

# Food Sensing – some sensors and applications

Helmut Teichmann



**Photonics 4**  
**Food**

Zollikofen | 1 June 2016

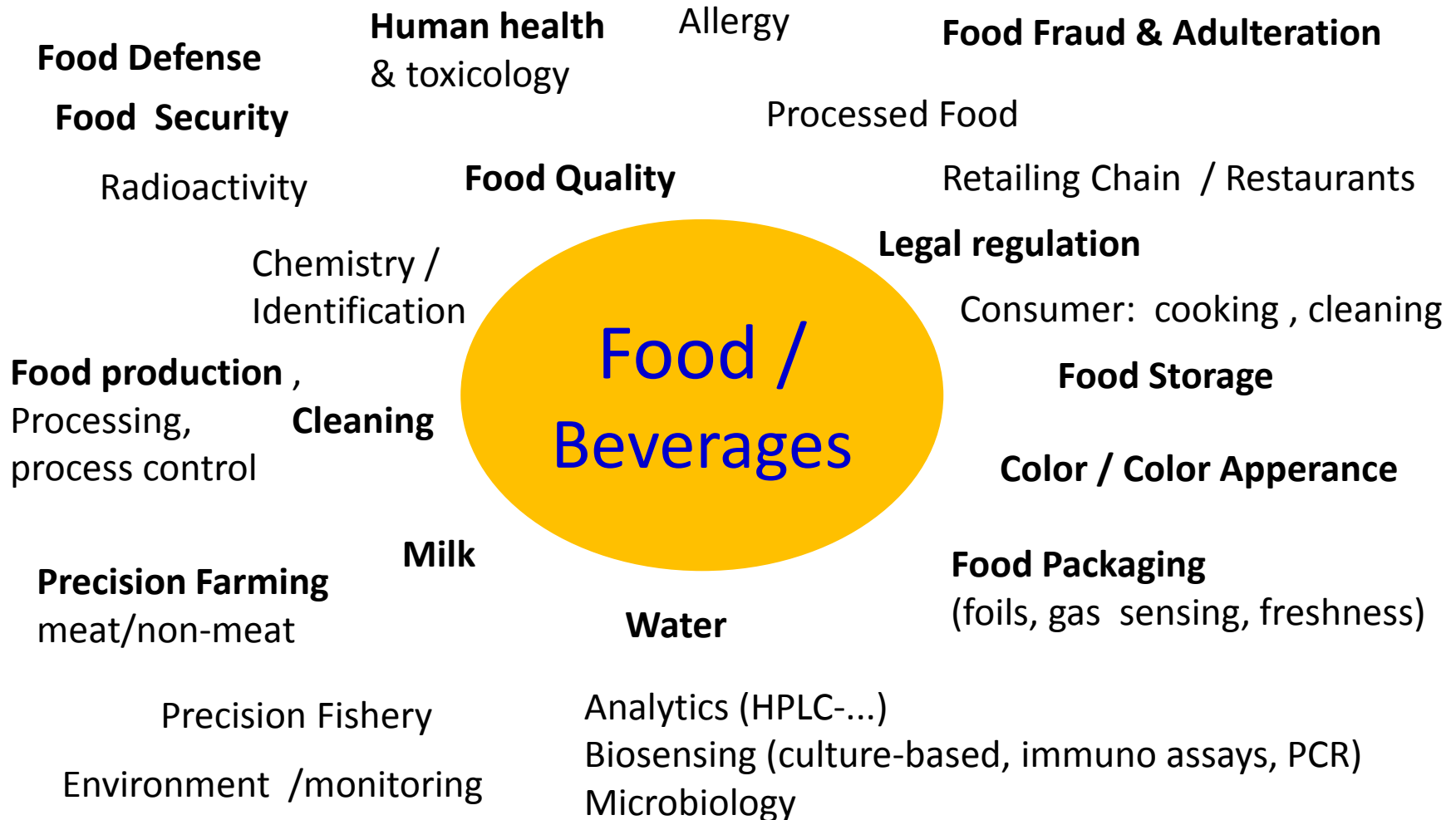


PHOTONICS PUBLIC PRIVATE PARTNERSHIP

**PHOTONICS<sup>21</sup>**



## Food – a world in its own



## Food - a regulated world

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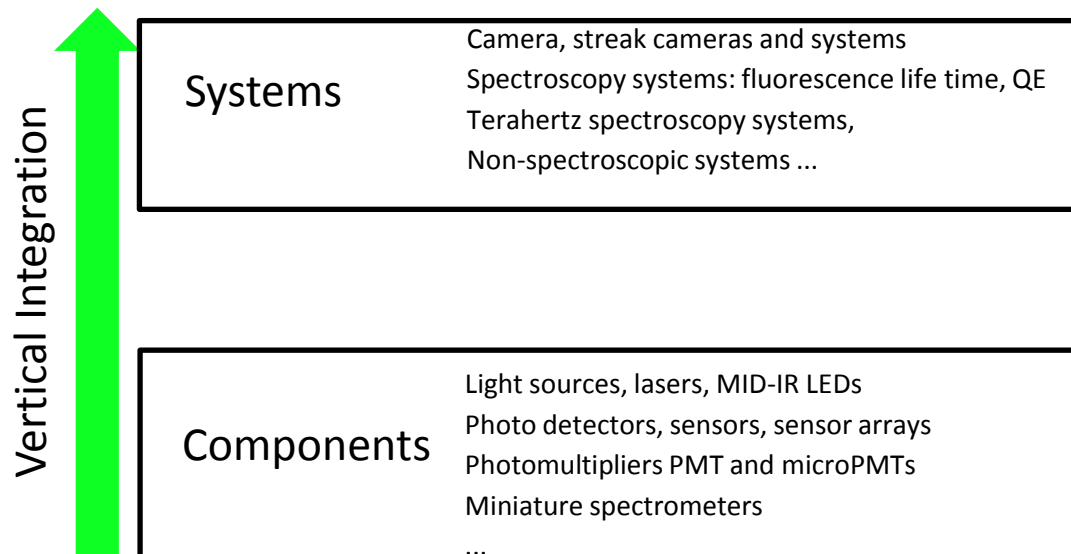
### **Legal regulation:**

- **US: EPA**      **Env. Protection Agency+FoodQ**
- **D: BMEL+V**    **BuMi Ernährung Landw. +VerbrS**
- **CH: BLV**      **BuAmt f. Lebensmittelsicherheit  
und Veterinärwesen**
- **CH: EEK**      **Eidg. Ernährungskommission**

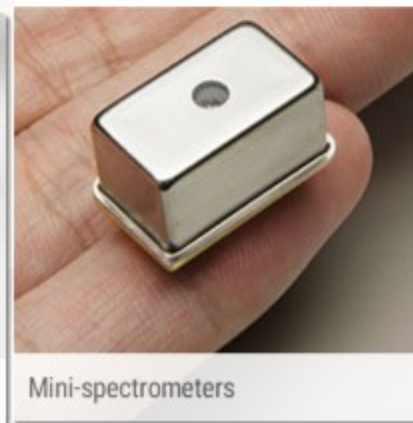
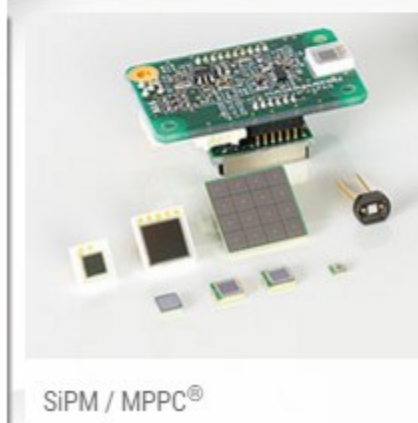
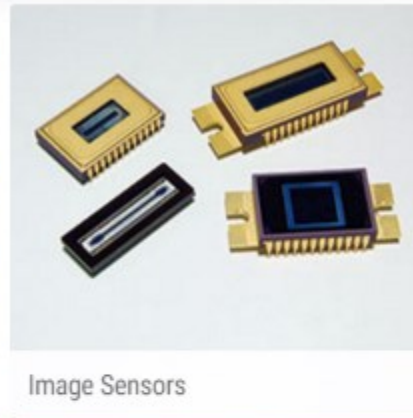
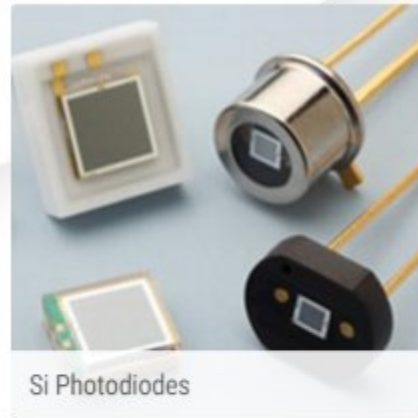
## Short introduction to Hamamatsu Photonics

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- Leading supplier for Optoelectronics
- 4000 Employees in 4 Divisions
- Active worldwide
- Products:



## Typical Hamamatsu Component Products



- More than 60 different product trees !
- One important customer segment for us: **Analytical Market, OEM**

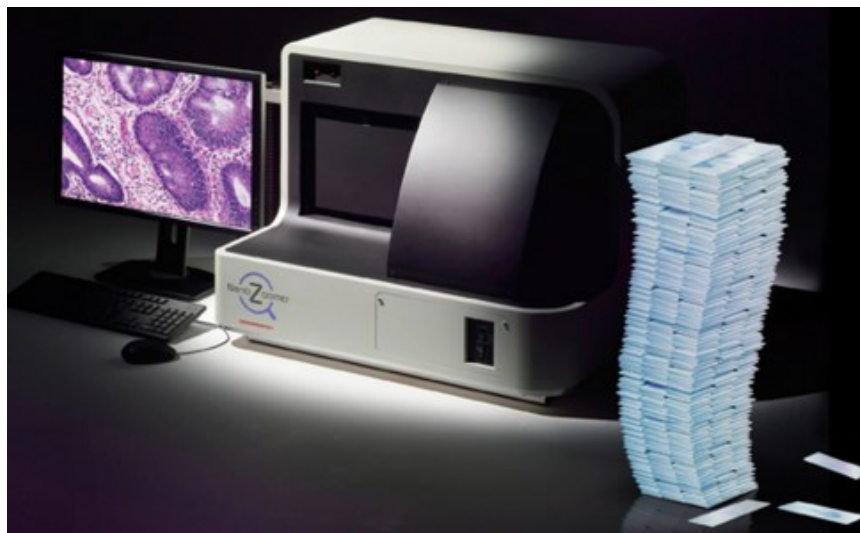
## Some Hamamatsu Systems Products



**Camera Systems**  
industrial OEM,  
Life Science



**Functional Drug Discovery System**  
kinetic fluorescence MultiWellPlate reader

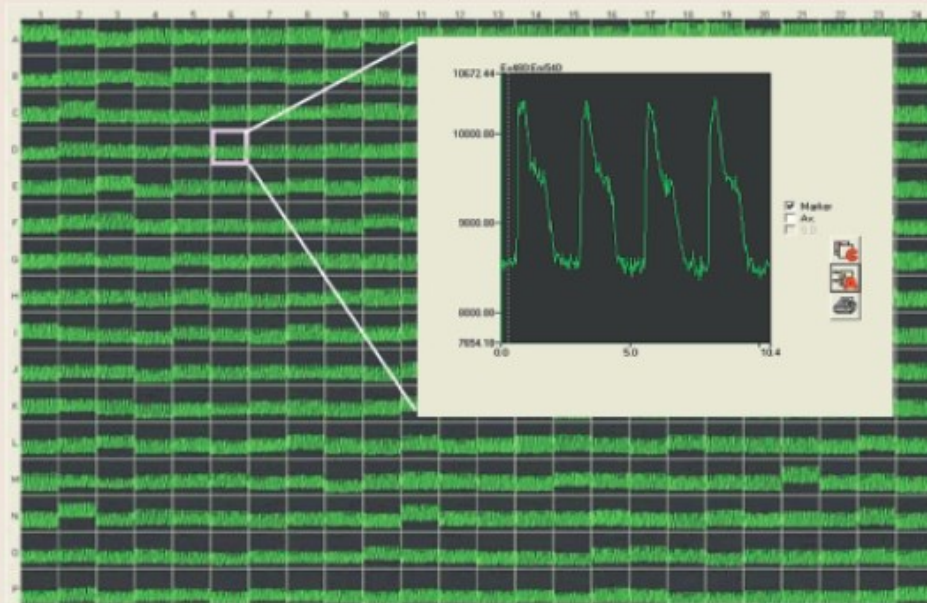


**Nanozoomer Slide Scanner**

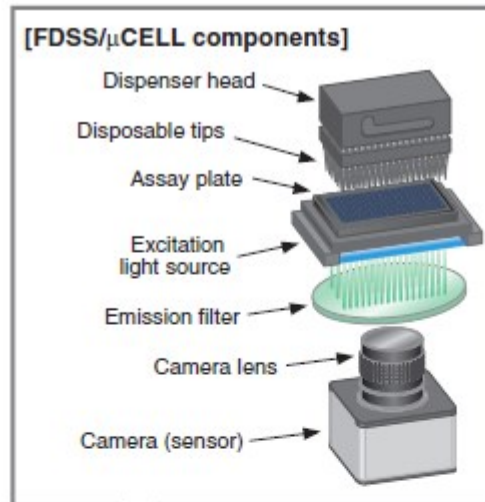
# Stem-cell Based Toxicology for Drug Discovery

## Ca<sup>2+</sup>-transient measurements in human iPS-derived cardiomyocytes

Cells: Cor.4U<sup>®</sup> human induced pluripotent stem (iPS) cell-derived cardiomyocytes (Axiogenesis AG)



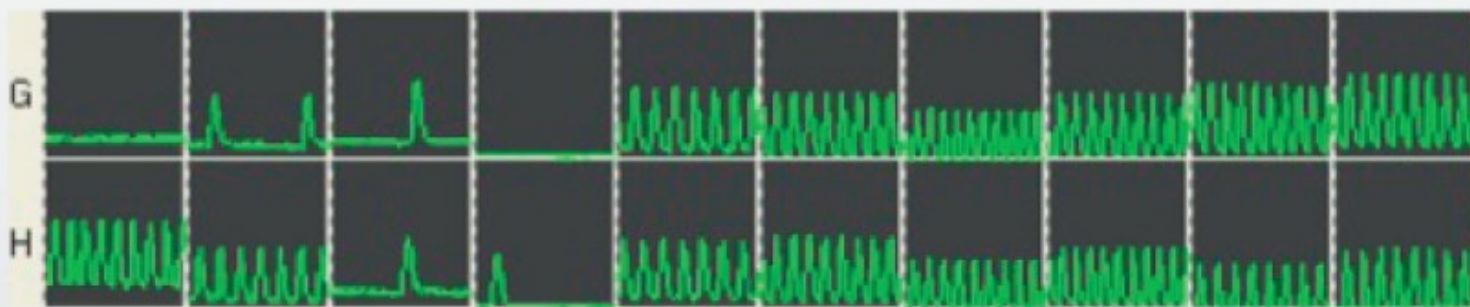
FDSS/ $\mu$ CELL is capable of measuring Ca<sup>2+</sup>-transients in iPS/ES-derived cardiomyocytes in 96/384-well plate format.



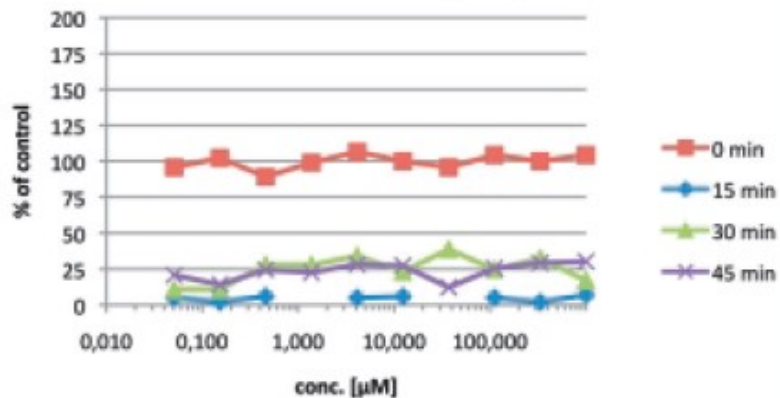
## Effect of TTX Tetrodotoxin on Cardio-cells

# FDSS $\mu$ Cell - Effect of Tetrodotoxin (TTX)

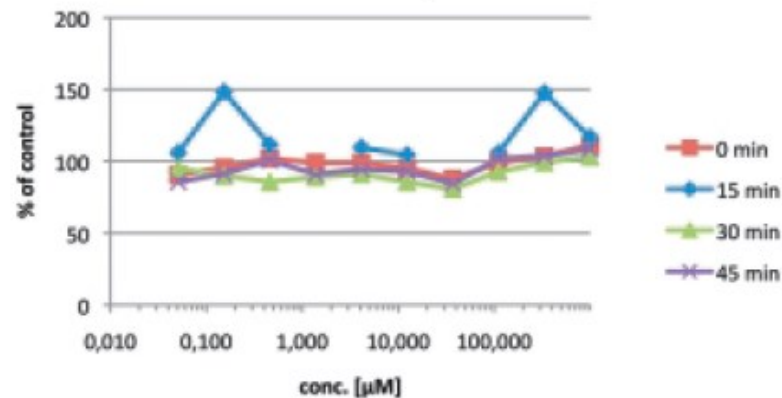
50    16,67    5,56    1,852    0,617    0,206    0,0686    0,0229    0,0076    0,0025  $\mu$ M



relative P rate [ /min]



relative Amplitude



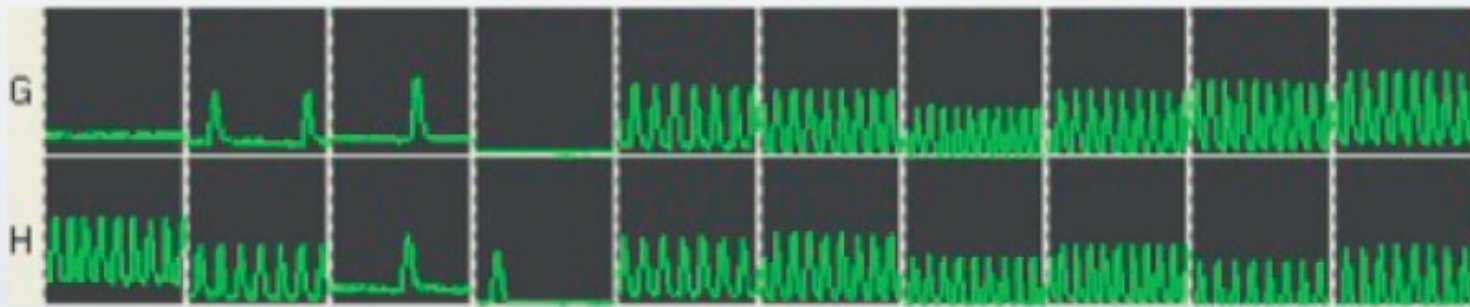
[http://www.hamamatsu.com/resources/pdf/sys/SBIS0098E\\_FDSSuCELL\\_AX.pdf](http://www.hamamatsu.com/resources/pdf/sys/SBIS0098E_FDSSuCELL_AX.pdf)



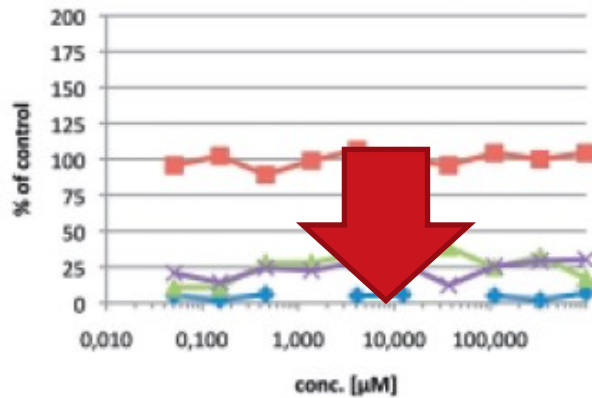
## Effect of TTX Tetrodotoxin on Cardio-cells

# FDSS $\mu$ Cell - Effect of Tetrodotoxin (TTX)

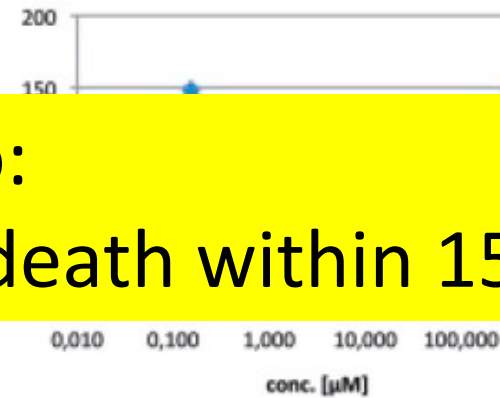
50    16,67    5,56    1,852    0,617    0,206    0,0686    0,0229    0,0076    0,0025  $\mu$ M



relative P rate [ /min]



relative Amplitude



**In Vivo:  
heart death within 15 min**

## Hamamatsu Photonics: Headquarter and Production in Hamamatsu City, **JAPAN**

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- Japan, *the* Land of **FOOD**
- Europe's thinking = Sushi



Historically: **Sushi** = **high tech** fast food



Shiso (jap. Perillia): natural antibiotics



Situation: You are offered a FUGU dinner from your business partner

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Cont... You are offered a FUGU dinner from your business partner



- Deepest obeisance and huge appreciation
- Not eating is a 'little bit impossible'

Then it comes to you mind

THE WALL STREET JOURNAL.

Home [World](#) U.S. Politics Economy Business Tech Markets Opinion Arts

# Five Hospitalized After Eating Fugu Fish

By [JUN HONGO](#)

Mar 2, 2015 2:12 pm JST

0 COMMENTS



This file photo taken in June 2012 shows a 'fugu' puffer fish being prepared at a restaurant in Tokyo. AGENCE FRANCE-PRESSE/GETTY IMAGES

## Fishbones: Dual energy detection for better contrast

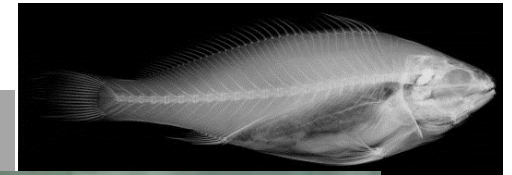
<https://www.youtube.com/watch?v=Tnofuo9Qx9M>



TXR X-ray inspection machine

## Fishbones: Dual energy detection for better contrast

<https://www.youtube.com/watch?v=Tnofuo9Qx9M>



TXR X-ray inspection machine



## Fishbones: Dual energy detection for better contrast

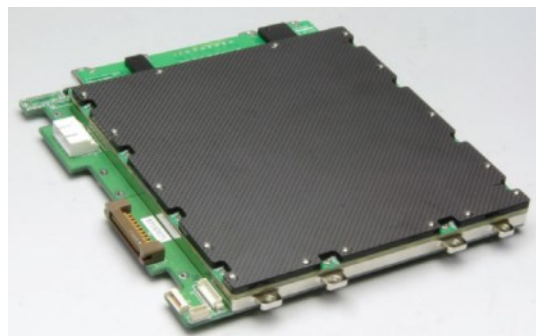
<https://www.youtube.com/watch?v=Tnofuo9Qx9M>



TXR X-ray inspection machine

## Some Hamamatsu Products for X-Ray detection

Microfocus X-ray Sources - sealed type



**C10900D Flat panel sensor**



**C7942CA-22  
Flat panel sensor**



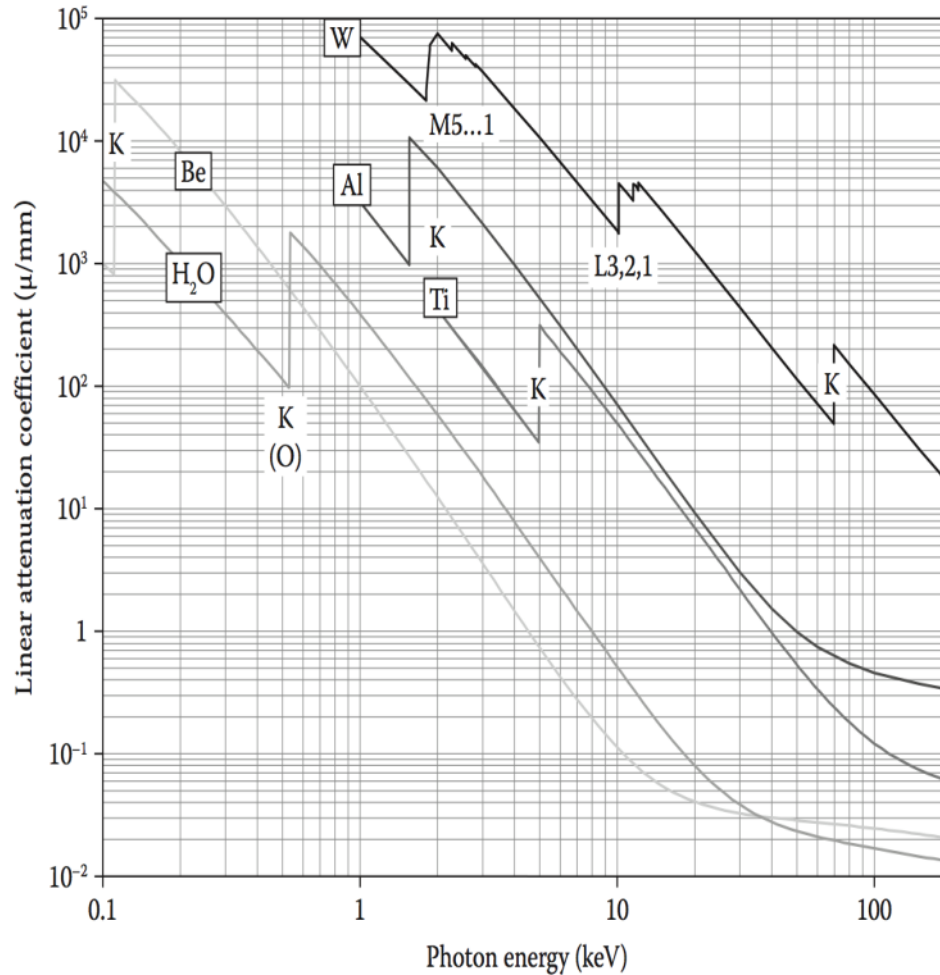
**C12200 X-ray TDI cameras**



**X-ray sCMOS Camera C12849-102U**

... and many more products ...

# Fundamentals about the interaction of X-rays with matter

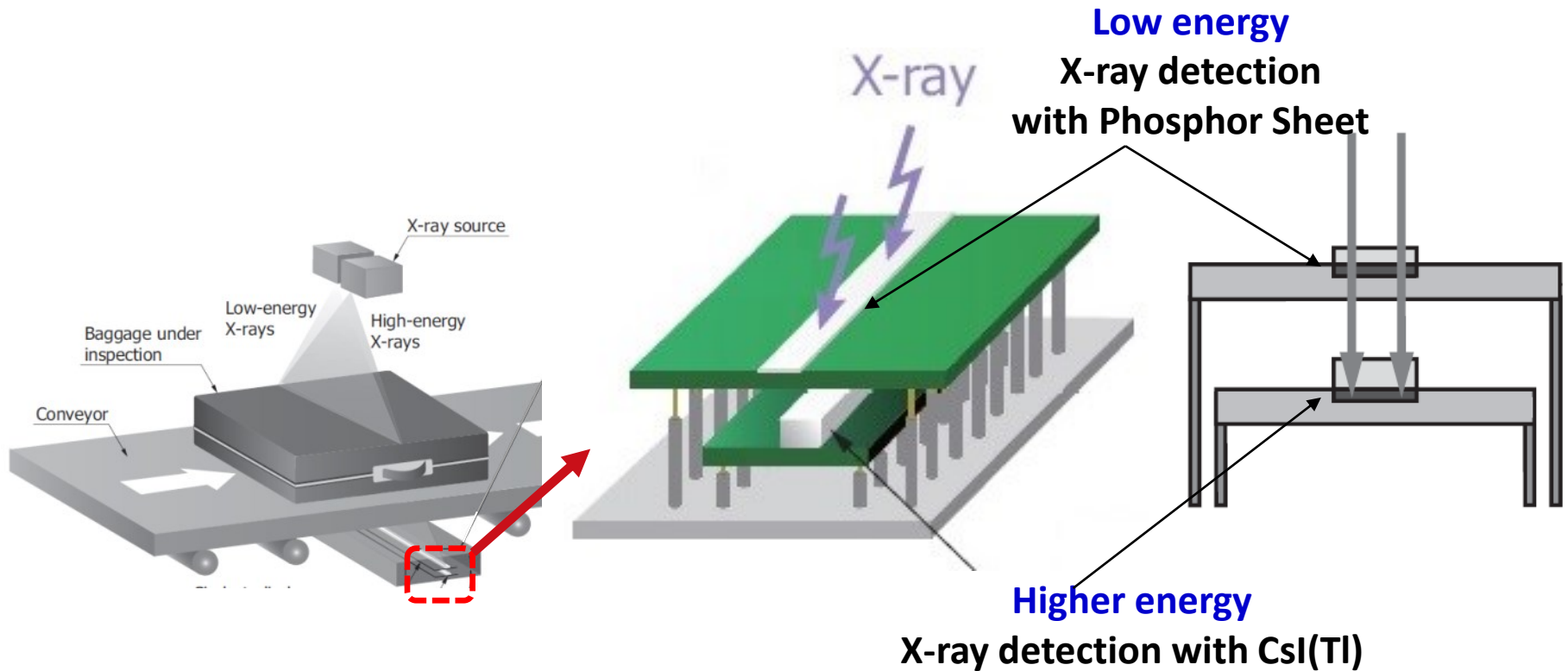


|    | atomic number |
|----|---------------|
|    | Z             |
| Be | 4             |
| Al | 13            |
| Ca | 20 (Fishbone) |
| Ti | 22            |
| W  | 74            |

higher atomic number Z  
→ higher X-ray absorption

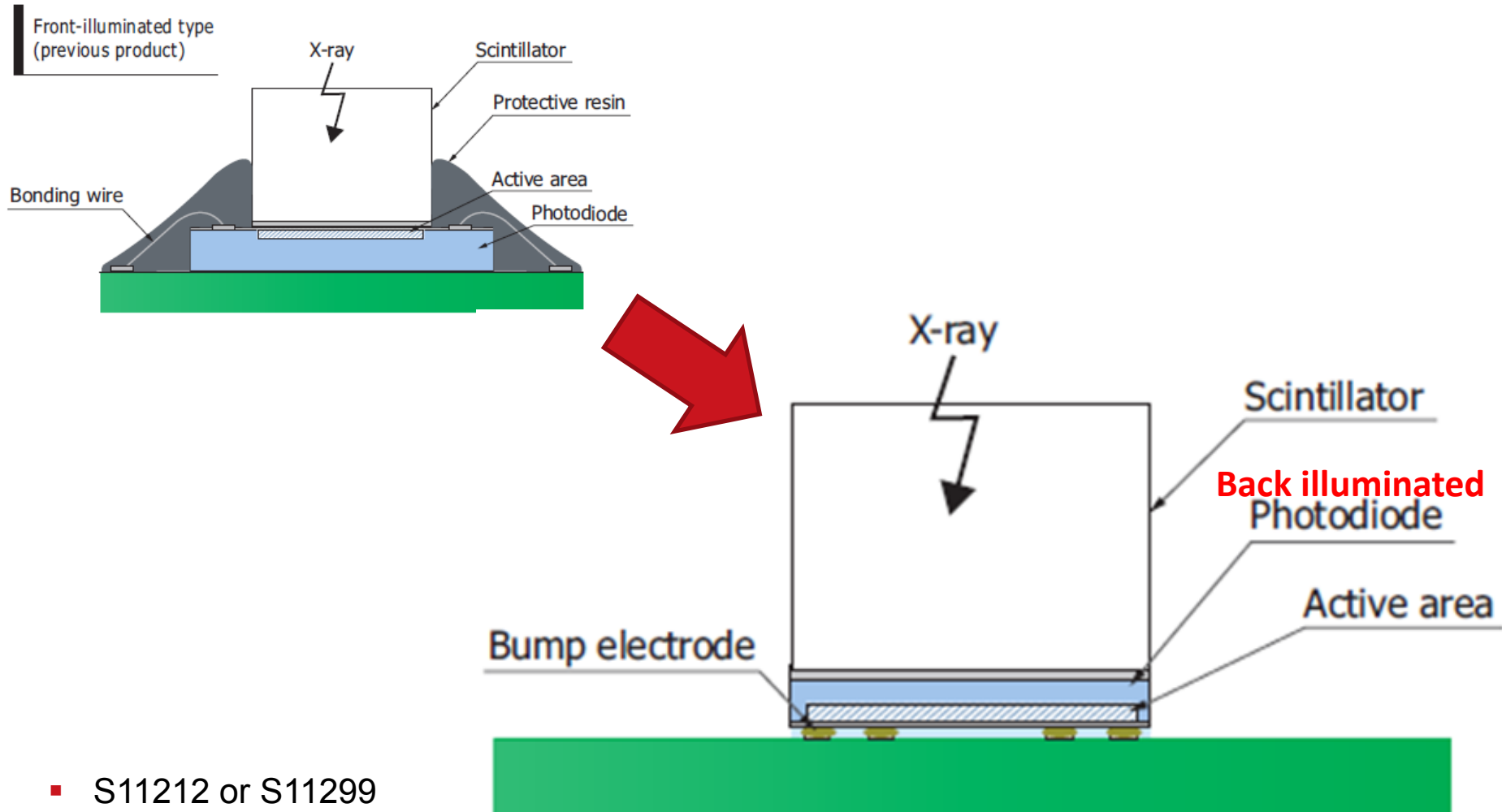
**X-Ray radiography = ATTENUATION IMAGING**

## Dual Energy X-Ray Imaging



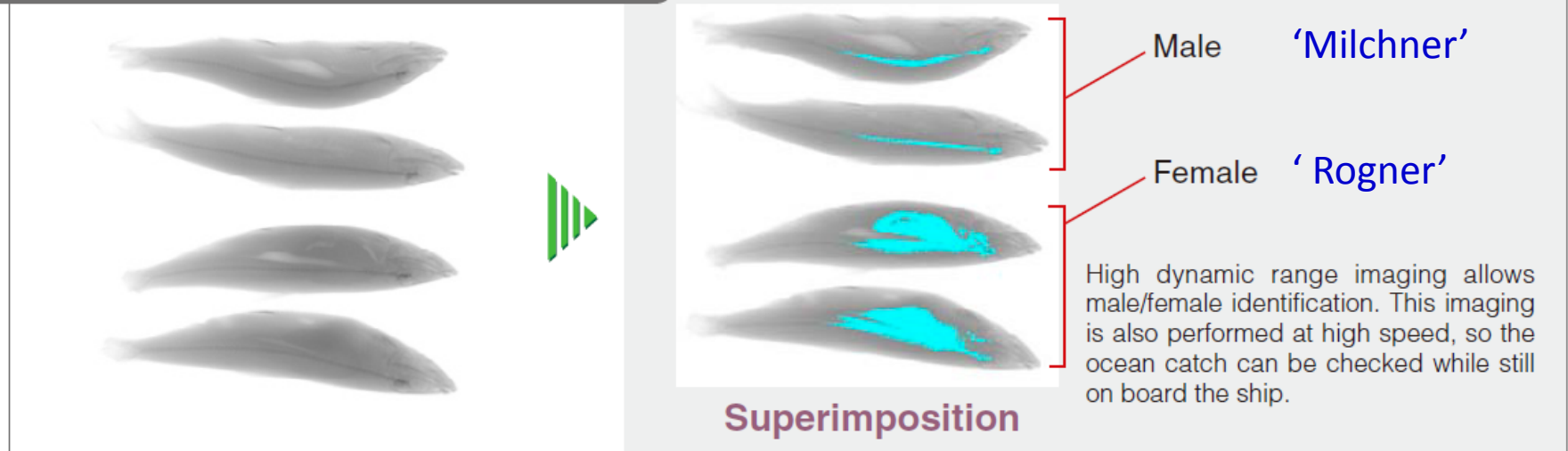
S11212 S11299 (buttable N x) 16 photo diode array system

# X-Ray backilluminated sensors high tech MEMS devices: (inhouse packaging)



## Herring: male or female

### Herring (Male/Female identification)



- Future:
  - Live selection ?
  - Sensing the fish before catching ?

## Still the Fugu is waiting to be eaten



- Tetrodotoxin:
  - LD50: 8  $\mu\text{g}$  per kg
  - ‘Zombie sleep’:  
pathogen does not  
cross blood brain barrier



## Mobile Food Scanner:

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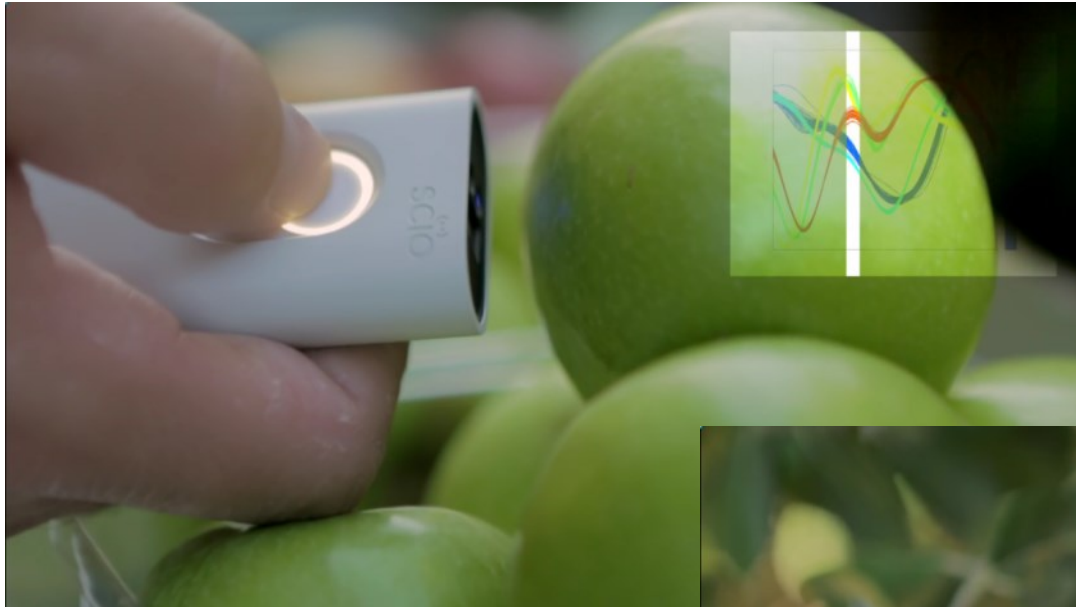


Source: urbanmoms.ca

Device: Tellspec.com



# Megatrend +Market Race: Food scanning

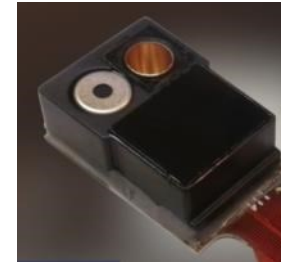


Source: SCiO  
<https://www.consumerphysics.com/>



# Today: The run for the handheld and the mobile phone applications

- **SCiO** (Consumer Physics/ Verifood)



[www.consumerphysics.com/](http://www.consumerphysics.com/)

[www.nanolambda.net](http://www.nanolambda.net)

- **TELLSPEC.com**



- Others:

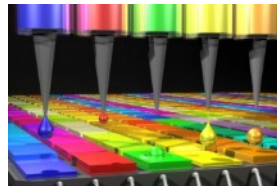
- **Nanolambda**

[www.nanolambda.net](http://www.nanolambda.net)



- **q-dot spectrometer**

Nature 523, 67–70  
(02 July 2015)

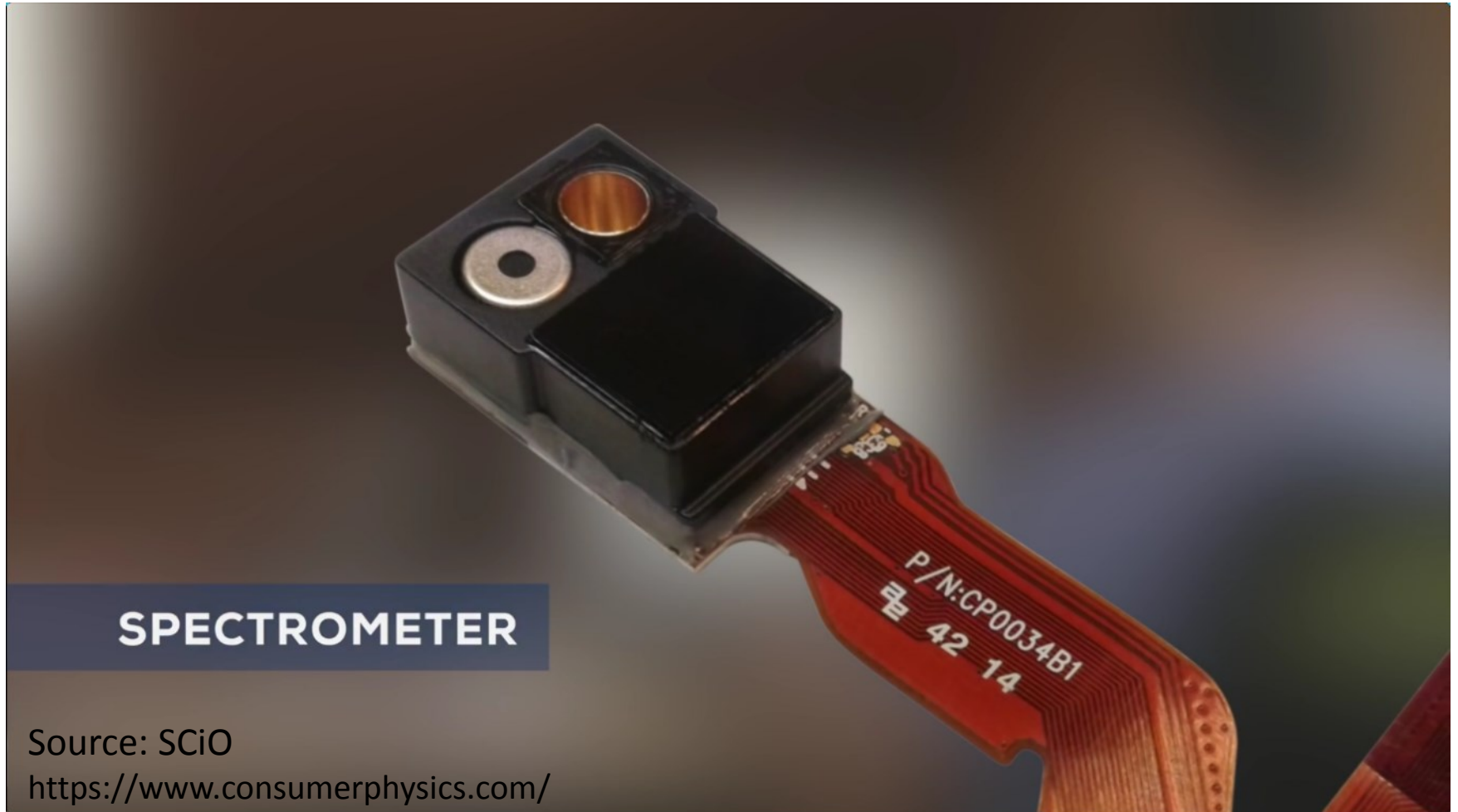


- **FrinGOe**

<http://fringoe.com/>



# Spectral Detection unit of SCiO

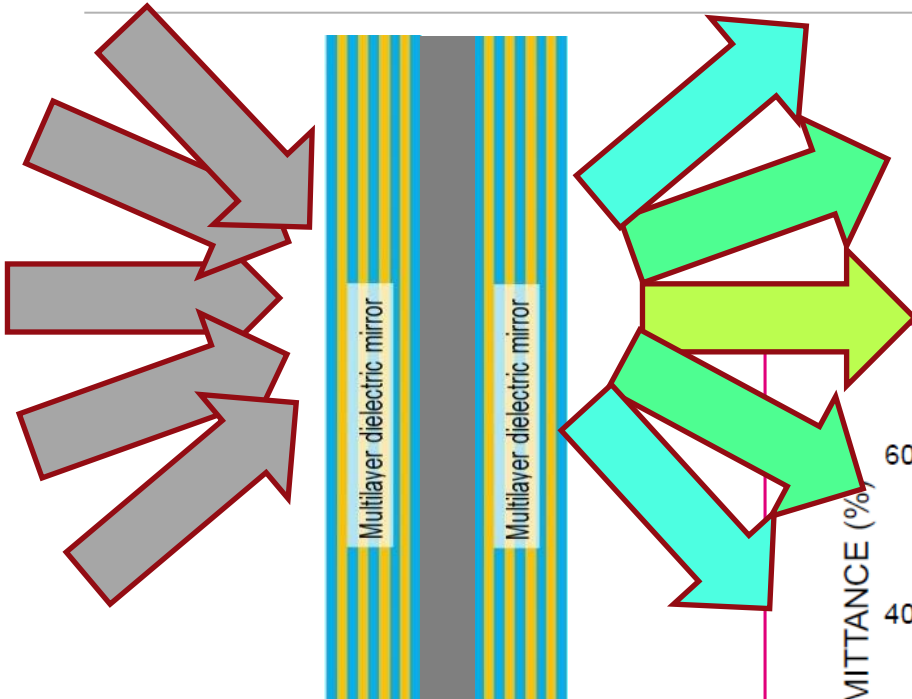


**SPECTROMETER**

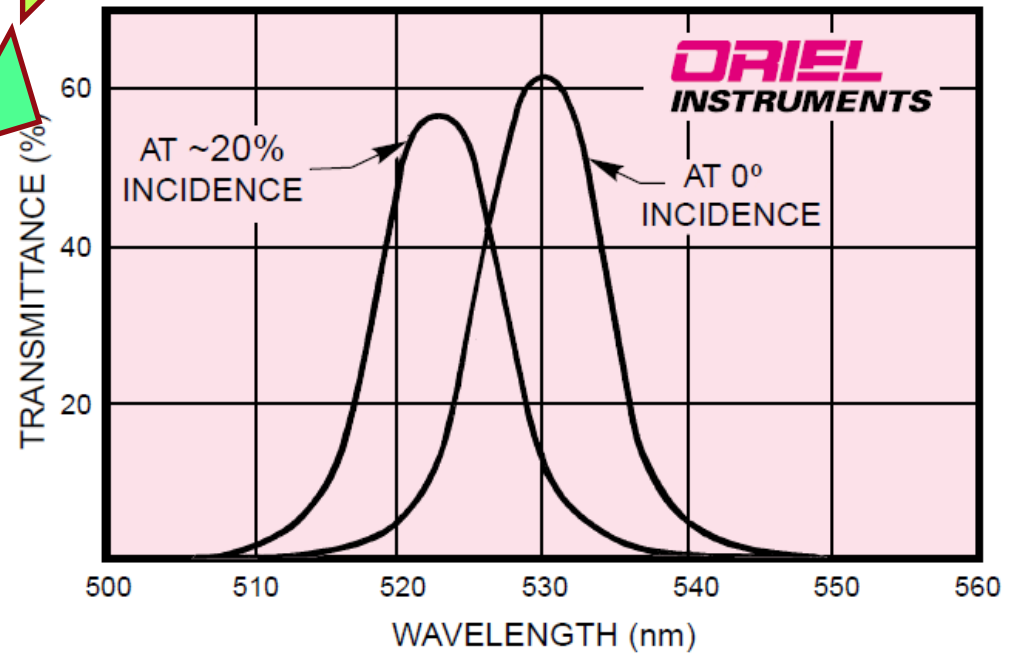
Source: SCiO

<https://www.consumerphysics.com/>

# Wavelength dependence of a dielectric band pass filter

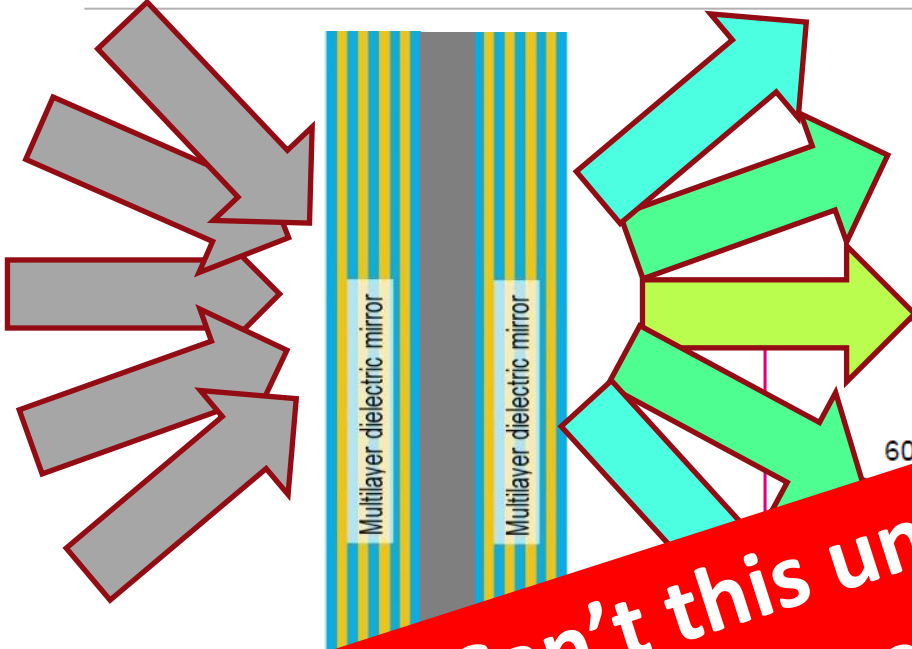


$$\lambda_{\theta} = \lambda_0 [1 - (n_0 / n^*)^2 \sin^2 \theta]^{1/2}$$



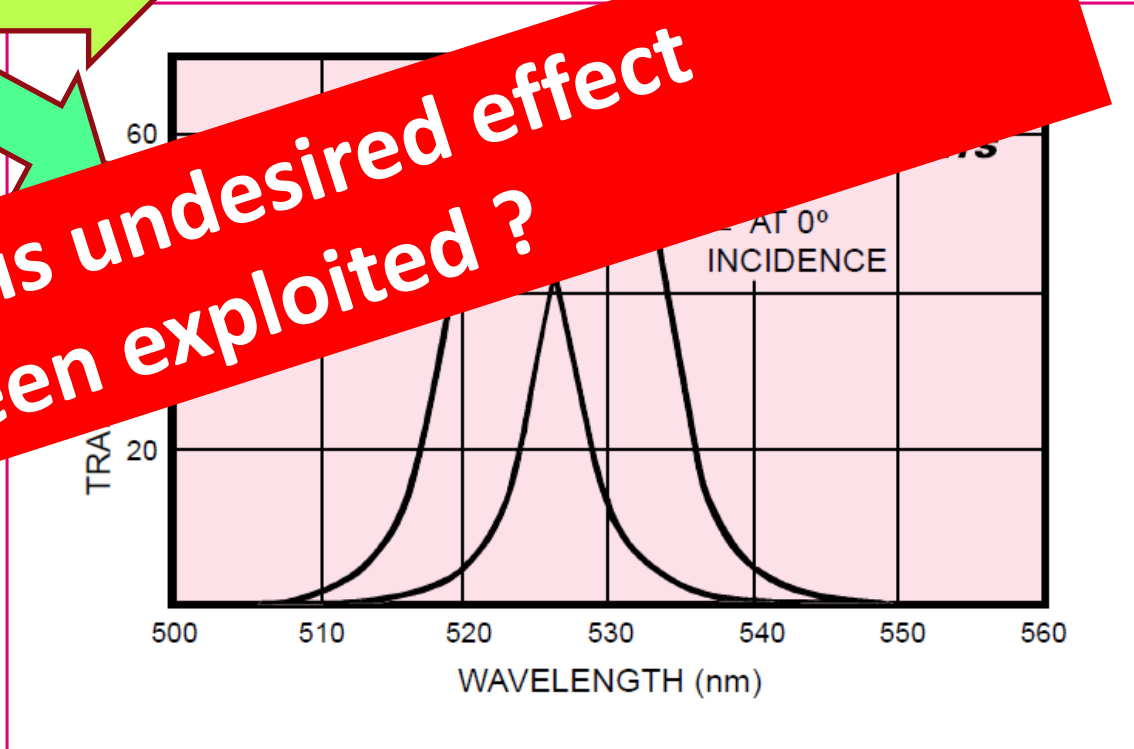
530 nm center wavelength filter at normal incidence and at ~20°

# Wavelength dependence of a dielectric band pass filter



$$\lambda_{\theta} = \lambda_0 [1 - (n_0 / n^*)^2 \sin^2 \theta]^{1/2}$$

**Can't this undesired effect  
be exploited ?**



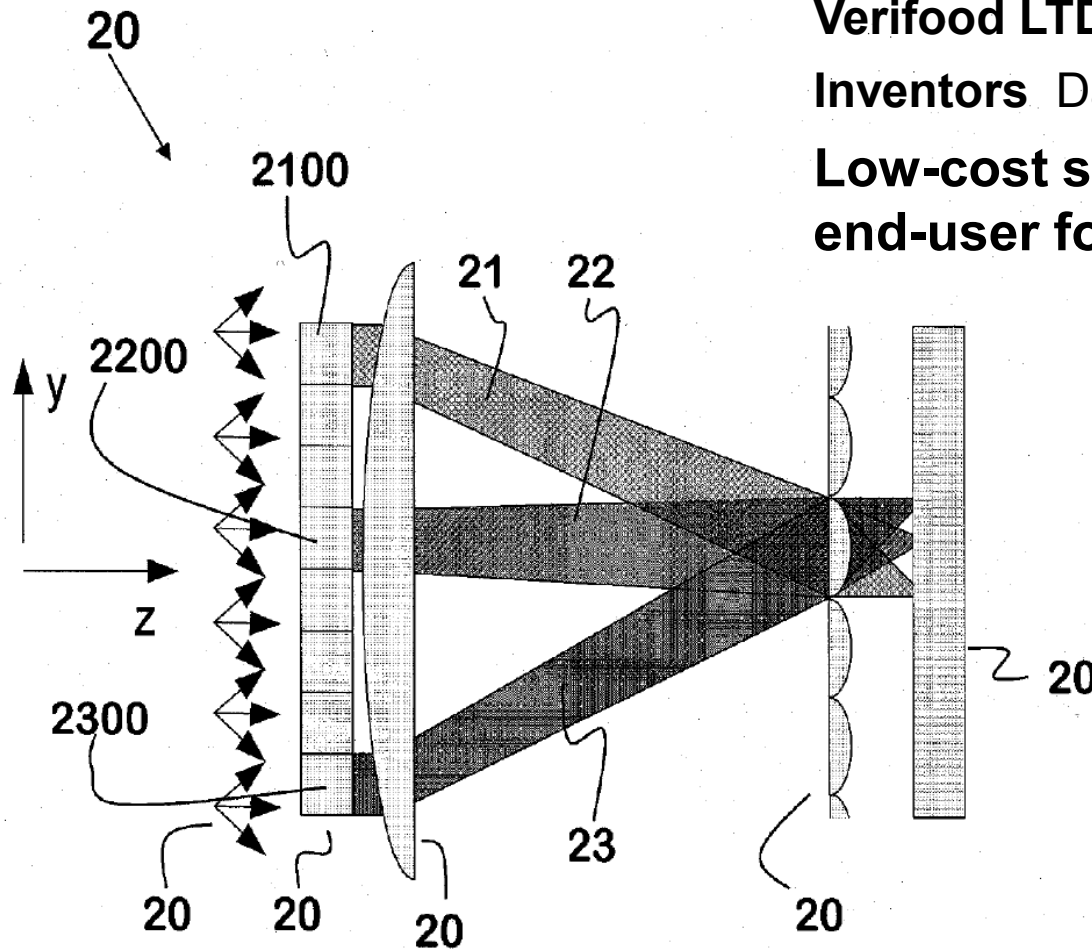
530 nm center wavelength filter at normal incidence and at ~20°

SCiO: Dror Sharon, CEO  
is co-inventor of following patent:

**US 2014/ 0320858 A1**

**Verifood LTD (IL)**

**Inventors** Damian Goldring, Dror Sharon,  
**Low-cost spectrometer system for  
end-user food analysis**



**FIG. 5**

## Feedback Uni Delft

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<http://cookie.tudelft.nl/index.php?action=ask&origin=http://scio2015.weblog.tudelft.nl//>

### Comparing SCiO with Professional Devices

[ .... ]

NIR spectroscopy sits within the 700-2500 nm range. Within this range different materials show multiple peaks in the graph. The first overtone peak sits around 900-1100 nm and the second around sits around 1200-1400 nm. The range of the SCiO device is only 700-1200 nm. This means that it will measure only one or maybe two overtone peaks and the results from the SCiO device will give less data to compare, thereby giving less reliable results.

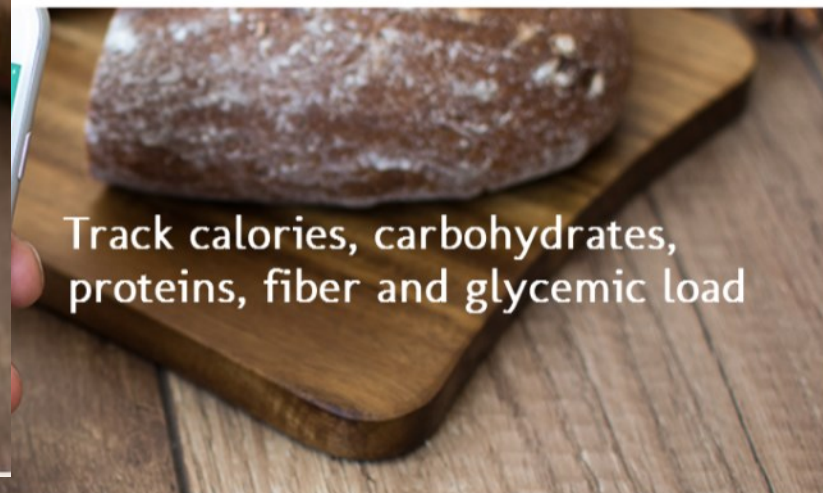
[ .... ]

Taking all of our findings in consideration, we doubt that the SCiO device with its user database will give reliable results. It will be possible to recognize different materials. However the SCiO device will not be able to reliably recognize the difference between to different samples of the same material.

# Competition: tellspec (tellspec.com)



Order Technology About Partnership Tellspecopedia Media Blog





# Tellspec's Specs

Spectroscopy

Near-infrared (900 nm to 1700 nm)



|                                   |   |
|-----------------------------------|---|
| Spectroscopy                      | Near-infrared (900 nm to 1700 nm)               |
| Battery                           | Internal Lithium Battery (rechargeable via USB) |
| Connection                        | Bluetooth 4.0 LE                                |
| Physical Dimensions (Final units) | 9 cm (L) x 6 cm (W) x 2.5 cm (H)                |
| Physical Dimensions (Beta units)  | 9 cm (L) x 6 cm (W) x 4.5 cm (H)                |
| Weight                            | 120 g   |
| OS Support                        | Android, iOS                                    |
| Colors                            | White, Black, Red, Green, or Turquoise Blue     |

Source: Tellspec.com



Narrow down food sensitivities

**Tellspec App  
Coming this fall!**

| Tell Us How You Feel       |                       |
|----------------------------|-----------------------|
|                            | Low Medium High       |
| Rash, Hives or Swelling    | <input type="range"/> |
| Sneezing or Running Nose   | <input type="range"/> |
| Red, Itchy or Watery Eyes  | <input type="range"/> |
| Sore Throat or Itchy Mouth | <input type="range"/> |
| Cough, Wheezing or Asthma  | <input type="range"/> |
| Headache                   | <input type="range"/> |

Source: Tellspec.com

# KNOW YOUR FOOD

TellSpecopedia is a dynamic, up-to-date consumer resource for objective, evidence-based information on thousands of global food ingredients and their impact on health.



|                         |                   |                    |            |              |                      |             |
|-------------------------|-------------------|--------------------|------------|--------------|----------------------|-------------|
| 2,4-di-tert-butylphenol | 4-Hexylresorcinol | Abamectin          | Acaricides | Acesulfame K | Acesulfame potassium | Acetamiprid |
| Acetic acid             | Achiote           | Acid-proof caramel | Acrolein   | Acrylamide   | Adzuki beans         | Agar        |
| Agave                   | Agave syrup       | Alanine            | ALA        |              | Alfalfa              | Algacide    |

Source: [Tellspec.com](http://Tellspec.com)

# KNOW YOUR FOOD

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|                         |                   |           |            |              |                      |             |
|-------------------------|-------------------|-----------|------------|--------------|----------------------|-------------|
| 2,4-di-tert-butylphenol | 4-Hexylresorcinol | Abamectin | Acaricides | Acesulfame K | Acesulfame potassium | Acetamiprid |
|-------------------------|-------------------|-----------|------------|--------------|----------------------|-------------|

.. can't find pathogens like TTX Tetrodotoxin



# KNOW YOUR FOOD

TellSpecopedia is a dynamic, up-to-date consumer resource for objective, evidence-based information on thousands of global food ingredients and their impact on health.



|                         |                   |           |            |              |                      |             |
|-------------------------|-------------------|-----------|------------|--------------|----------------------|-------------|
| 2,4-di-tert-butylphenol | 4-Hexylresorcinol | Abamectin | Acaricides | Acesulfame K | Acesulfame potassium | Acetamiprid |
|-------------------------|-------------------|-----------|------------|--------------|----------------------|-------------|

.. can't find pathogens like TTX Tetrodotoxin  
... on ppt level



... without suited sample preparation ...

## Business Model (1/2): enabling others to make new APPs

SCiO- Explore More!

**A NEW AND EXCITING PLATFORM FOR APPLICATIONS DEVELOPMENT**

1:52 / 2:02

YouTube

## Business Model (2/2):

### Patent of Company Tellspec: Cloud-based Data Base

- Analyzing and correlating spectra, identifying samples and their ingredients and displaying related personalized information
- **WO2015/019265 A1**
- Tellspec Inc.
- Inventors: Watson, Correa

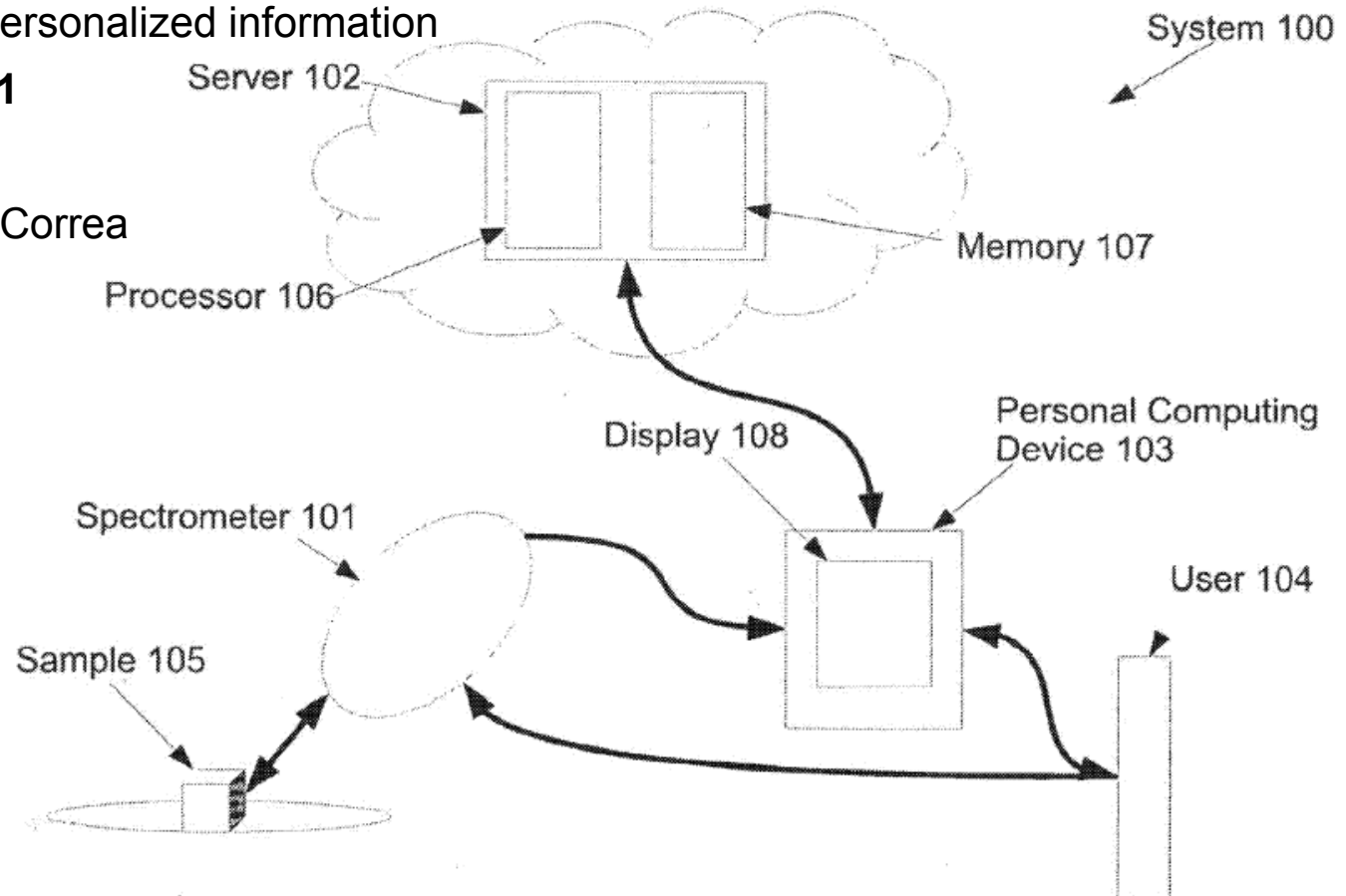


Fig. 1

WO 2015/019265

## Spectroscopic Applications with VIS/NIR/MIR

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- Zeiss: see:
  - [http://www.zeiss.com/microscopy/en\\_us/website/oss/solutions/solutions-for-the-foodstuff-industry.html](http://www.zeiss.com/microscopy/en_us/website/oss/solutions/solutions-for-the-foodstuff-industry.html)
  - [http://www.zeiss.com/microscopy/en\\_us/website/oss/solutions/solutions-for-the-agriculture-industry.html](http://www.zeiss.com/microscopy/en_us/website/oss/solutions/solutions-for-the-agriculture-industry.html)
- Strawberries: Ripeness, etc: <http://www.nature.com/articles/srep02585>
  - Analyzing Strawberry Spoilage via its Volatile Compounds Using Longpath Fourier Transform Infrared Spectroscopy
  - Daming Dong, Chunjiang Zhao, Wengang Zheng, Wenzhong Wang, Xiande Zhao & Leizi Jiao
  - Scientific Reports 3, Article number: 2585 (2013)
  - doi:10.1038/srep02585
- ... Many more interesting spectroscopic applications



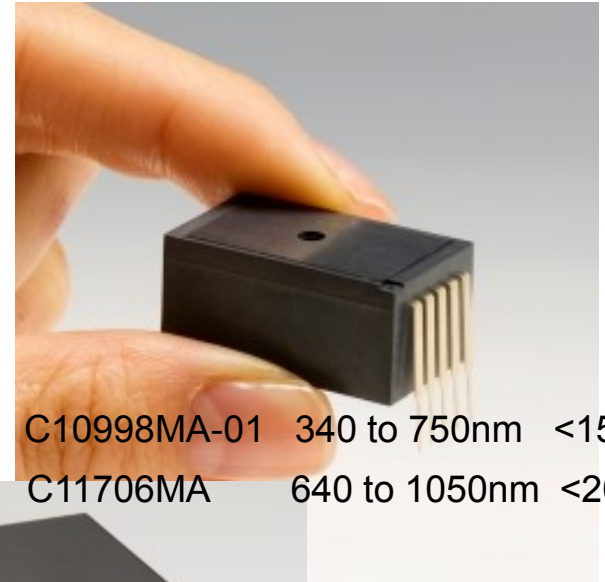
# OEM Minispectrometer, including high end OEM Si or InGaAs linear sensors



C13054MA: 790 to 920nm 0.4 nm  
C13055MA: 340 to 830<3.0 nm



C11482GA 900 to 1700 <7 nm



C10998MA-01 340 to 750nm <15nm  
C11706MA 640 to 1050nm <20nm



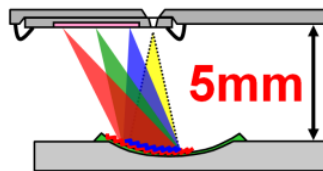
C9404CA (H) 200 to 400 nm 3(1) nm  
C9405CB 500 to 1100 nm 5 nm



C11118GA 900 to 2550 nm 20nm  
C9913GB 900 to 1700 7nm  
C9914GB 1100 to 2200 8nm

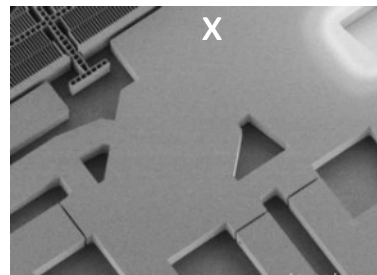
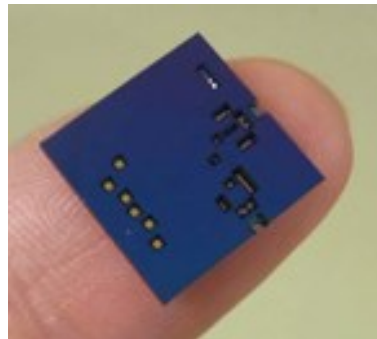
# MEMS Minispectrometers: examples

PDA Spektrometer



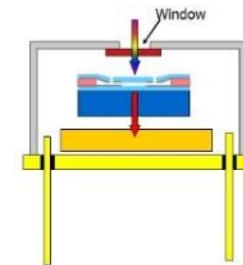
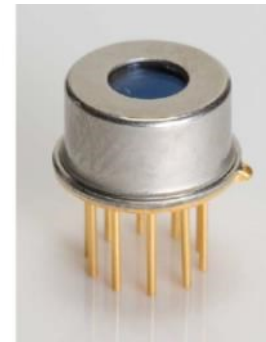
380 – 780nm  
650 – 1050nm

MEMS FTIR



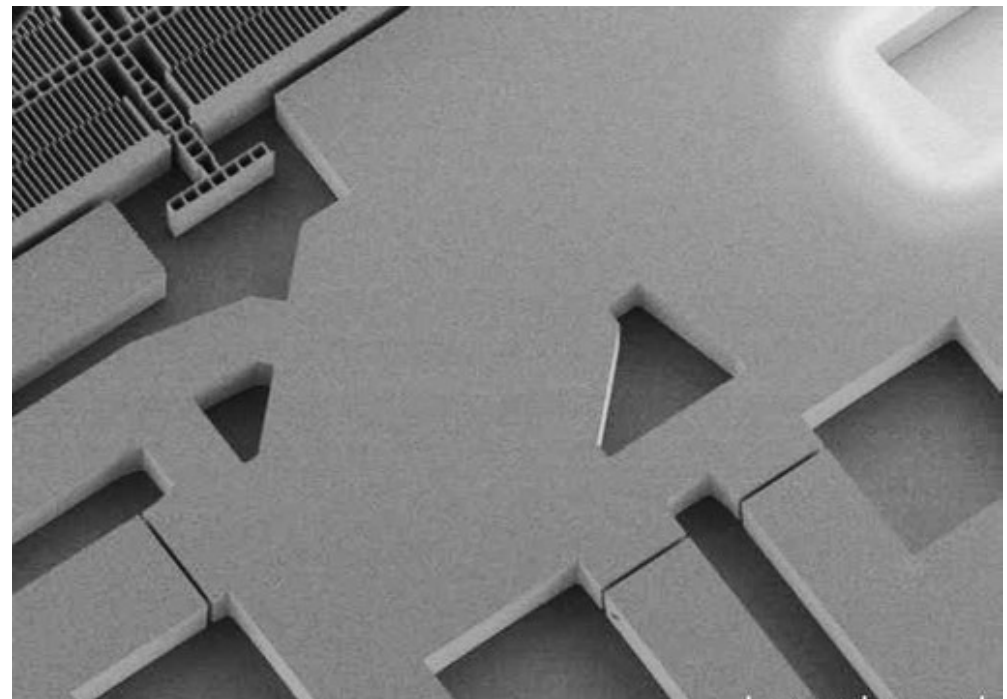
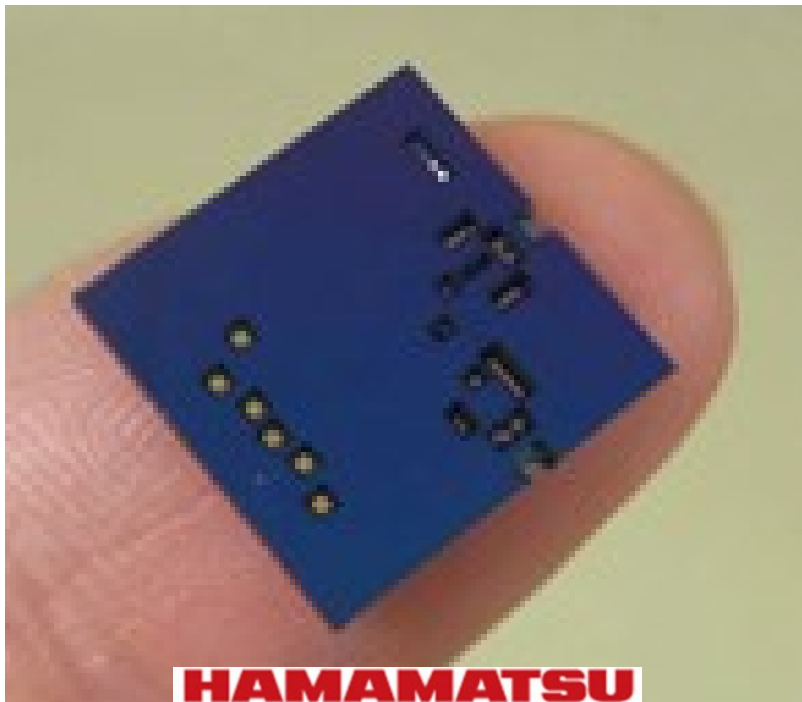
1.15 – 1.65  $\mu\text{m}$   
1.15 – 2.05  $\mu\text{m}$

MEMS Fabry-Perot Interferometer



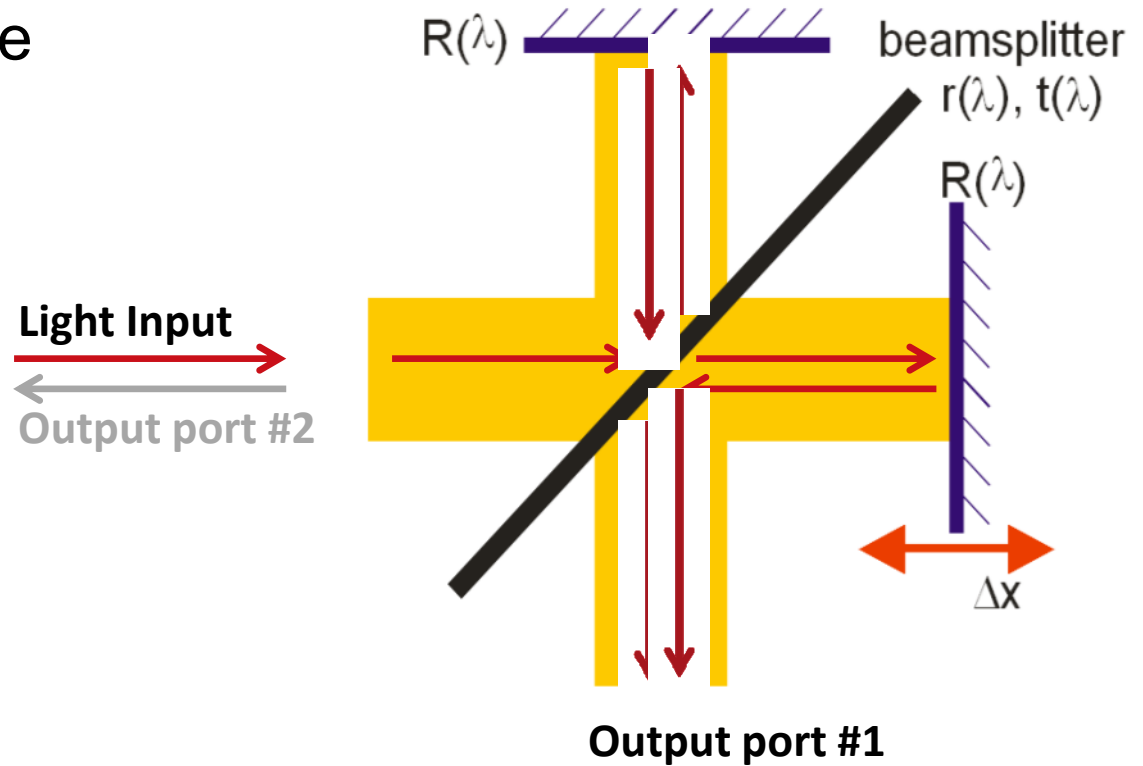
1.55 – 1.85  $\mu\text{m}$

# MEMS based Fourier Transform Infrared FTIR Spectrometer



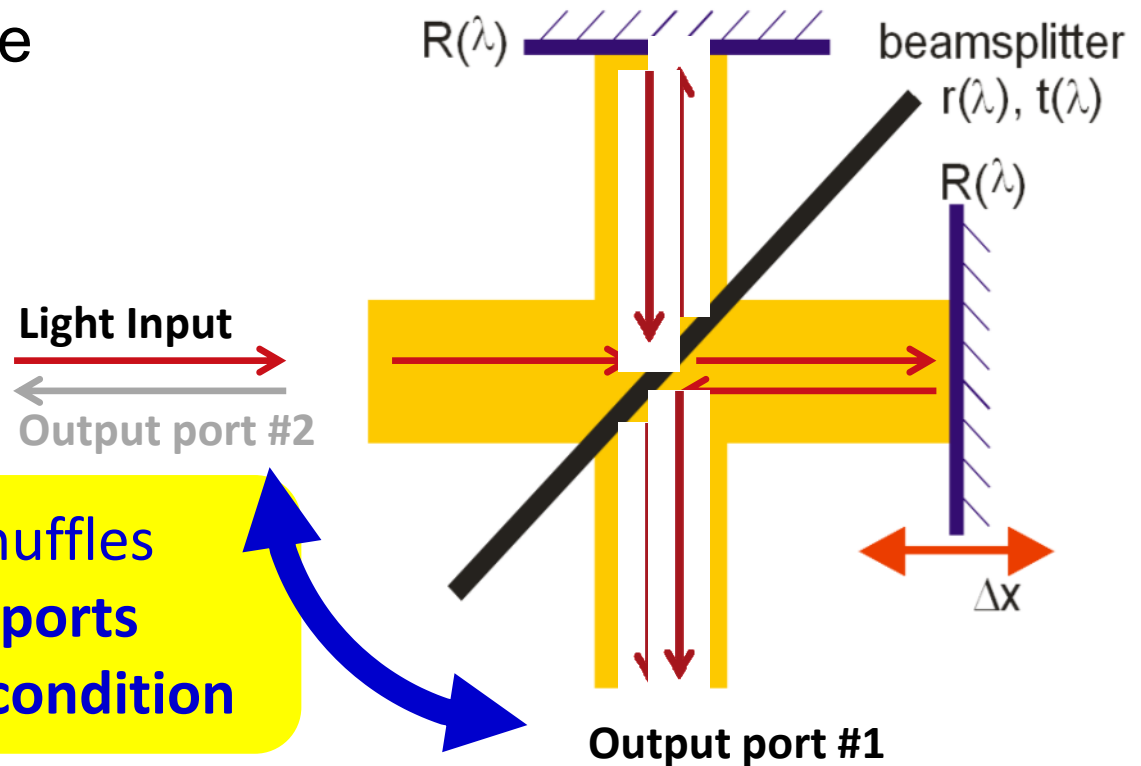
# The Michelson Interferometer

- 2-beam interference
- 1 optical input
- 2 output ports



# The Michelson Interferometer

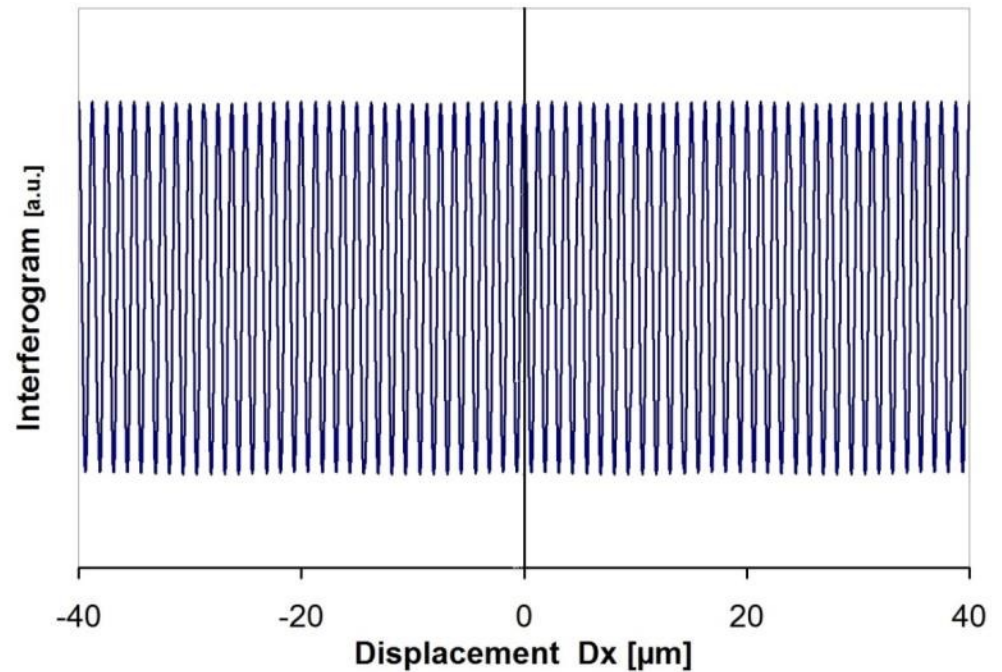
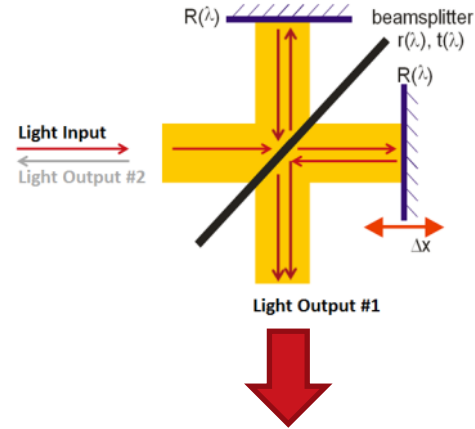
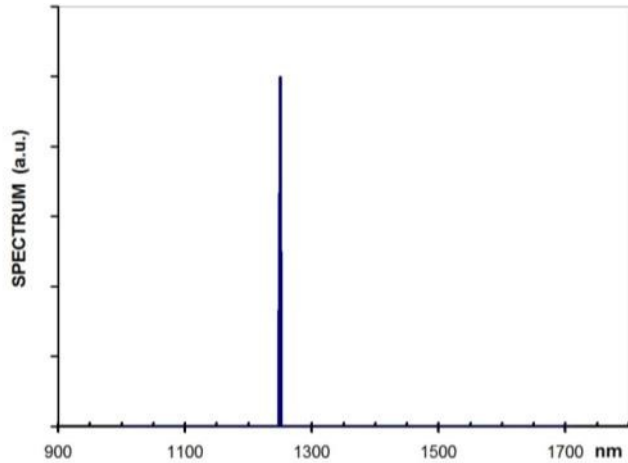
- 2-beam interference
- 1 optical input
- 2 output ports



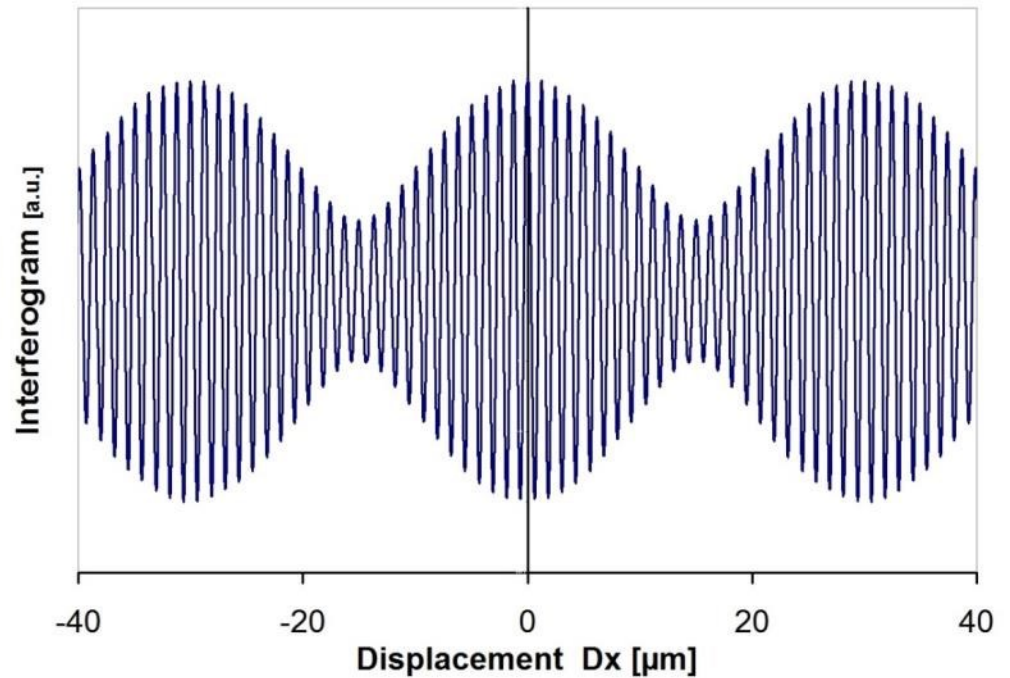
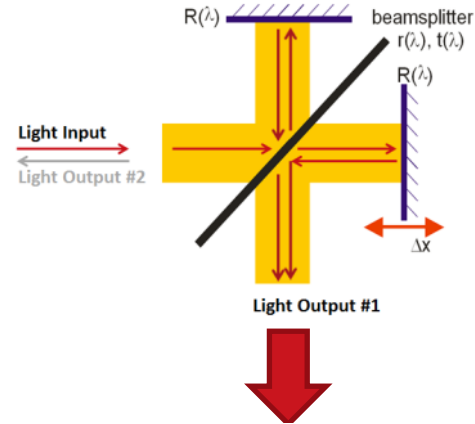
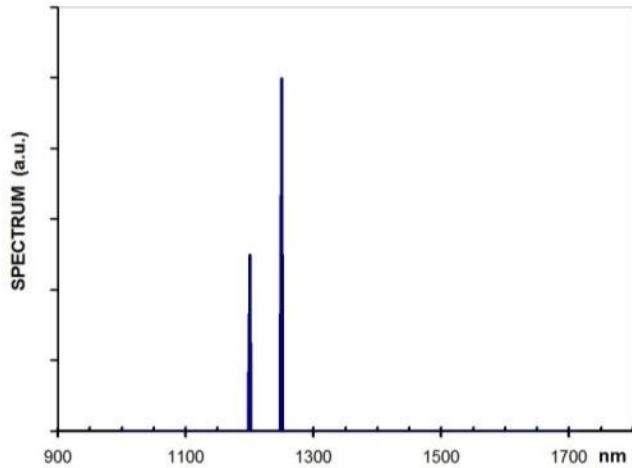
The interferometer shuffles light between output ports depending on phase condition

$$\cos^2 \left( \frac{2\pi}{\lambda} * 2\Delta x + .. \right)$$

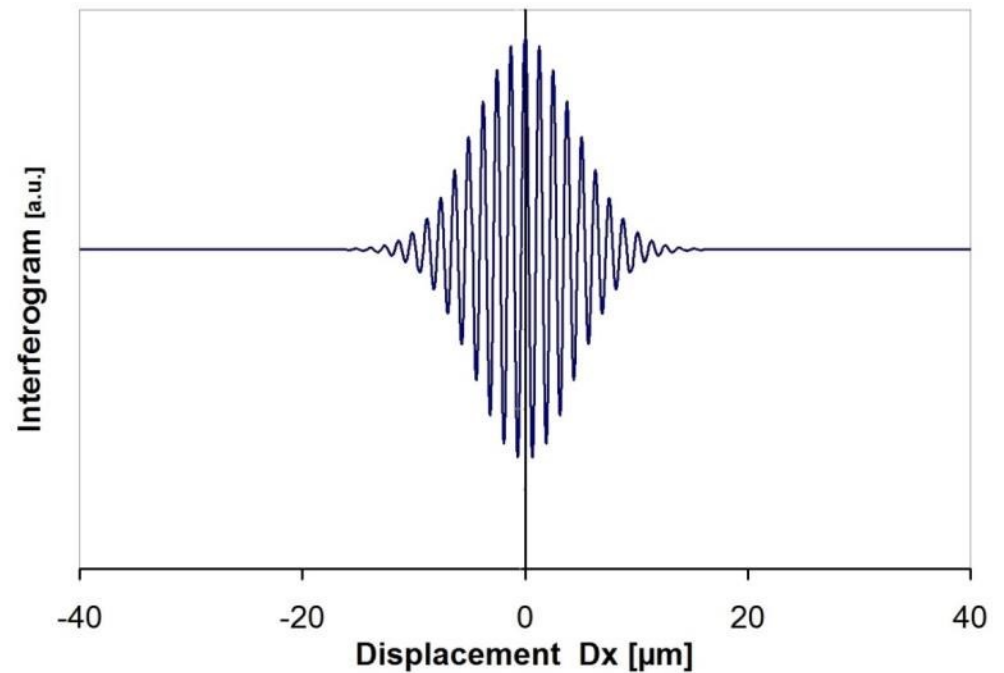
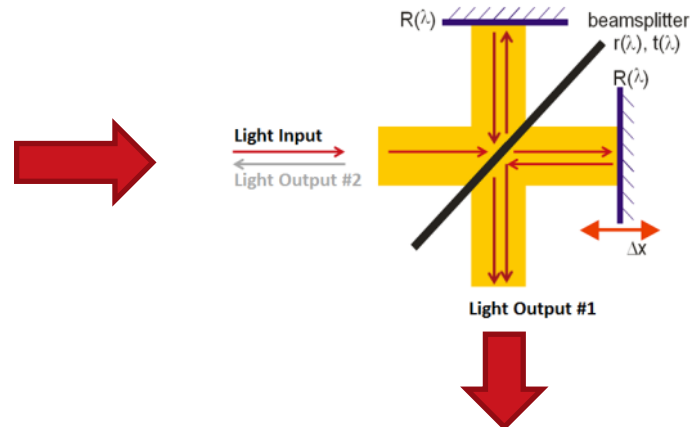
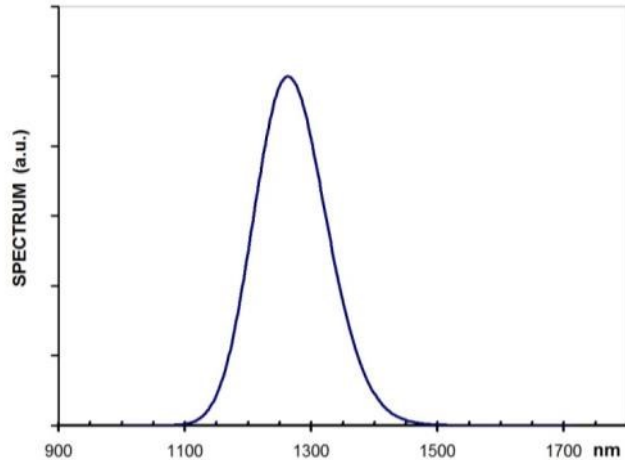
# The Michelson Interferometer: Examples



# The Michelson Interferometer: Examples

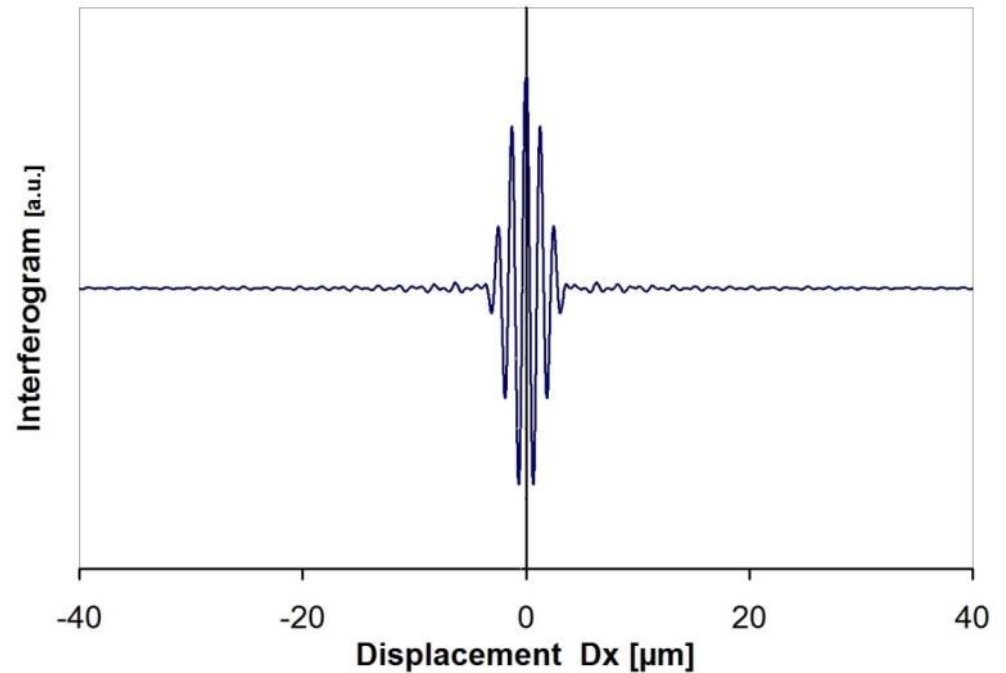
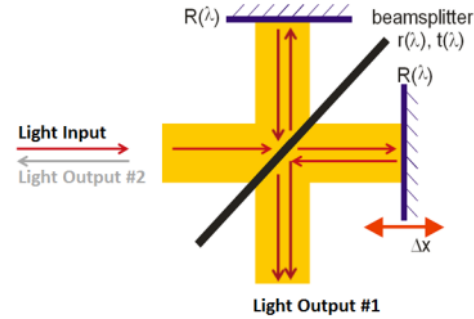
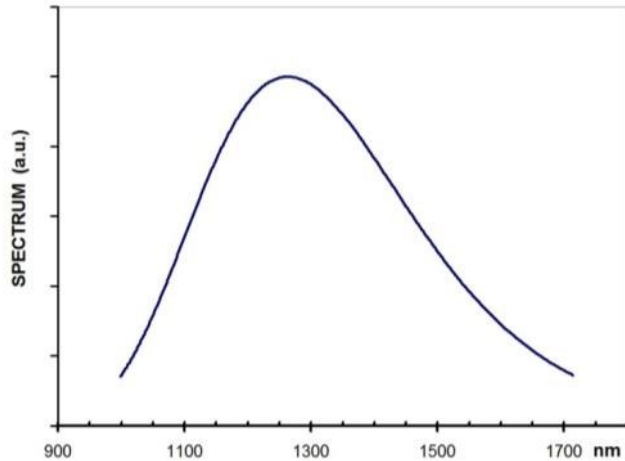


# The Michelson Interferometer: Examples

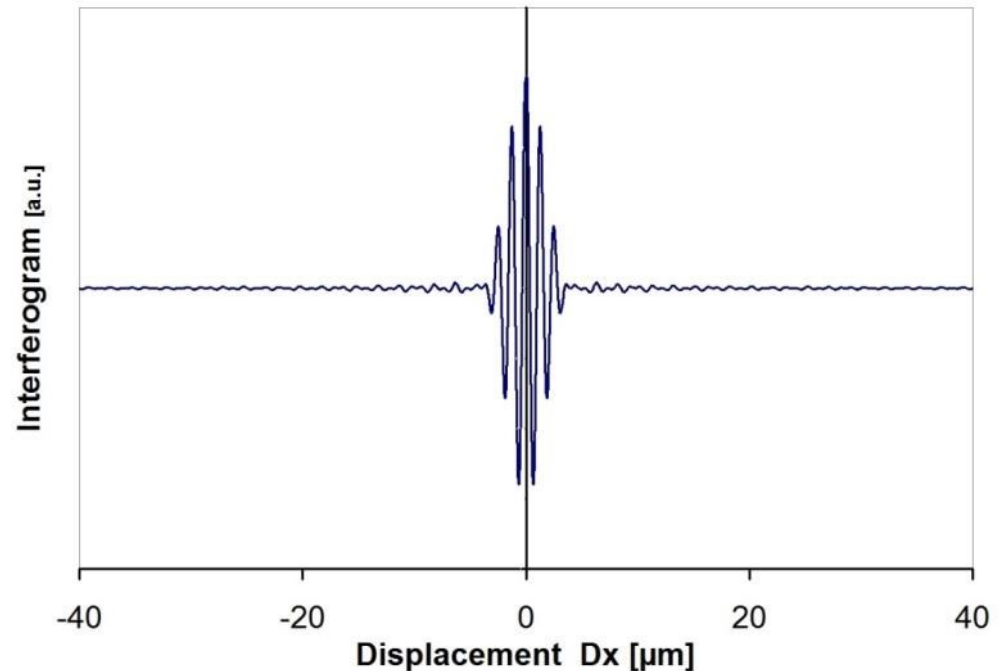
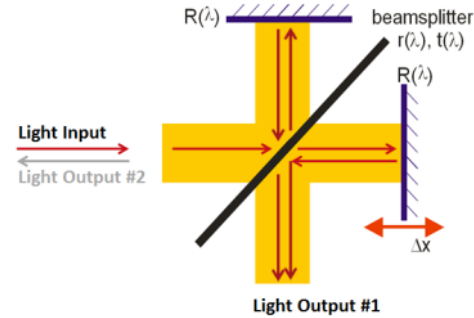
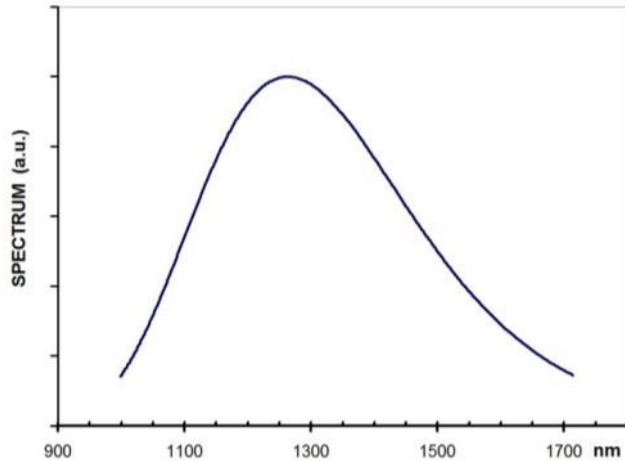




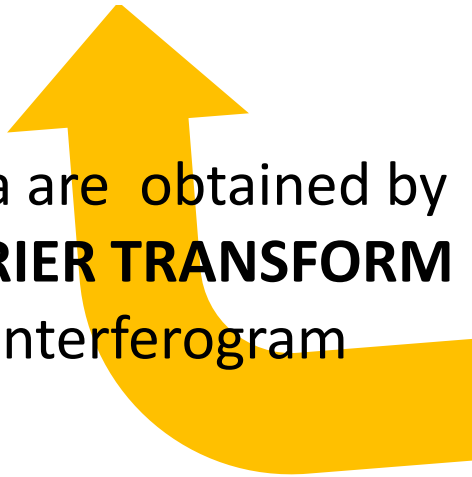
# The Michelson Interferometer: Examples



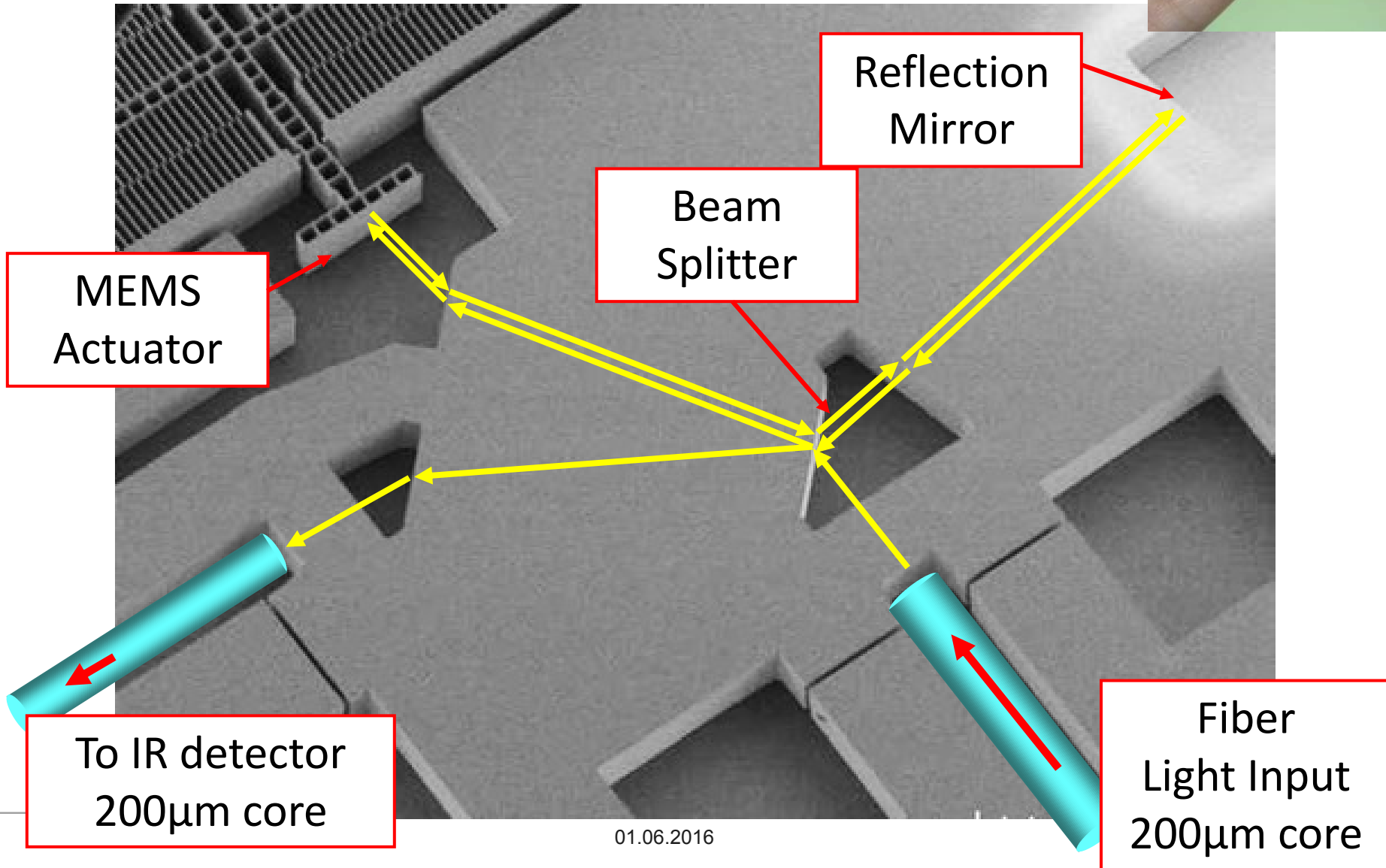
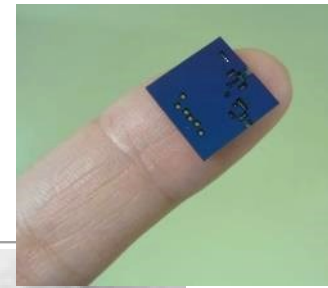
# The Michelson Interferometer: Examples



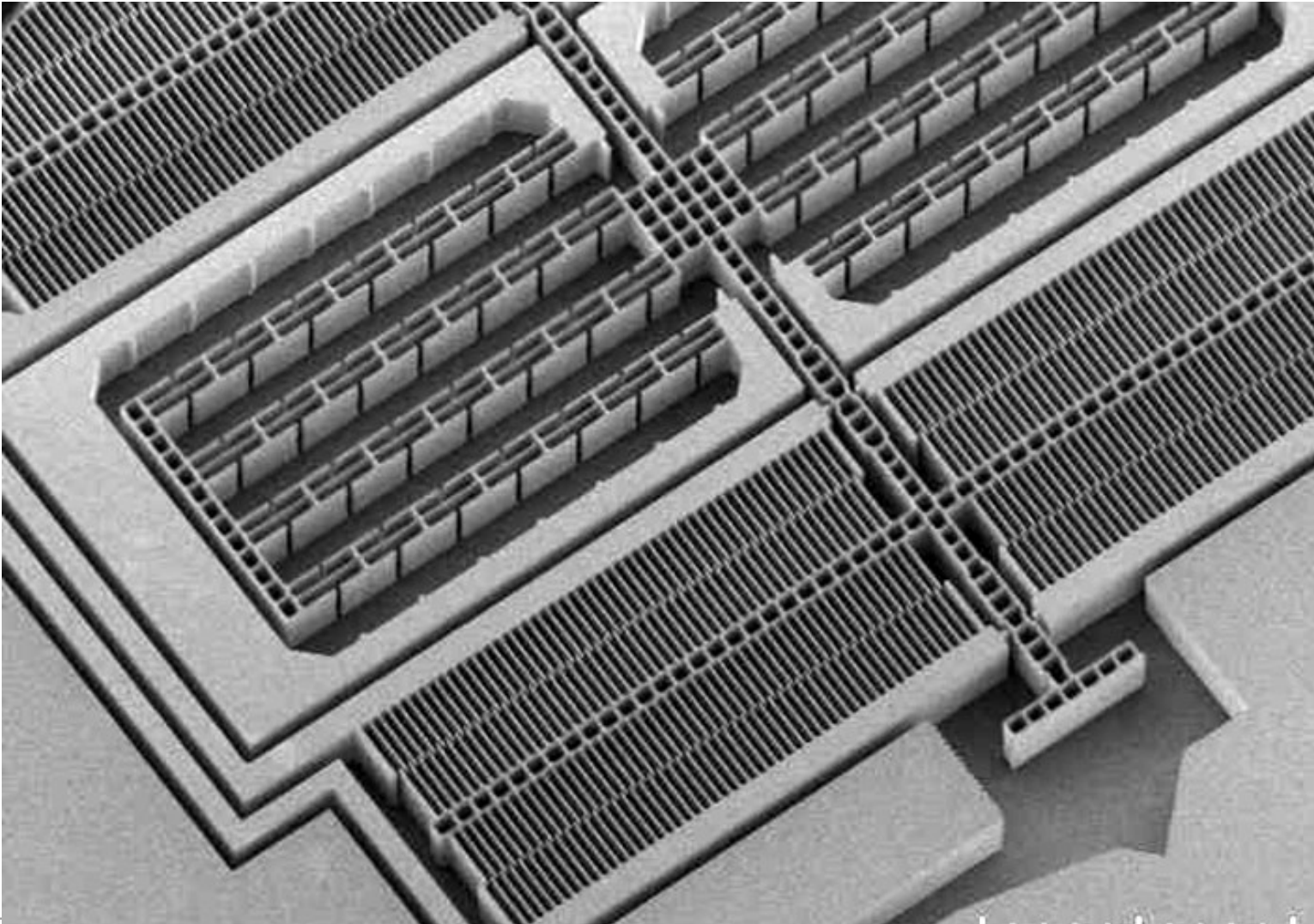
Spectra are obtained by a **FOURIER TRANSFORM** of the Interferogram



# MEMS FTIR Engine

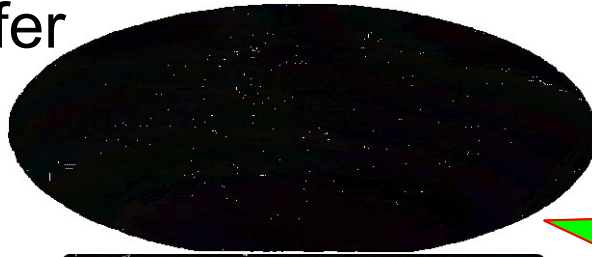


# Electrostatic MEMS Actuator and Mirror



# Wafer level package and functional system

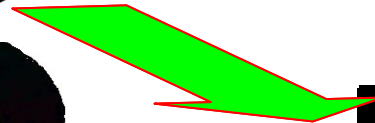
Cap wafer



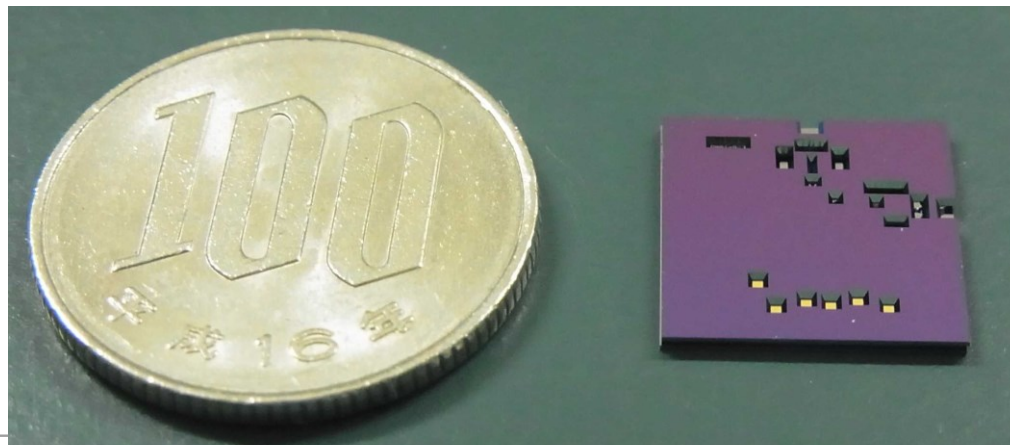
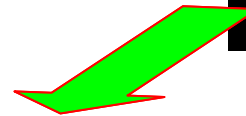
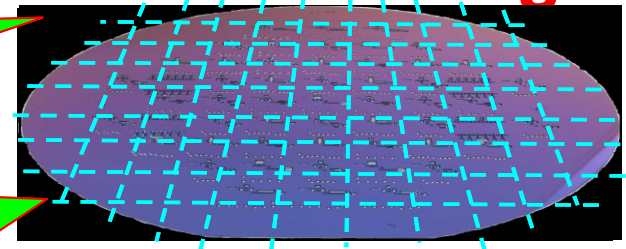
FTIR  
Engine  
wafer



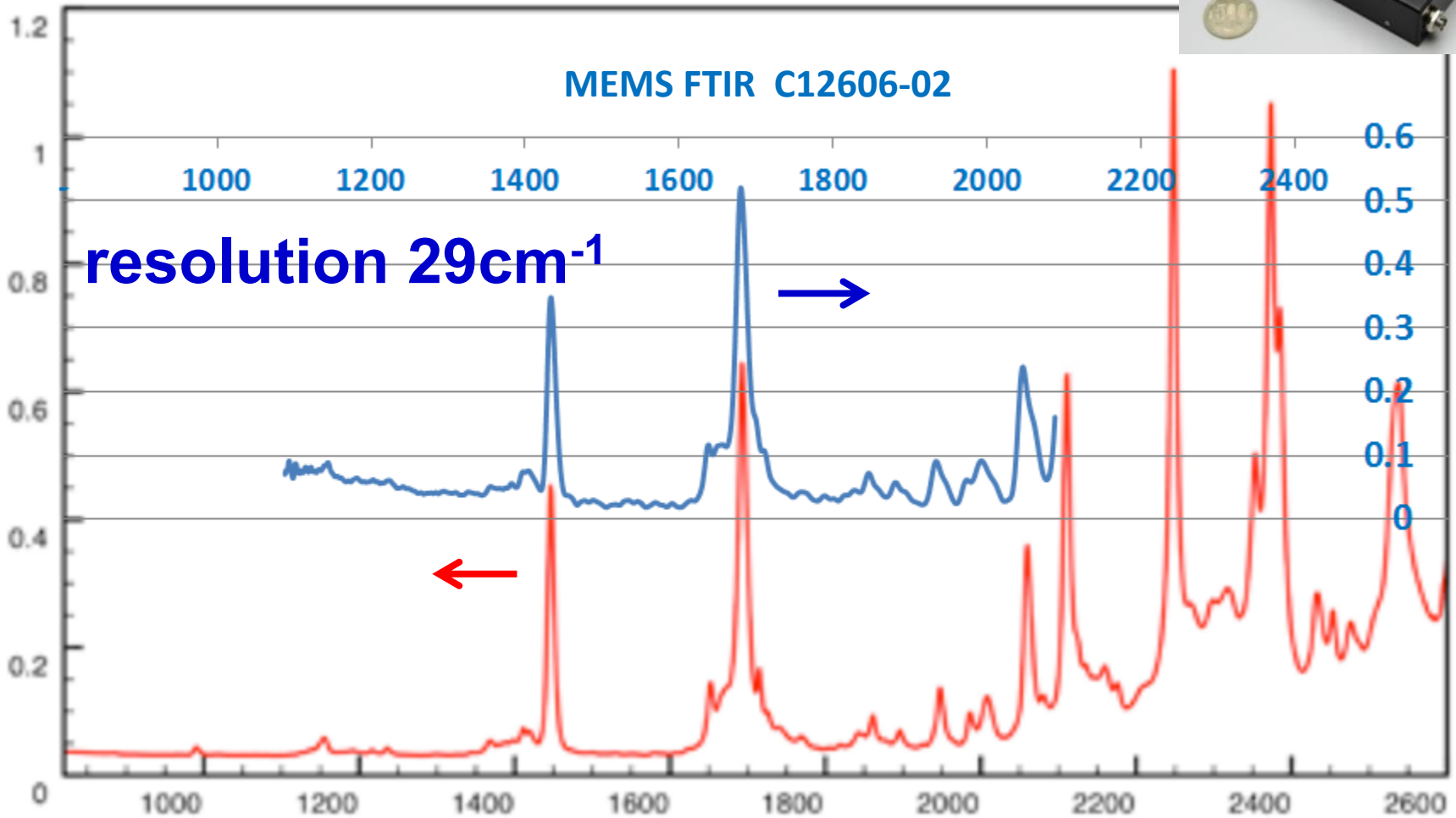
**Wafer bonding**



**Stealth  
Dicing**



# Reference Standard Measurement (STARNA RM NIR/T)

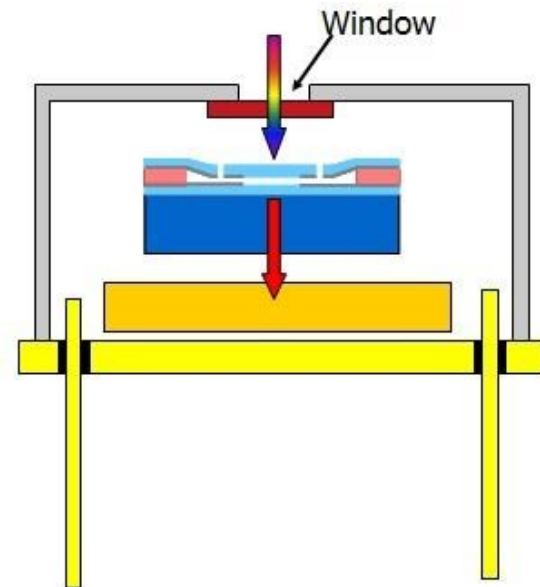


Source: [http://www.starnacells.com/d\\_ref/d\\_wl/NIR.html](http://www.starnacells.com/d_ref/d_wl/NIR.html)

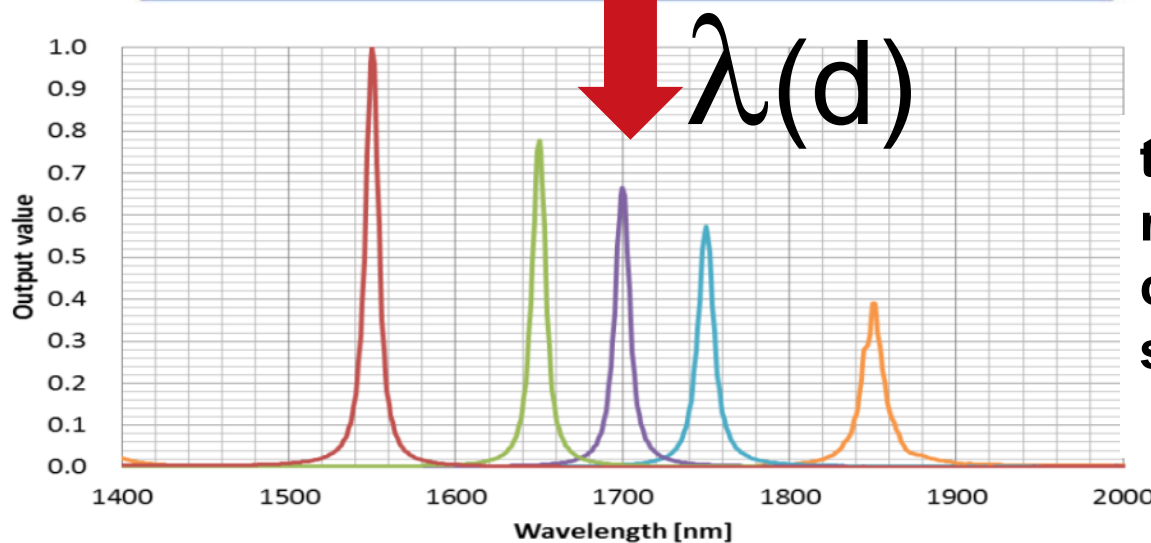
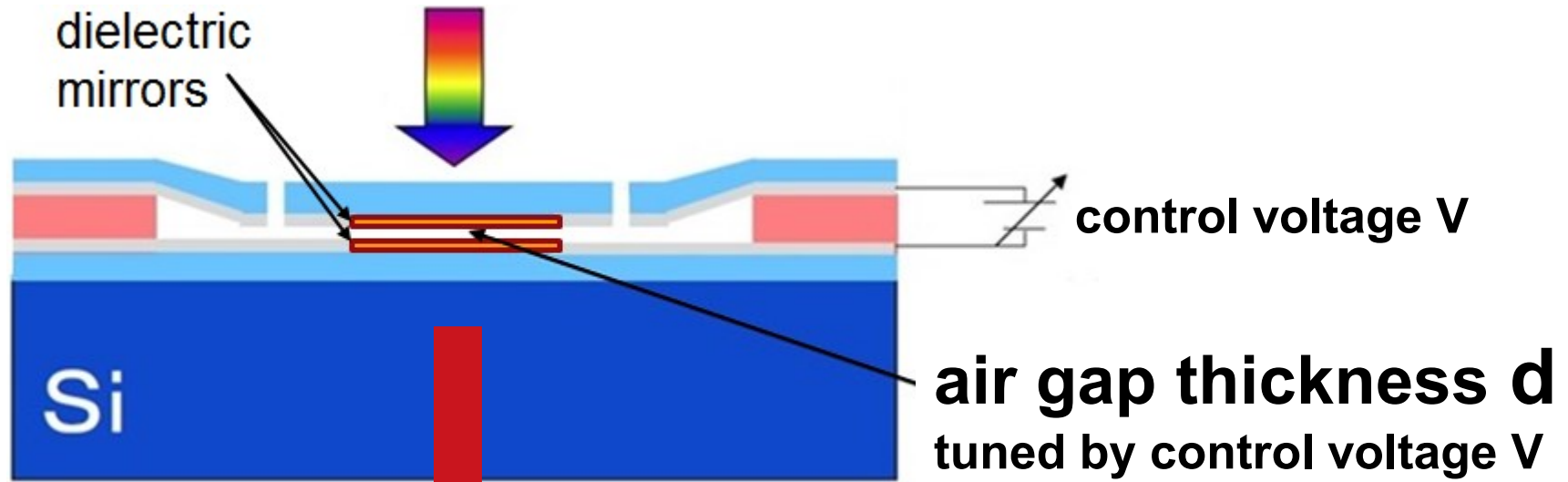
# Tunable Fabry-Perot Etalon FPI



**HAMAMATSU**



# MOEMS Fabry Perot Interferometer



**tuning range** 1550 - 1850nm  
**resolution:** < 20nm max.  
**control  $V$ :** 20 to 37 V typ.  
**settling time:** 1ms typ.

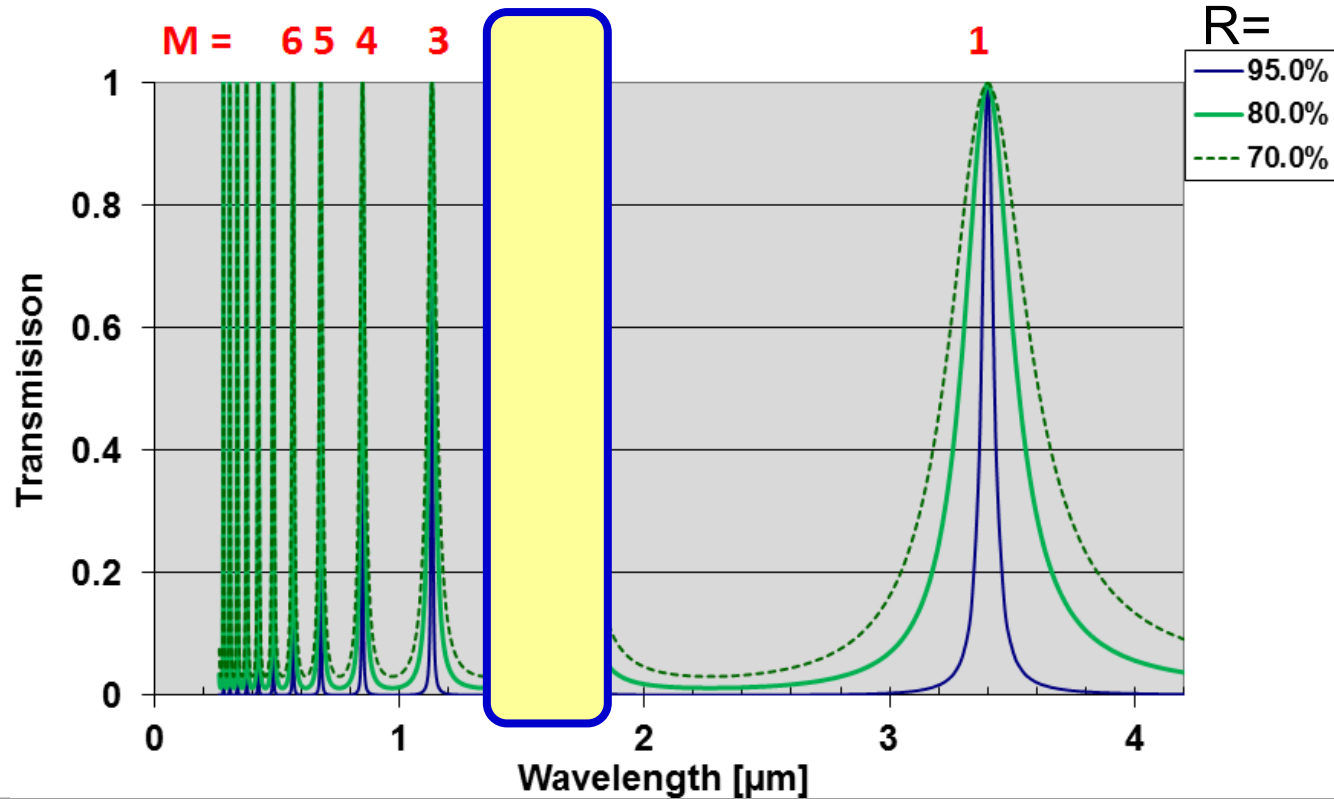
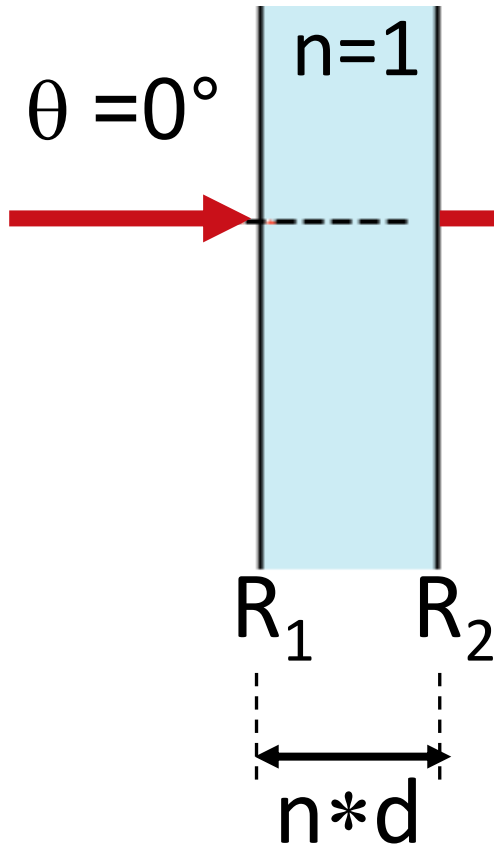


# Thin film interference



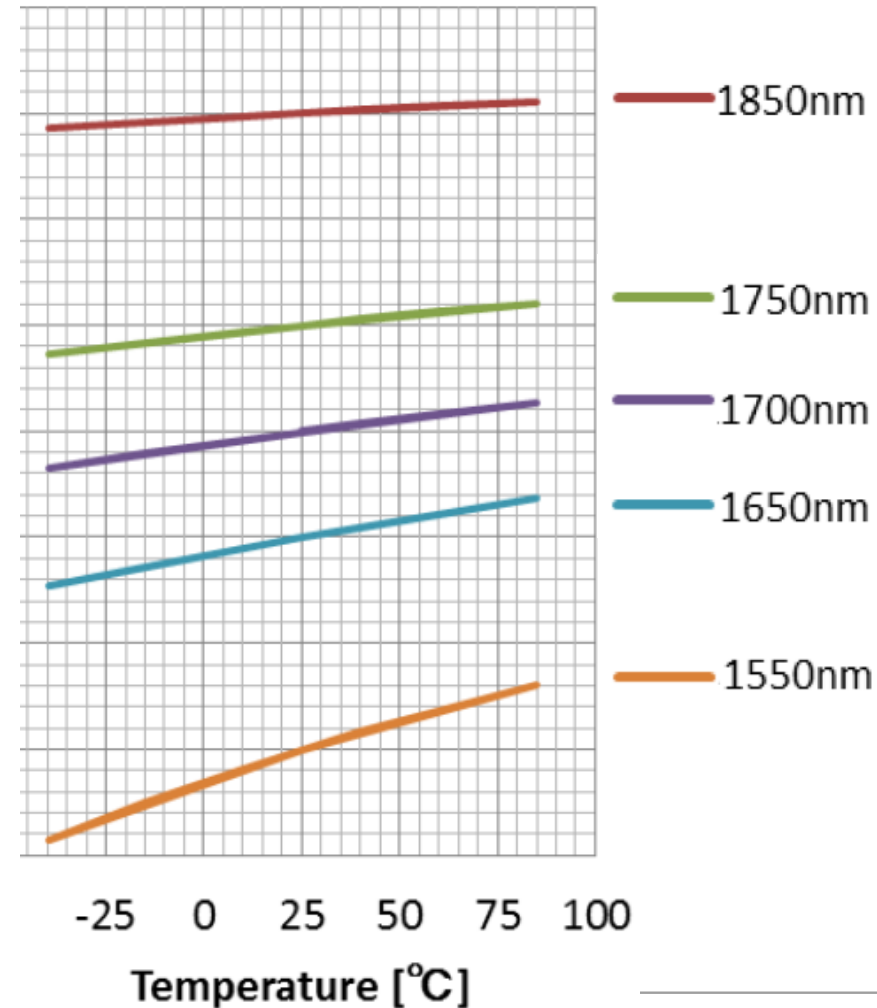
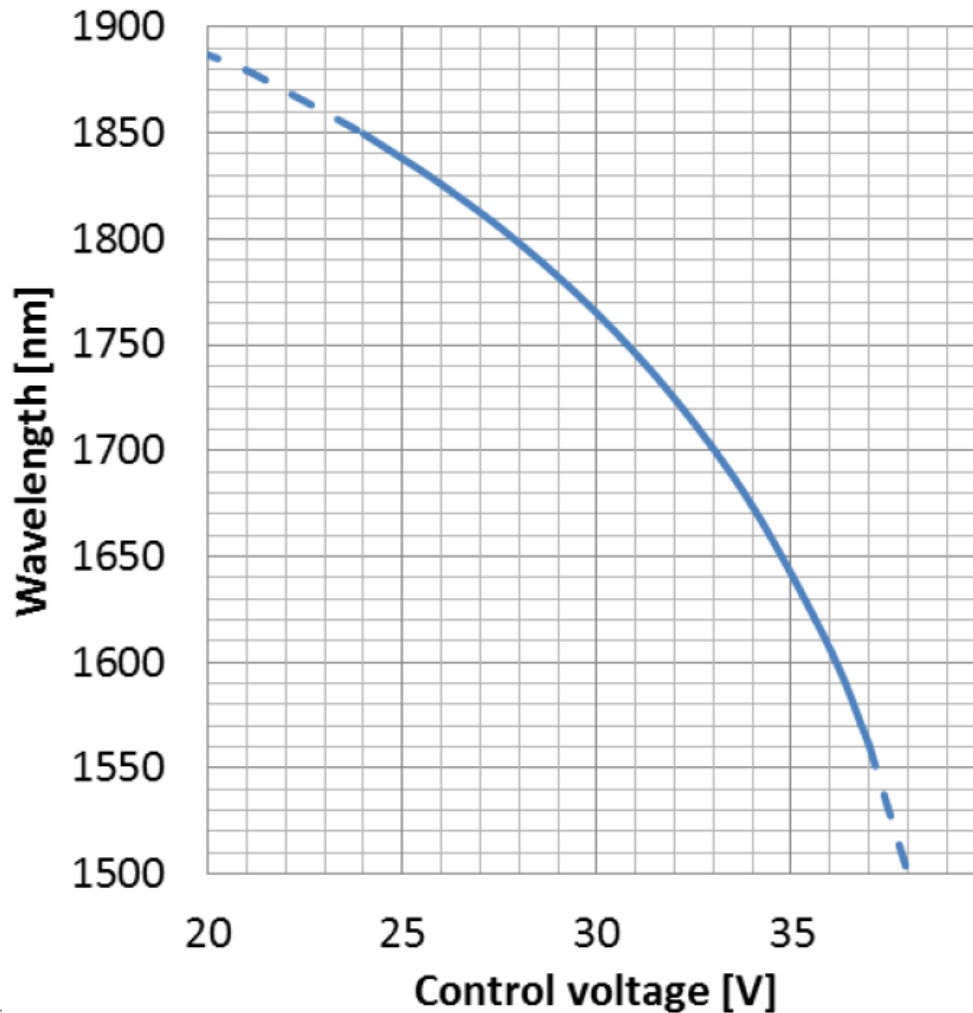
Transmission occurs if:

$$M * \lambda = 2 * n * d$$



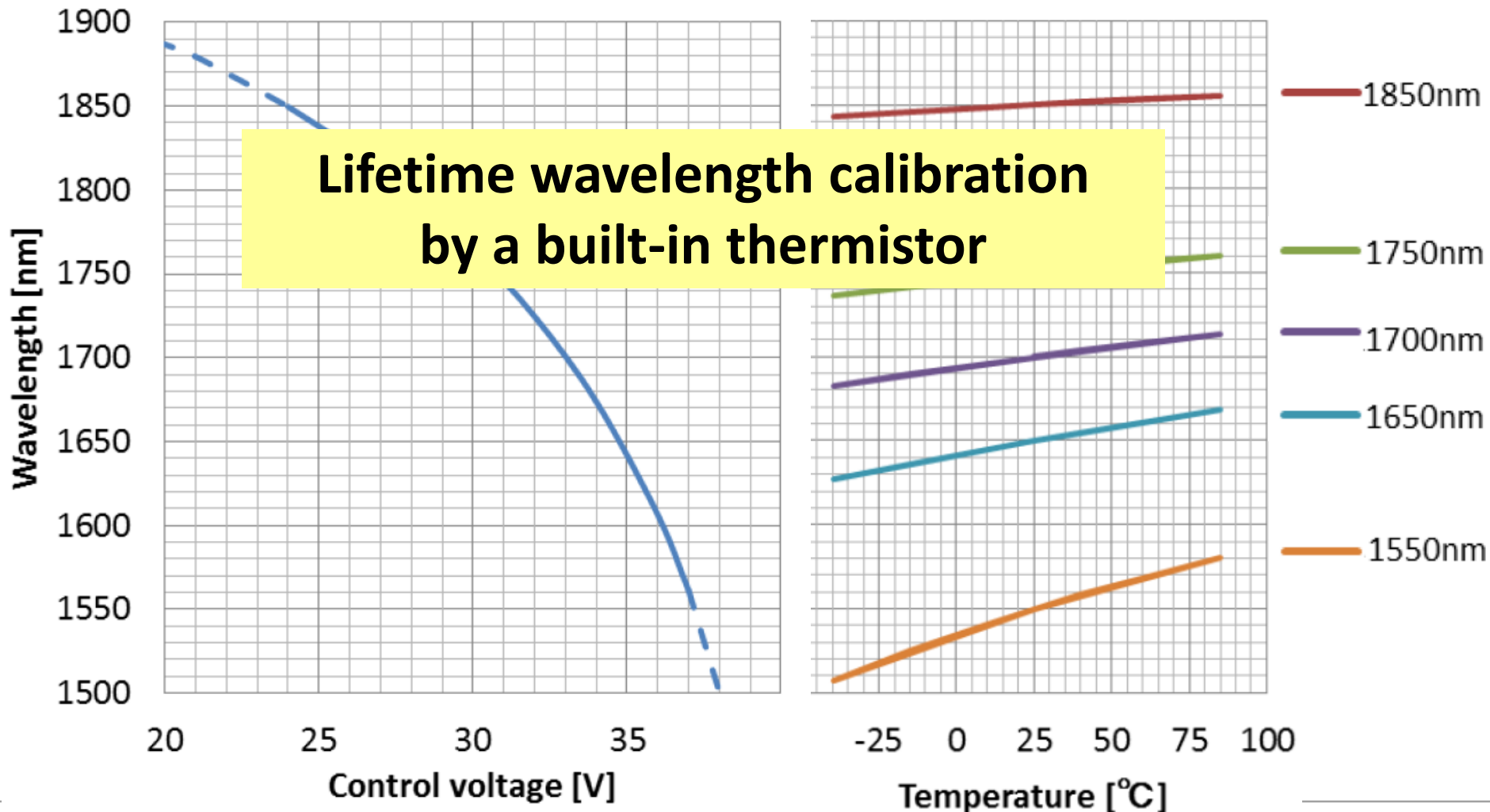
# Transmission wavelength vs. tuning voltage and vs. temperature

( $T_a=25\text{ }^\circ\text{C}$ , Incidence angle :  $0^\circ$  , Photodetector NA = 0.09)



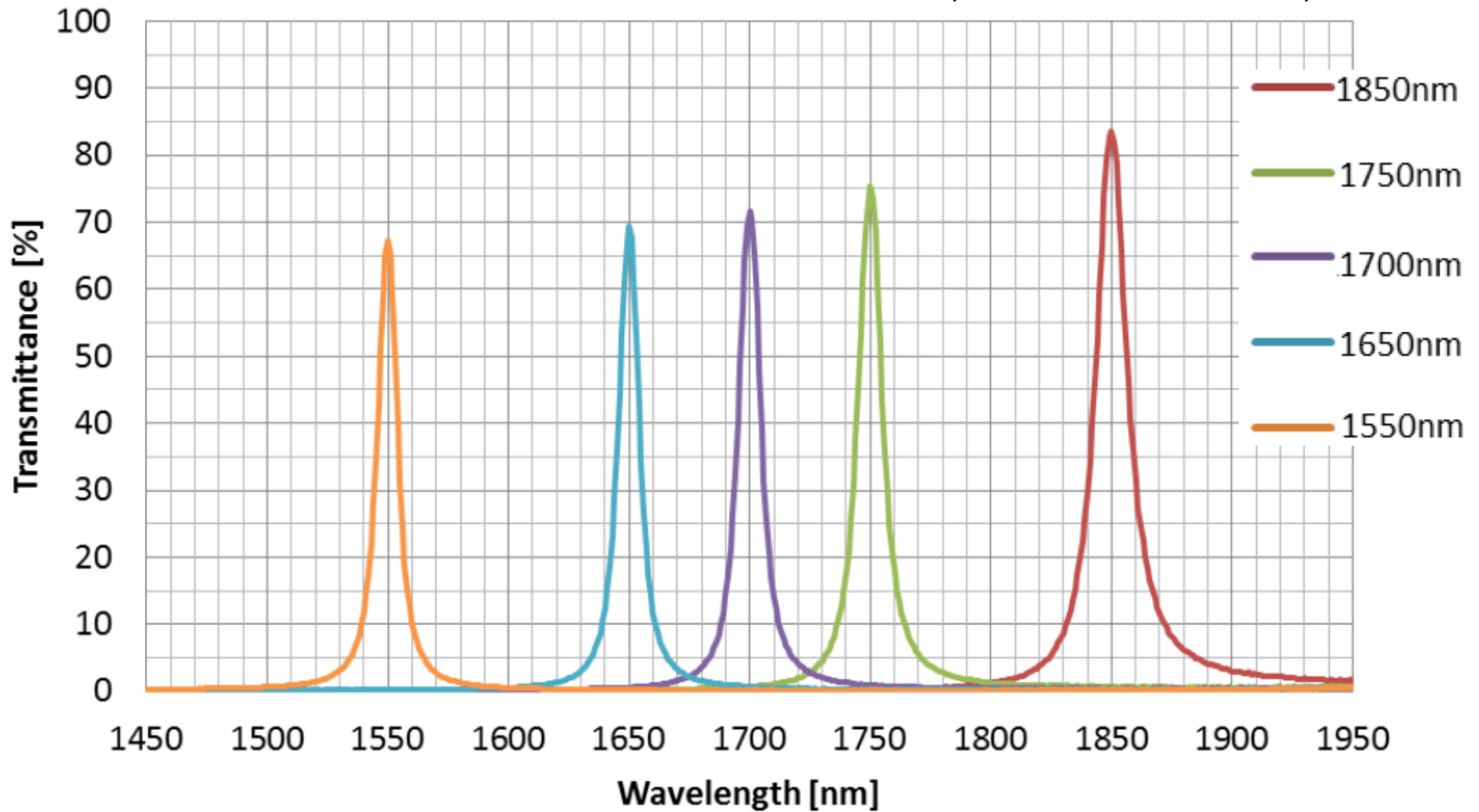
# Transmission wavelength vs. tuning voltage and vs. temperature

( $T_a=25\text{ }^\circ\text{C}$ , Incidence angle :  $0^\circ$  , Photodetector NA = 0.09)



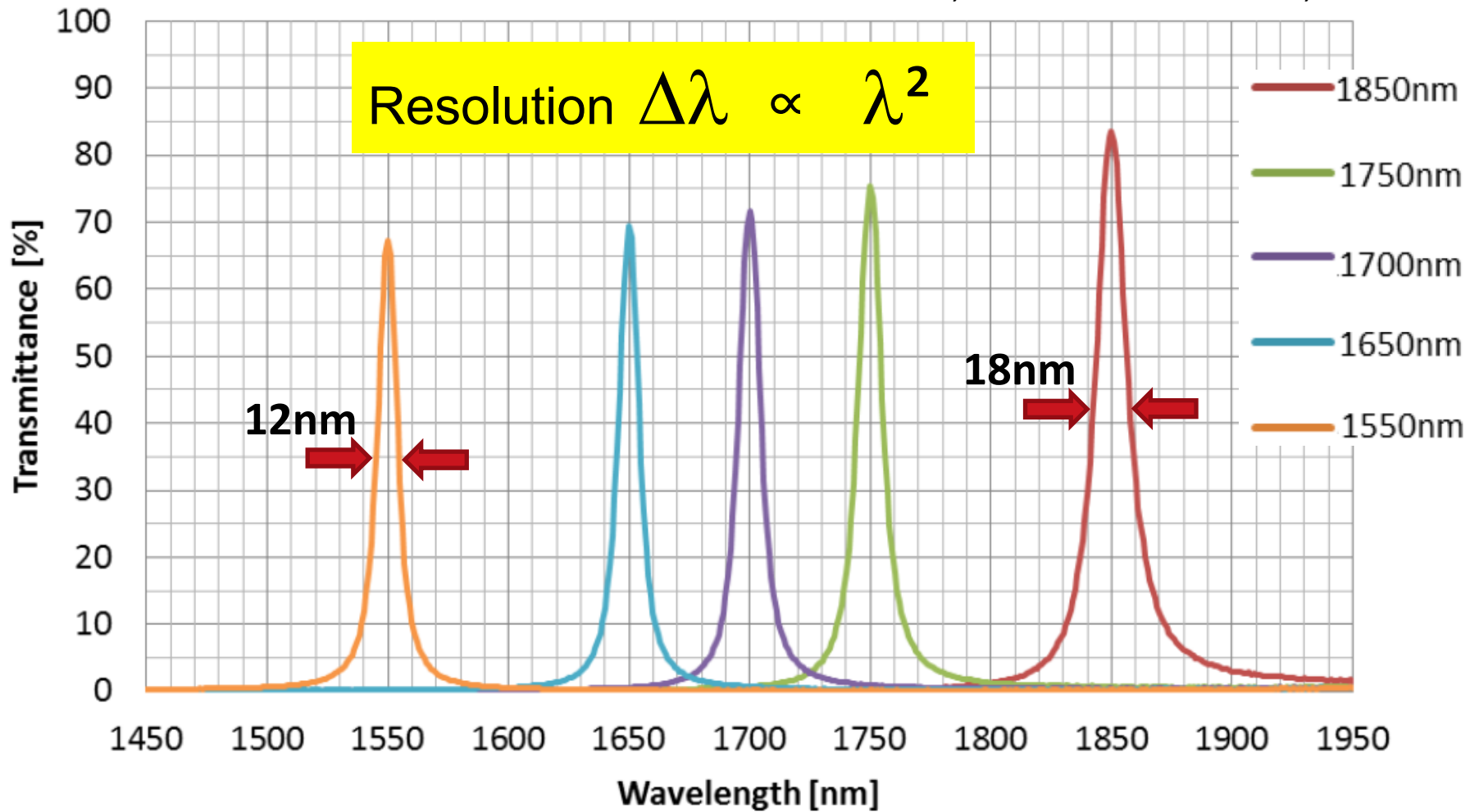
# Transmission Spectra of FPI

T=25°C; incident N.A. = 0.09;



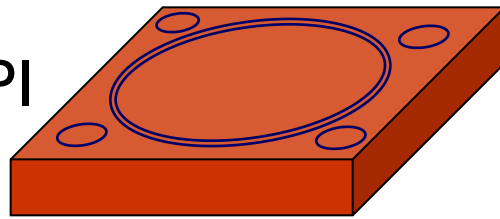
# Transmission Spectra of FPI

T=25°C; incident N.A. = 0.09;

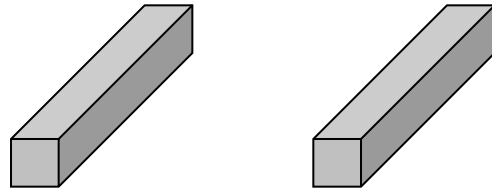


# Packaged FPI Sensor

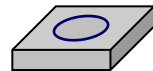
MEMS-FPI



Spacer

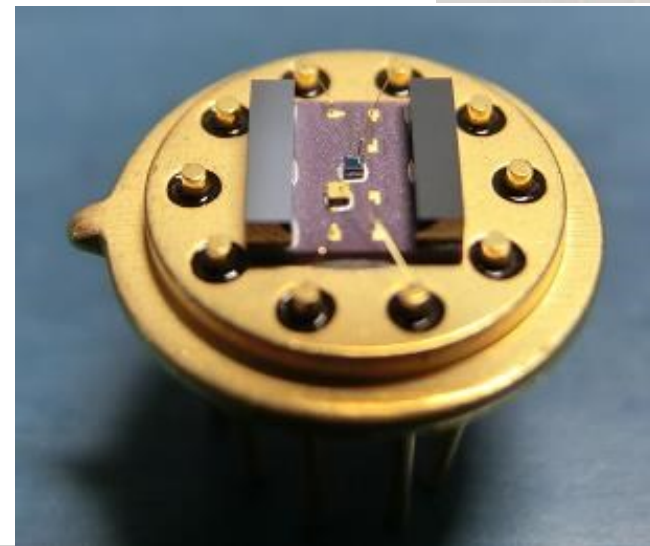
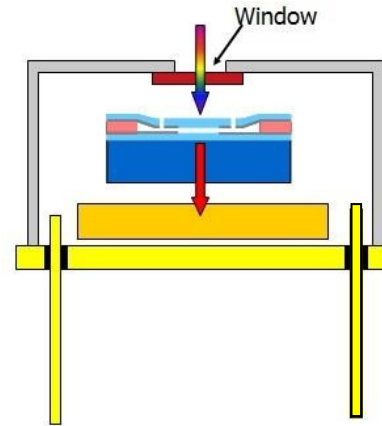
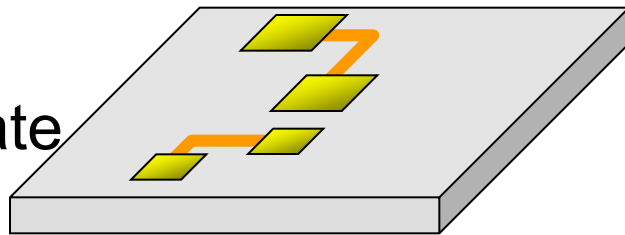


IR detector



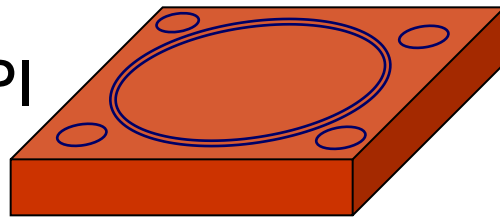
InGaAs

Substrate

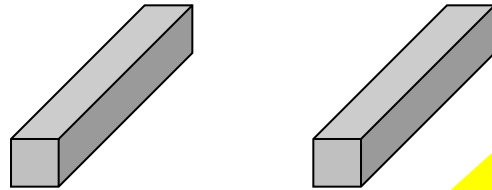


# Packaged FPI Sensor

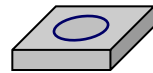
MEMS-FPI



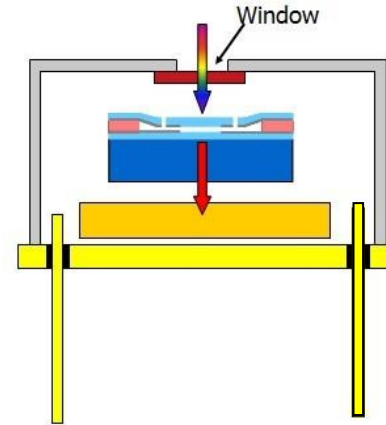
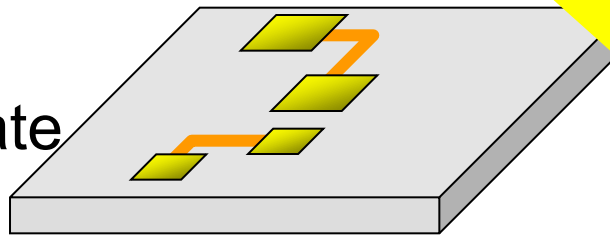
Spacer



IR detector



Substrate



Fast  
hyperspectral sensor  
possible too



## How about Food Safety management for TTX (Tetrodotoxin) of FUGU

- Mouse bio assay → unsafe
- Breeding of non-toxic versions of Fugu (shirasabafugu) → no accepted solution
- HPLC or GC-MS combined with
  - Mass spectroscopy
  - TOF MS
- UV Spectroscopy → limited significance



- **New approach confirmed scientifically: SERS**

Today: --> Industrially processed Fugu, but production output is not yet 100% tested

Target: Reduction of complexity and effort for sample preparation  
e.g. Into a single dilution step



# SERS for Chemical Analysis for Food

**Comprehensive REVIEWS** in Food Science and Food Safety

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Original Article

**Surface-Enhanced Raman Spectroscopy for the Chemical Analysis of Food** 

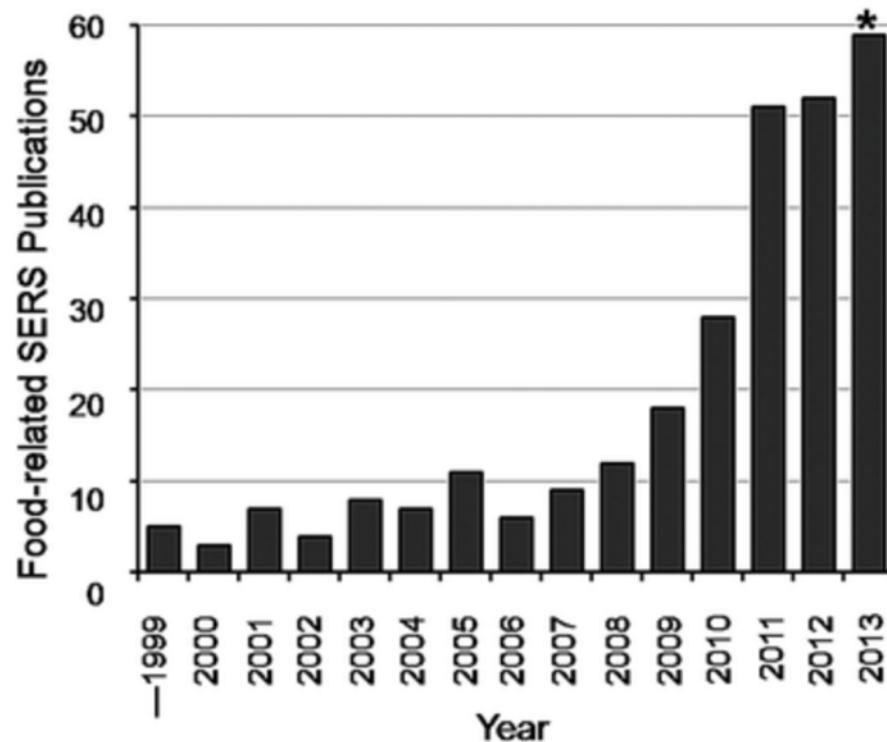
Jinkai Zheng<sup>1,2</sup> and Lili He<sup>1,\*</sup> Issue

Version of Record online: 16 APR 2014  
 DOI: 10.1111/1541-4337.12062  
 © 2014 Institute of Food Technologists®



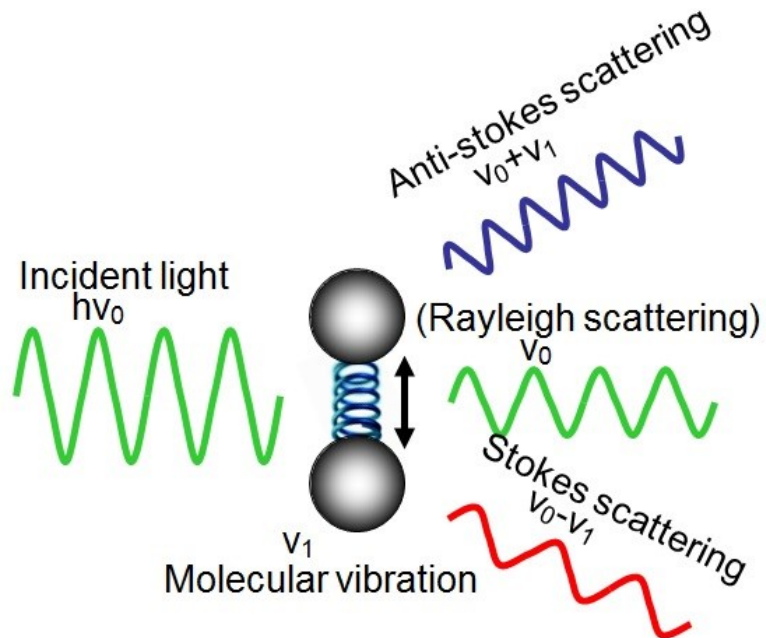
Comprehensive Reviews in Food Science and Food Safety  
 Volume 13, Issue 3, pages 317-328, May 2014

<http://onlinelibrary.wiley.com/doi/10.1111/1541-4337.12062/full>



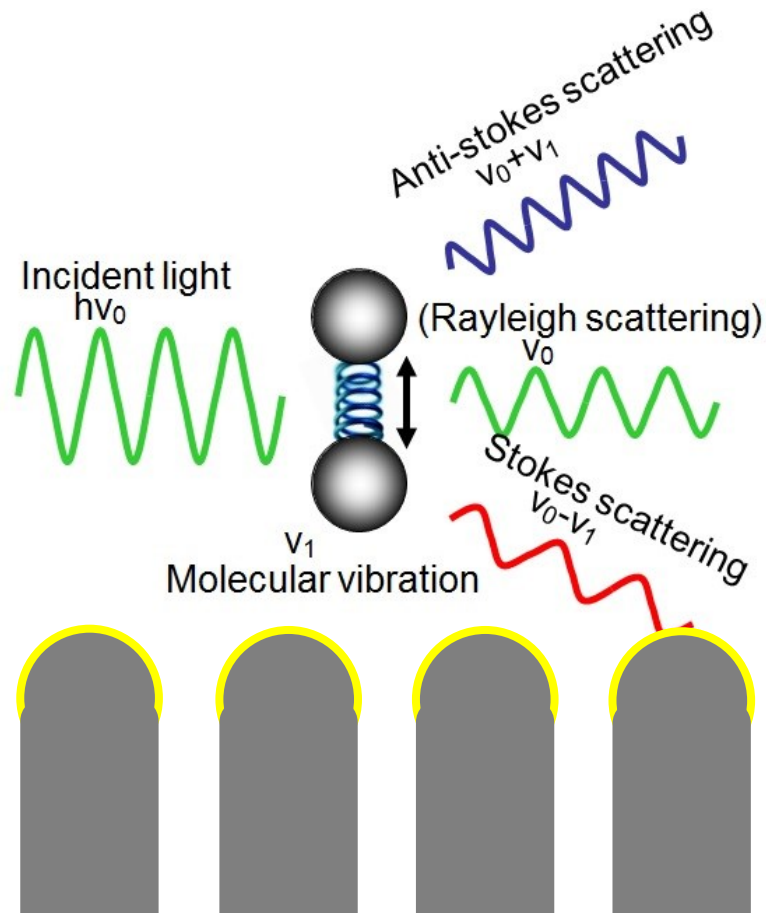
**Figure 2.** Numbers of scientific publications regarding SERS in food-related study every year (\*Counted up to Oct. 2013).

## Raman Scattering Process: Inelastic Scattering



- Excitation by laser
- **Detection of Raman shift**
- Raman shift spectra are fingerprints to the substance analysed
- Usually extremely weak

## Raman Scattering Process: Inelastic Scattering

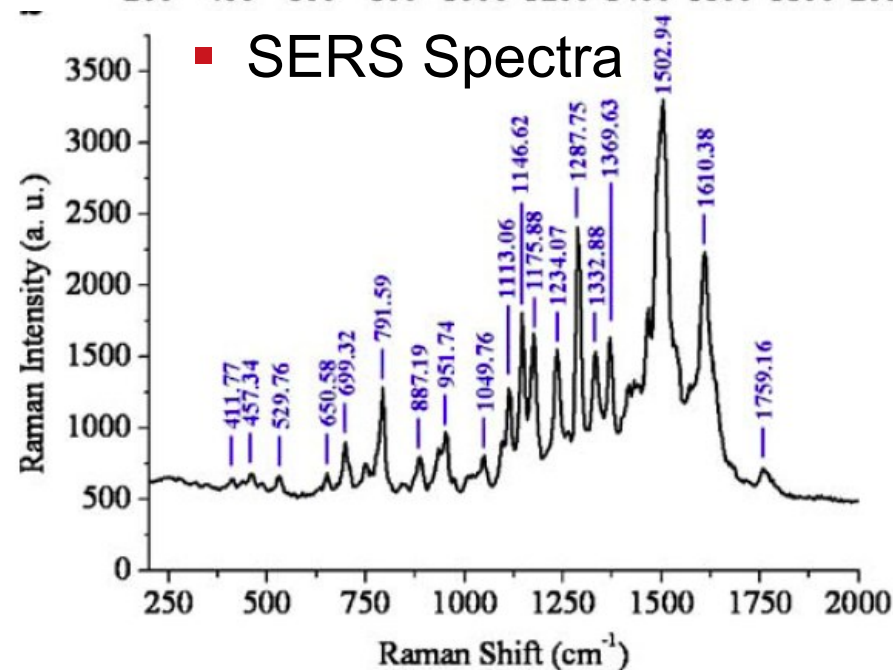
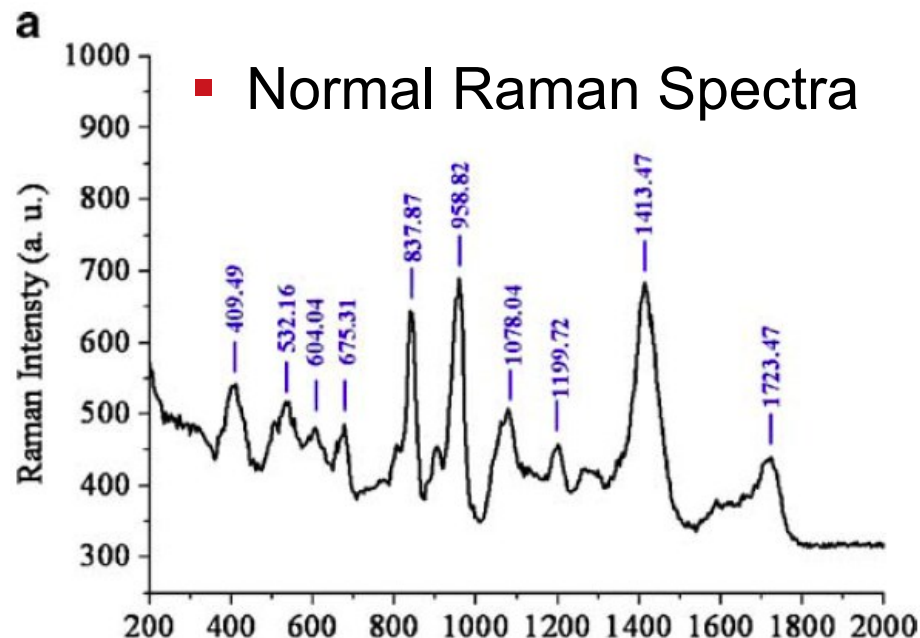
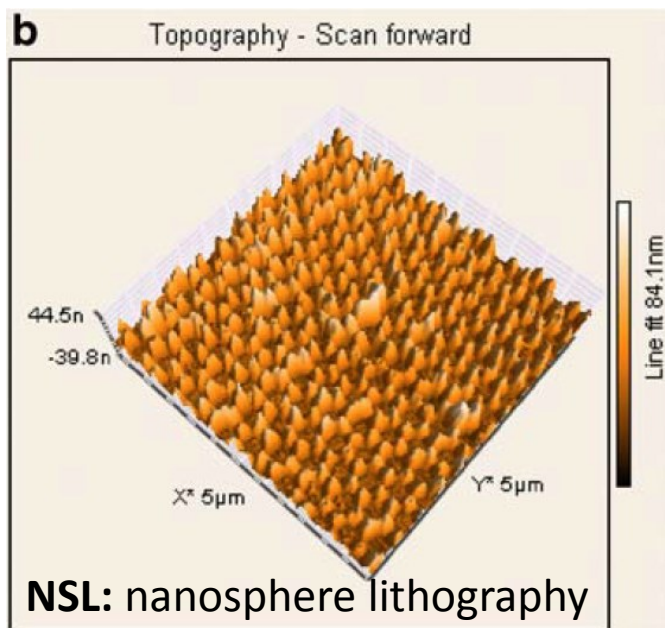


Au or Ag-coated nanostructure surface

- Excitation by laser
- **Detection of Raman shift**
- Raman shift spectra are fingerprints to the substance analysed
- Usually extremely weak
- **Enhancement by SERS**  
**Surface Enhanced Raman Scattering:**  
**up to factor  $10^{10}$**

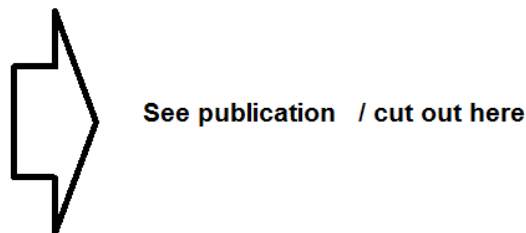
# RAMAN and SERS Spectra of TTX Tetrodotoxin

Lin et al.; SERS study of tetrodotoxin (TTX) by using silver nanoparticle arrays. Plasmonics. 2009;4:187–192.



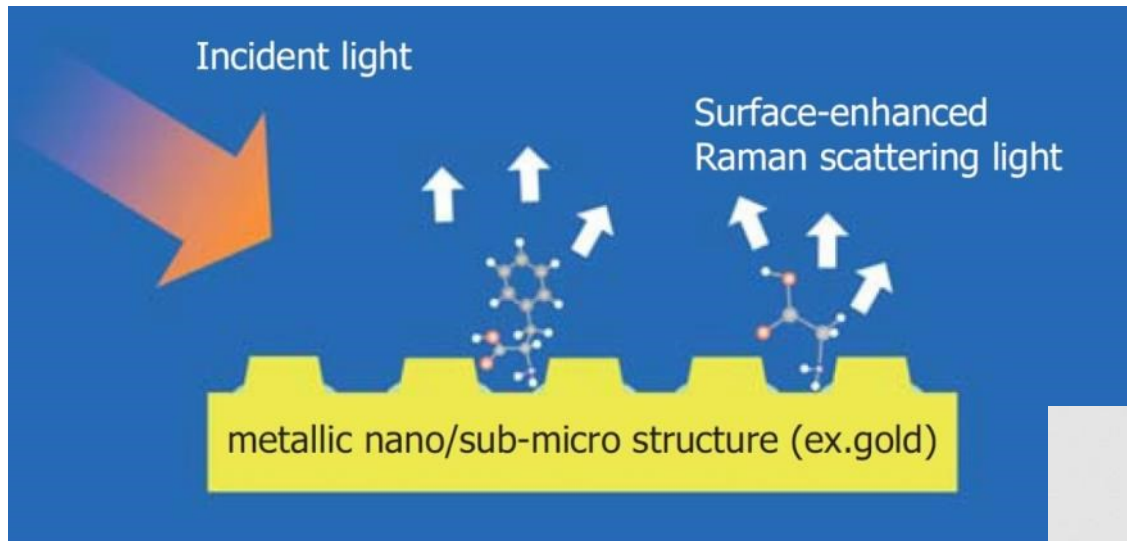
**Table 1. Summary of primary small-molecular analytes and their substrates, main characteristic wavelength, and the limit of detection (LOD) of food-related SERS detection (3 different units were adopted here to describe the LOD values based on different sampling conditions)**

| Analytes   | Substrates                          | LOD*                 | References  |
|--|-------------------------------------|----------------------|---|
| <b>Food additives:</b>                             |                                     |                      |   |
| Benzoic acid                                       | Au colloids                         | –                    | (Gao and others <a href="#">2013</a> )  |
| Phthalic acid                                      | Au colloids                         | –                    | (Gao and others <a href="#">2013</a> )  |
| <b>Pesticides:</b>                                 |                                     |                      |   |
| <b>Antibiotics and illegal drugs:</b>              |                                     |                      |   |
| <b>Melamine:</b>                                   |                                     |                      |   |
| <b>Illegal food dyes:</b>                          |                                     |                      |   |
| <b>Mycotoxins and other small-molecule toxins:</b> |                                     |                      |   |
| Aflatoxin B1                                       | Ag nanorod array                    | $5 \times 10^{-5}$ M | (Wu and others <a href="#">2012</a> )   |
| Aflatoxin B2                                       | Ag nanorod array                    | $1 \times 10^{-4}$ M | (Wu and others <a href="#">2012</a> )   |
| Aflatoxin G1                                       | Ag nanorod array                    | $5 \times 10^{-6}$ M | (Wu and others <a href="#">2012</a> )   |
| Aflatoxin G2                                       | Ag nanorod array                    | $5 \times 10^{-6}$ M | (Wu and others <a href="#">2012</a> )   |
| Saxitoxin  | Ag colloids                         | $2 \times 10^{-9}$ M | (Olson and others <a href="#">2011</a> ; Huai and others <a href="#">2013</a> ) |
| <b>Tetradotoxin</b>                                | Triangulated Ag nanoparticle arrays | 900 ppt              | (Lin and others <a href="#">2009</a> )  |
| Microcystin  | End-to-end assembly of Au nanorods  | 5 ppt                | (Zhu and others <a href="#">2012</a> )  |

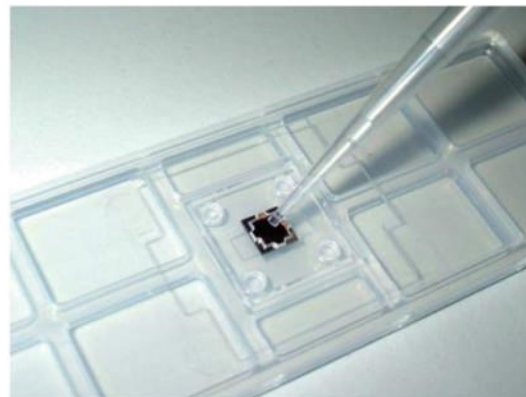


<http://onlinelibrary.wiley.com/doi/10.1111/1541-4337.12062/full>

## Hamamatsu's Approach:

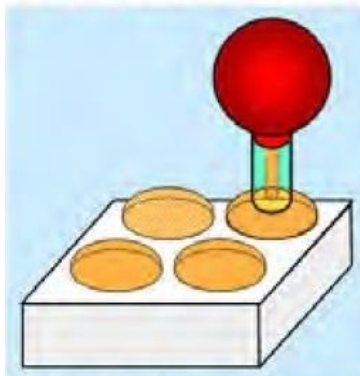


using well defined  
MEMS structures fabricated  
by **NanoImprint Lithography**  
(NIL) and Au-coating

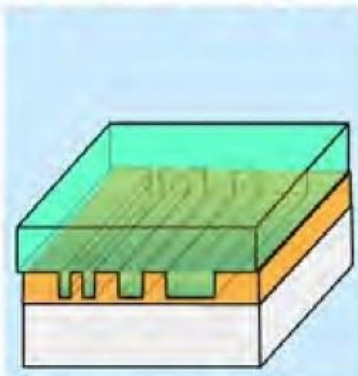


disposable substrate J12853

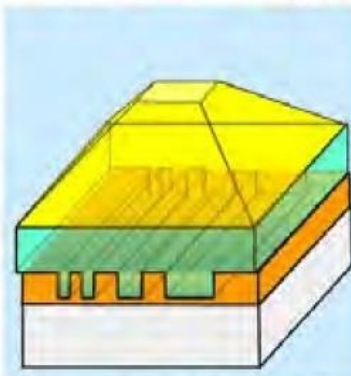
# Nanoimprinting Lithography



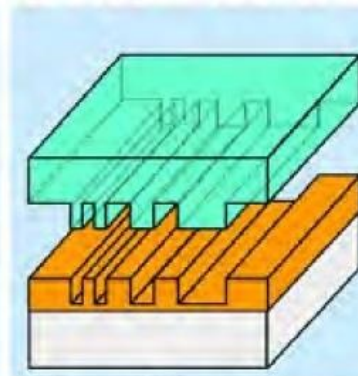
dispensing of liquid resin



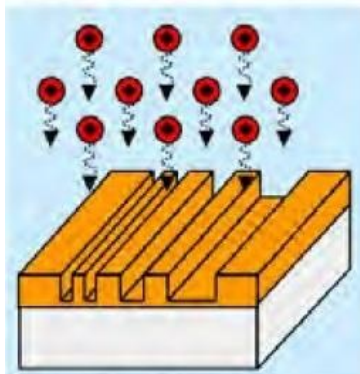
alignment (wedge control) of stamp



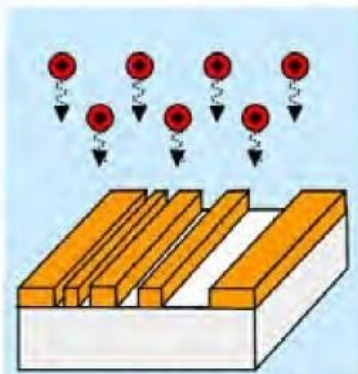
exposure through stamp (curing)



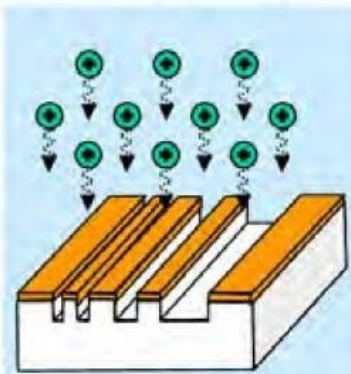
demolding



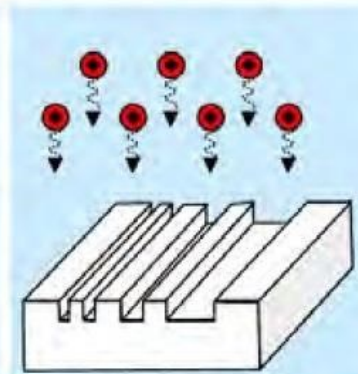
residual layer RIE etch



substrate window opening



pattern transfer into substrate (RIE)



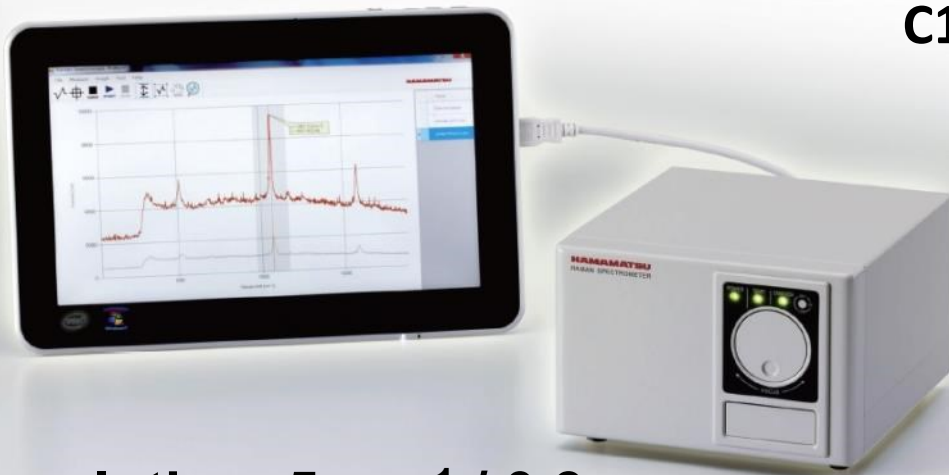
removing of resist



Taken from H. Schiff, **NaPANIL Library of Processes**, 2nd Ed., PSI Switzerland

## Readers for the MEMS based SERS substrate

### C12710 Portable Type



**Resolution 5 cm<sup>-1</sup> / 0.3nm**

- Both modules**
- Laser integrated  
 $\lambda = 785\text{nm}$
  - Spectral range:  
**400 – 1850 cm<sup>-1</sup>**
  - Very high sensitivity  
APS-CMOS sensor



**Compact Type**  
for OEM  
80 x 60 x 16mm<sup>3</sup>

**Resolution 20 cm<sup>-1</sup> 1.2nm**



## Summary

---

- Trend: food sensing devices for consumer
- New OEM hardware approaches for new spectral applications
- SERS as replacement of HPLC / GC-MS
- Toxicology by cardiomyocytes - a model for food ?
  
- Not discussed:
  - !! Terahertz !! ATR-Spectrometer - already portable today !  
See Zomega web site: portable Time Domain THZ Spectrometer
  
  - functionalized surface silk based ‘sensors to eat’ with RF or THz readout  
see [rogers.matse.illinois.edu/files/2012/silksensorsadvmater.pdf](http://rogers.matse.illinois.edu/files/2012/silksensorsadvmater.pdf)  
Silk-Based Conformal, Adhesive, Edible Food Sensors;  
Hu Tao, Mark A. Brenckle, et al  
Adv. Mater. 2012, 24, 1067–1072  
wileyonlinelibrary.com

Next time in Japan, try out Fugu – it is ‘almost’ safe :-)



Thank you very much for your attention !



## Contact

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