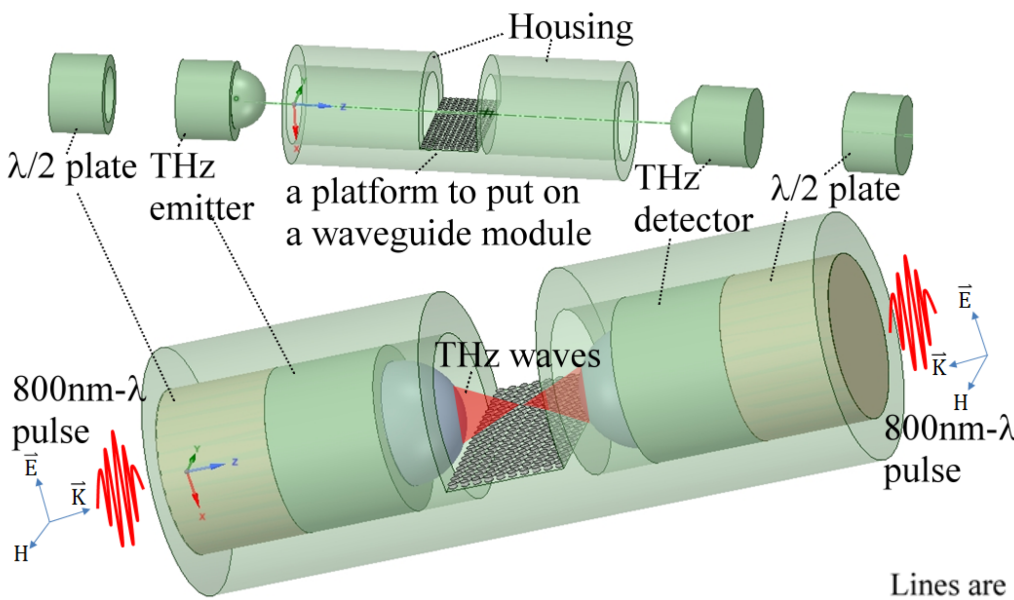
- Terahertz spectroscopy can show us the dynamical properties of hydration water.



- Hydration of polymers

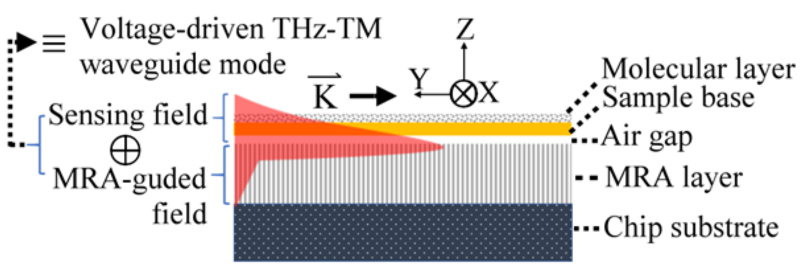
Advanced THz Optics-1

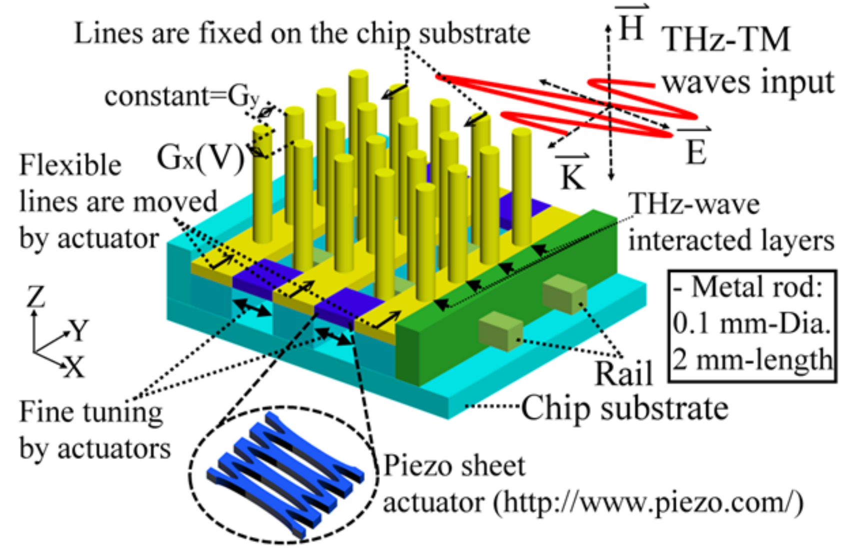
Research purpose-1: System on the chips



Knowledge background:

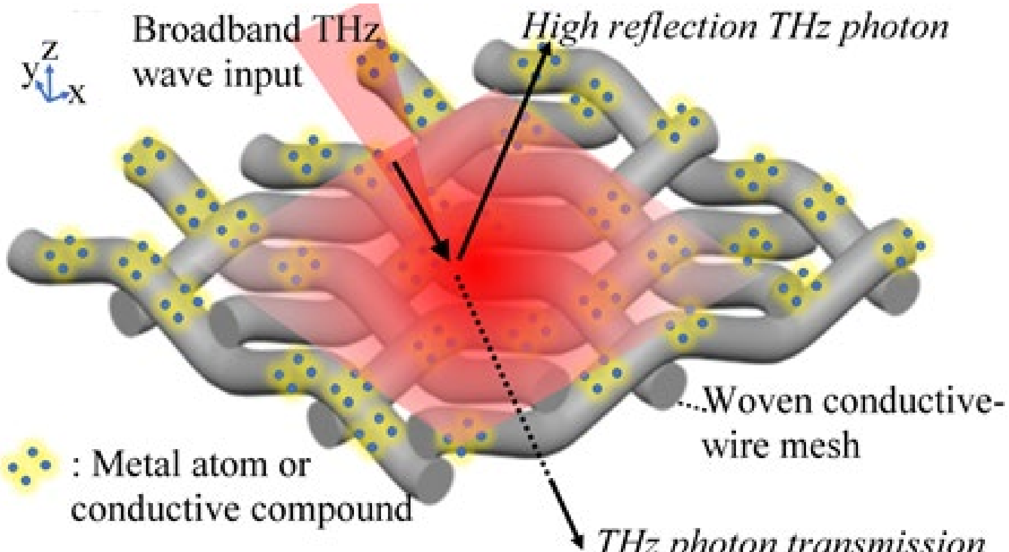
1) Integrated Optics
2) Integrated Sensors





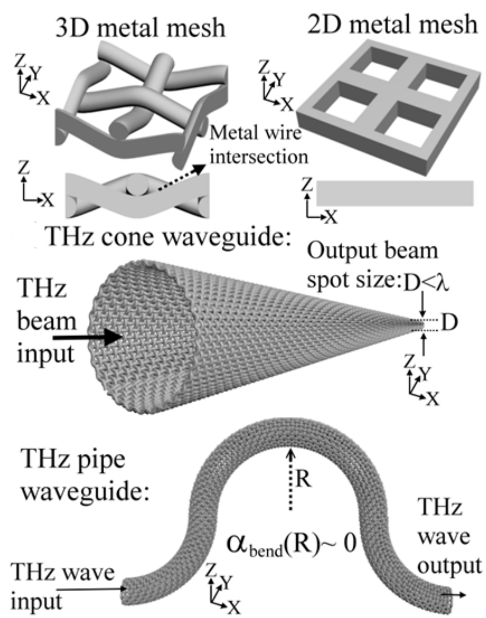
Advanced THz Optics-II

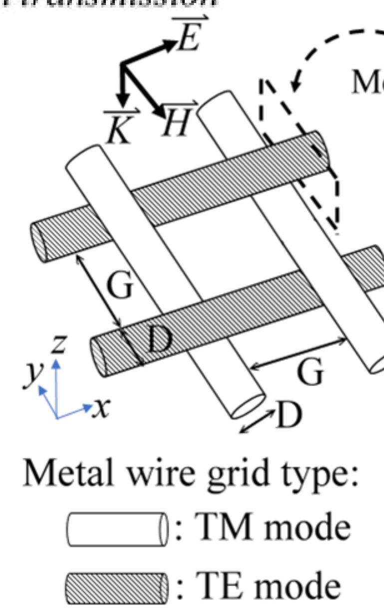
Research purpose-II: Artificial materials

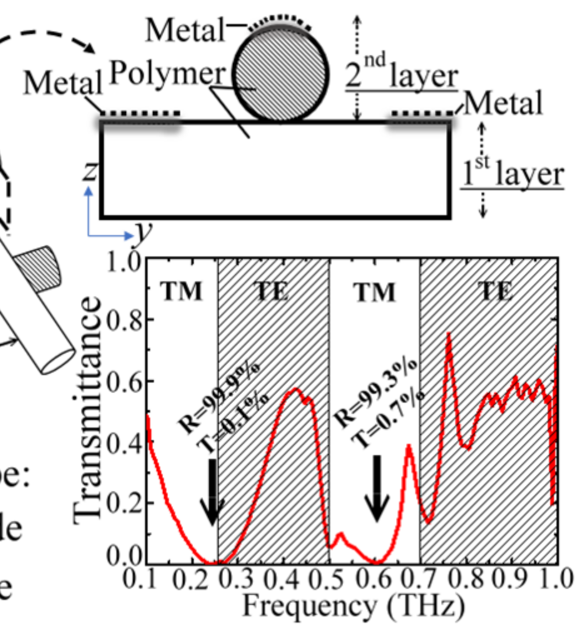


Knowledge background:

1) Optical thin-film engineer
2) Optical properties of materials
3) Photonic/plasmonic structures



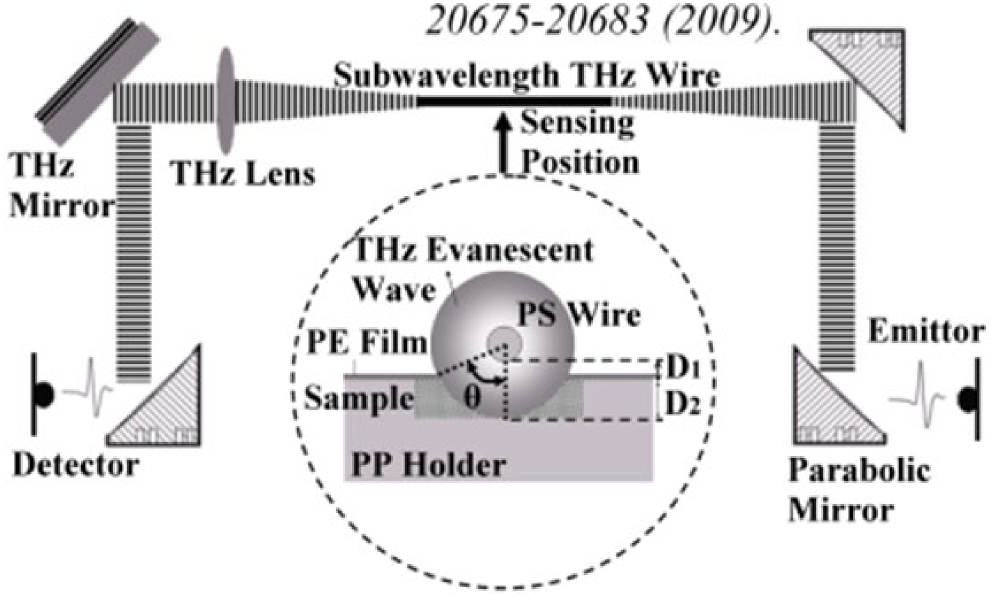




Advanced THz Optics-III

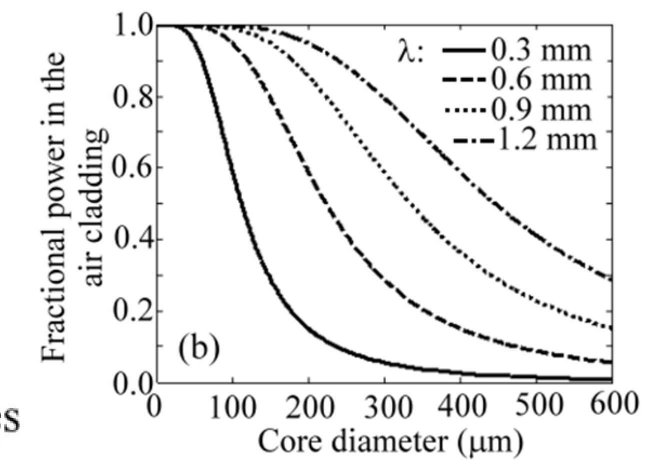
Research purpose-III: Fiber sensing technology

Optics Express 17, 20675-20683 (2009).



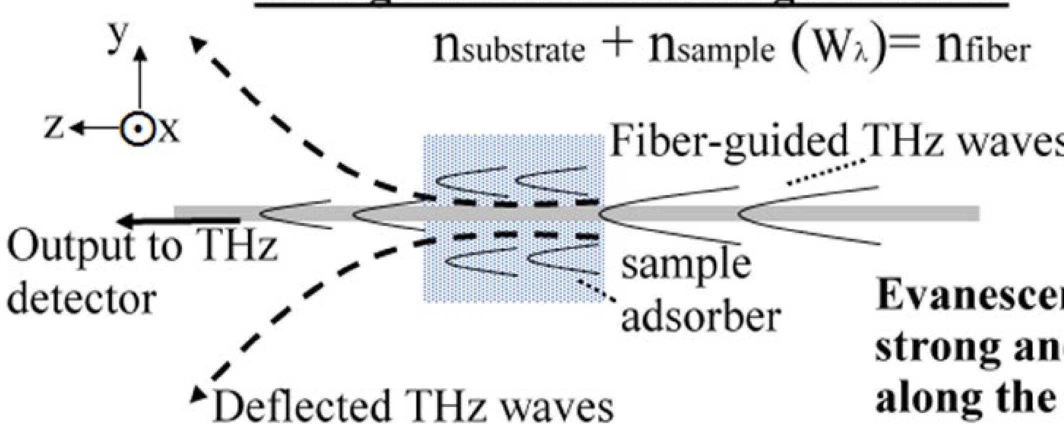
Knowledge background:

1) Fiber Optics
2) Ultrafast Optics
3) Time-Domain Spectroscopy



Waveguide index matching condition:

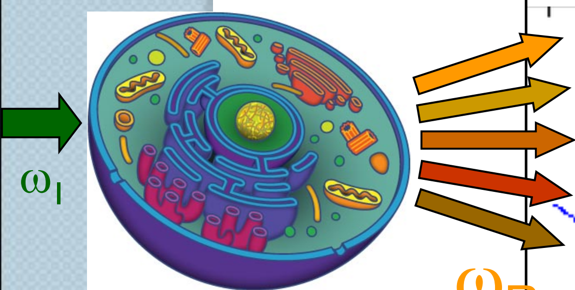
$$n_{substrate} + n_{sample}(W_{\lambda}) = n_{fiber}$$



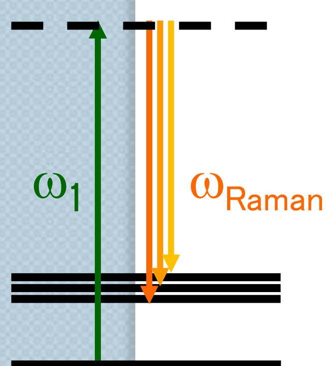
Evanescent wave is strong and uniform along the fiber !!

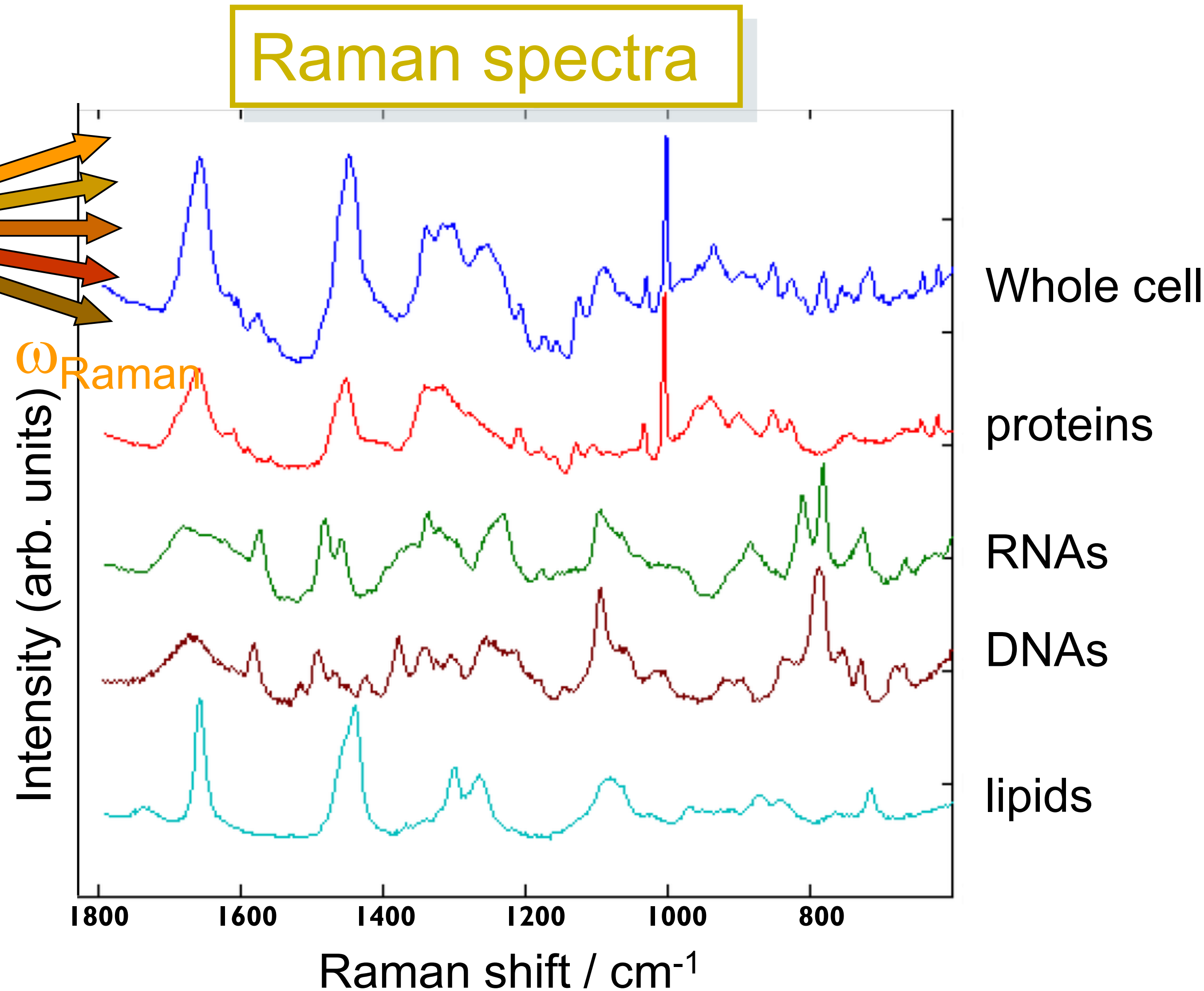
Exploring new horizons of life and medical sciences using nonlinear Raman spectroscopy

Spectra are letters from molecules



http://www.stemcellsinc.com/Science/Stem-Cells-101.htm





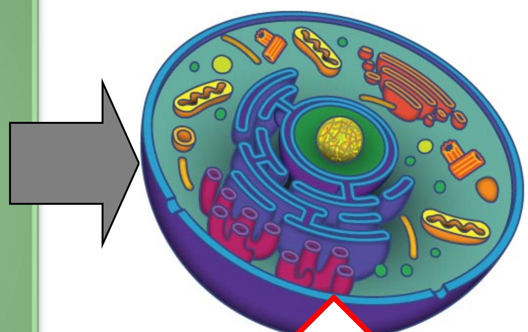
I. Notingher, *Sensors* 7, 1343 (2007).

Nonlinear Raman by white-light laser

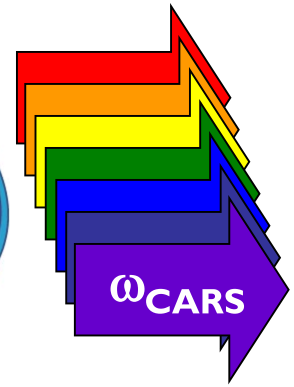
Development of white-light laser source
(JSPS bilateral with France)

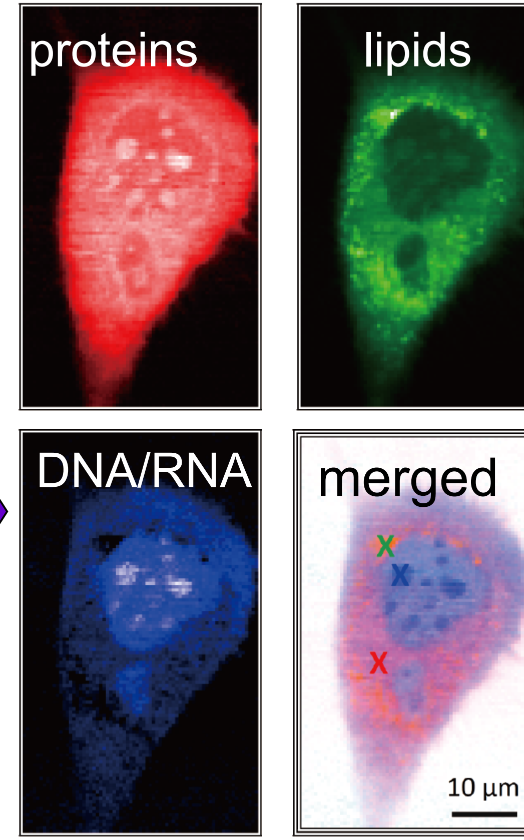
2007~

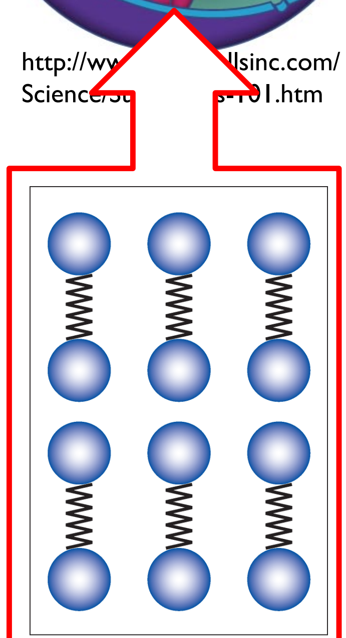
coherent anti-Stokes Raman scattering (CARS)

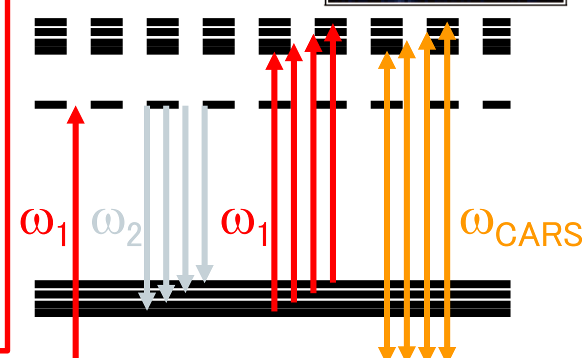


http://ww...llsinc.com/
Science/...s-101.htm









M. Okuno *et al,*
Angew. Chem. Int. Ed. 49, 6773 (2010);
PLoS ONE 9, e93401 (2014).

Research Highlight

- Unexpectedly found
  4th SHG-active protein filament

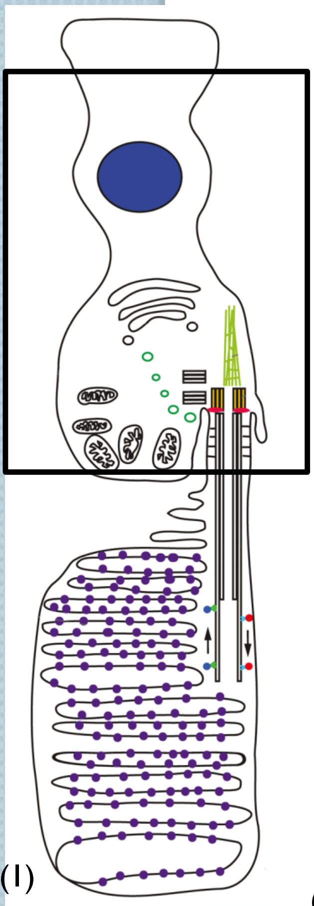
SCIENTIFIC REPORTS

OPEN

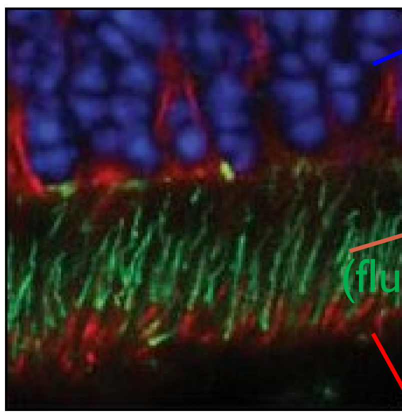
SHG-specificity of cellular Rootletin filaments enables naïve imaging with universal conservation

Received: 29 July 2016
Accepted: 30 November 2016
Published: 06 January 2017

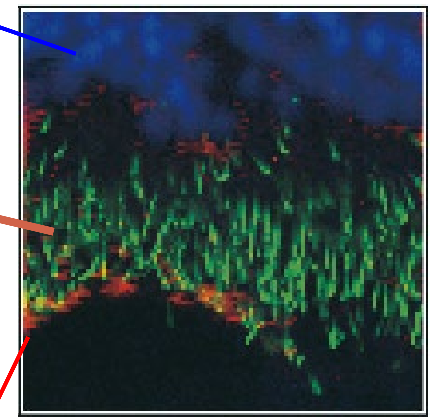
Toshihiro Akiyama[1,*], Akihito Inoko[2,*], Yuichi Kaji[3], Shigenobu Yonemura[4,5], Kisa Kakiguchi[4], Hiroki Segawa[6,†], Kei Ishitsuka[1], Masaki Yoshida[7], Osamu Numata[7], Philippe Leproux[8], Vincent Couderc[8], Tetsuro Oshika[3] & Hideaki Kano[1,9,10]


(1)

One-photon fluorescence[(2)]



Two-photon fluorescence & SHG
(present study)



DNA
(fluorescence)

Rootletin
(fluorescence) (SHG)

Ac-Tubulin
(fluorescence)

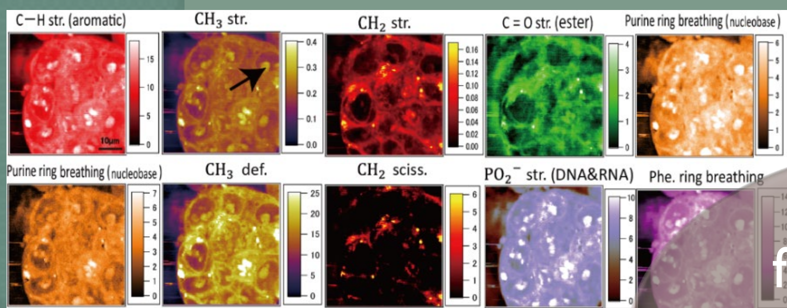
Excitation laser : 775 nm
Exposure time : 500 ms/ pix
Image area : 25 μm^2

Rootlet/Rootletin is SHG active !

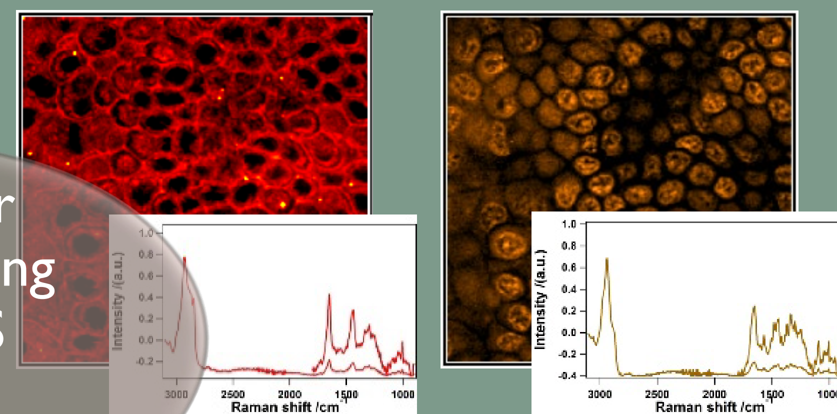
(1) Wheway *et. al. Landes Bioscience* , 10, 1 (2014)
(2) Rachel *et. al. HMG,* (2015)

Nonlinear Raman @ Univ. of Tsukuba

iPS & brown adipocytes（Medical dept., Prof. Hisatake lab.)



Eye tissues（Univ. hospital, ophthalmology, Prof. Ohshika and Prof. Kaji)

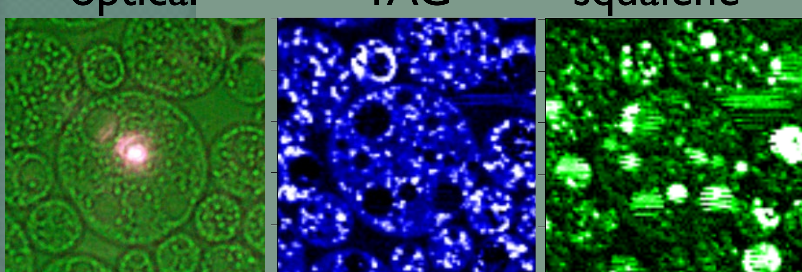


H. Segawa *et al.*, *J. Biophotonics* (2013)

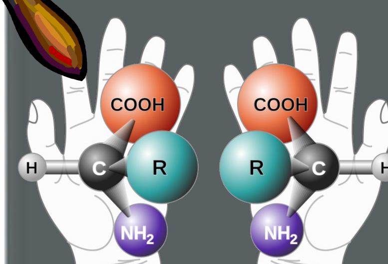
Molecular fingerprinting by CARS

Algae（dept. of life & envirnment, Prof. Watanabe)

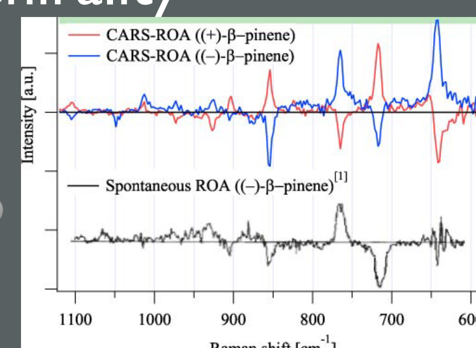
optical TAG squalene



Chirality



http://en.wikipedia.org/wiki/Chirality

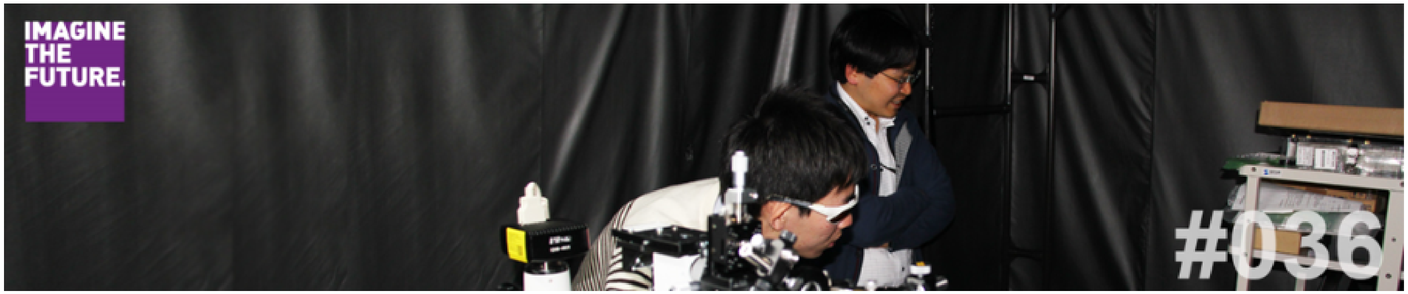


K. Hiramatsu *et al.*, *Phys. Rev. Lett.* 109, 083901 (2012).

For more details…

Interdisciplinary Collaboration on Molecular Fingerprints

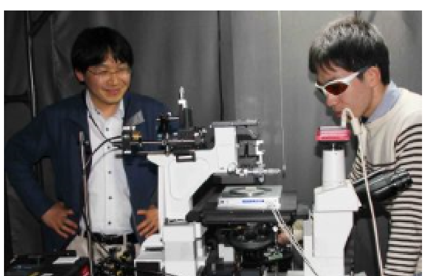
TSUKUBA FUTURE #036



How can we observe the structure of matter at the molecular level? Although it is impossible to see individual molecules with the naked eye, we can obtain information about the structure of matter by harnessing the power of light. When light is directed onto matter, the molecules vibrate and some of the light that is scattered has different color components than the original light. This phenomenon is detected as specific spectra that depend on the wavelength of the light and the types of chemical bonds in the matter. The theory behind this is that if you can interpret the spectrum, you can determine the molecular structure. This analytical technique is called "vibrational spectroscopy" and is performed using light of various wavelengths, including light of visible wavelengths as well as other types such as near infrared and ultraviolet light. There is also infrared spectroscopy, which is performed using infrared light.

In 1928, the Indian scientist Chandrasekhara Raman discovered that the light scattered by matter contains a very tiny amount of light with different wavelengths from the light that was originally directed onto the matter (Raman scattering). "Raman spectroscopy" is performed using this very small amount of light. One disadvantage of this method is that Raman scattering is extremely faint and difficult to detect. Nevertheless, it is widely used because it can analyze both organic and inorganic matter in solid, liquid, or gaseous form.

Prof. Kano is working on methods of observing living tissues using this Raman spectroscopy technique. For example, he has started developing a new method for discerning the molecular composition of eye tissues in collaboration with the ophthalmology department of University of Tsukuba Hospital. They have succeeded in visualizing the distribution of molecules in the eye in three dimensions by directing a laser at parts of the eye including the cornea, lens, and retina and analyzing what molecules are present at certain depths. Although in these experiments they analyzed eye tissue taken from rats, if the intensity of the laser is adjusted to an appropriate level that does not affect the human body, it may become possible to detect disease by pointing a laser directly at the human eye and analyzing differences in the composition or distribution of molecules.



Watching a graduate student set up a Raman microscope

Showing a graduate student how to operate a Raman microscope

https://www.tsukuba.ac.jp/en/people-list/tsukuba-future-036