Image Sensors and Spectrometers

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Hamamatsu Corporation
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Agenda

- Spectrometer Introduction
- UV – Visible Image Sensors and Spectrometers
- NIR Spectrometers and InGaAs Image Sensor
- Quest for the “Perfect” Spectrometer
- New and Exciting μ-Spectrometers
- Summary
Design of Mini-Spectrometer

Traditional Optical Spectrometer

- focusing mirror
- imaging sensor
- reflection grating
- entrance slit
- collimating mirror

Transmission Grating Spectrometer

- Focus lens
- Transmission grating
- Collimating lens
- Image sensor
- Input slit
Fundamental Building Blocks for Spectrometers

MOEMS Business Promotion

- Semiconductor Technology
- Packaging Technology
- Optical knowledge
- IC and ASIC Technology
- FPGA and Software

MOEMS

M: Micro
O: Opto
E: Electro
M: Mechanical
S: System
• MOEMS Technology in Hamamatsu

MEMS technologies
Fine processing is used to enhance the functions of optical devices.

- Etching
- Nanoimprint
- Resist spray coating
- Bonding
- Through-hole electrode

MOEMS for Spectroscopy

Quartz Grating Wafer

Narrow pitch and High aspect

Nanoimprinted Blazed grating
Example in Grating Spectral Orders

- Multiple emission orders.
- Optical characteristics depend on grating design and fabrication.
  - Wavelength coverage
  - Optical resolution
  - Stray Light
  - Efficiency
Gratings for mini-spectrometers (TG/TM series) use a transmission type (made of quartz) fabricated by a HAMAMATSU holographic process.

The detector that is the heart of the mini-spectrometer is a HAMAMATSU image sensor.
Mini-spectrometer
Market Challenges

• Spectrometers
  ✓ Demands for high precision, scientific instrument.
    ➢ Linearity, stray light, wavelength and repeatability.
  ✓ Moving the instrument to the sample, portability.
  ✓ Broad wavelength coverage, UV – MID IR.
  ✓ Flat response, consistent Signal to Noise ratio.
  ✓ High speed operation, electronic shutter with gating capability.
  ✓ UV hardness, reliability and lifetime.
Spectrometers for Spectroscopy Applications

- High sensitivity
- Rectangular active area
- Low noise, for low light applications
- Large saturation charge, wide dynamic range.
- Optical resolution.
- Stray light performance.

Example of NIR Spectrometer Stray Light
Image Sensor Operating Principle

1. Structure of two-phase CCD

2. Potential diagram

Charged Coupled Device (CCD)

\[ Q = CV = \int_{t_0}^{t_1} I(t) \, dt \]

CMOS (Passive & Active Pixels)

InGaAs

\[ Q = CV = I \Delta t \]
Consumer and Scientific image sensors

• **Consumer image sensors**
  - Digital camera, Mobile phone’s camera
    > small pixel size, narrow dynamic range
    > high sensitivity in visible
    > low price and mass production efficiency

• **Scientific image sensors**
  - Analytical and measuring equipment, Industrial camera
    > larger pixel size, wider dynamic range
    > high sensitivity from UV to NIR
    > high accuracy and good linearity
Market Demand ~ High Sensitivity (QE X Gain)

Front-illuminated type

Back-thinned type

Incident light

Electrode

Passivation

Gate oxide

Potential well

Silicon

Accumulation layer

Incident light

~600μm

~20μm
Visible - NIR Sensitivity Enhanced CCD

![Graph showing quantum efficiency vs. wavelength for different types of CCDs.]

- **Back-thinned (STD)**
- **Front-illuminated (STD)**
- **NIR enhanced**

*Ta=25°C*
High VUV sensitivity CCD

Quantum efficiency [%] vs Wavelength [nm]

VUV Enhanced
UV Enhanced CCD
Market Demand ~ Reliability and Lifetime

High VUV sensitivity and **reduced sensitivity deterioration** by UV irradiation

![Graph showing the comparison between Conventional and Improved UV sensitivity over irradiation dose.](graph.png)

Application (example):
- Water Analysis
- Excimer wavelength monitor
- Semiconductor
- Film Properties
- Spectroscopic measurement (liquid chromatography)
Why are CCD’s low light champions?

Three reasons - #1 Amplifier Noise

Floating Diffusion Amplifier (FDA)

Output Waveforms using camera head

Reset Gate (RG)
Summing Gate (SG)
CLAMP (external)
Output Source (OS)

Output Voltage
\[ \Delta V_o = \frac{(A \nu \times q)}{C_{fd}} \]

CCD Node Sensitivity
\[ S_v = 1.6 \times 10^{-10} \left( \frac{\Delta V_o}{A \nu} \right) \text{ V/e} \]
Reason #2 - CCD Vertical Line Binning Operation

(1) Signal flow

Summing in the analog domain, before pixel readout, reduces total noise.

Floating Diffusion Amplifier (FDA)
CCD Device Structure

- Full Frame Transfer (FFT-CCD).
- Readout on the order of mSec (1-10mSec).
CCD Line Binning Timing Chart

- Readout time determines spectrometers minimum exposure time.

Reason #3 – High QE and high conversion gain.
Market Demand High-speed electronic shutter

- low afterimage of 0.01%
- Short shutter period of 1 μsec.

![Graph showing image lag improvement](image.png)
# CCD with different charge transfer

|                       | Interline CCD | Resistive gate CCD | Binning readout |  |
|-----------------------|---------------|--------------------|-----------------|  |
|                       |               | Back thinned type  | Back thinned type |  |
| Product               | S15351(New)   | S15254(New)        | S703x, S10420, S11071 |  |
| **Charge transfer**   |               |                    |                 |  |
| Active area           |               |                    |                 |  |
| Transfer direction    |               |                    |                 |  |
| Voltage low           | Voltage high  |                    |                 |  |
| Potential             |               |                    |                 |  |
|                      |               |                    |                 |  |
| **Feature**           | General application | High sensitivity | High sensitivity | Wide dynamic range |

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High-speed electronic shutter

- Basic concept
  - Long pixel height
  - Back illuminated type linear CCD
  - High speed e-shutter function

- Specification
  - Pixel pitch: 14um
  - Pixel height: S15254: 200um, S15257: 2500um
  - Shutter speed: S15254: < 1us, S15257: 50us
  - Readout Speed: 5MHz(Typ), 10MHz(Max)
  - Full Well Capacity: 200ke-
  - Dynamic range: 6660
  - Low image lag

- Application
  - LIBS
  - Gating operation

*LIBS: Laser Induced Breakdown spectroscopy*
Market Demand Spectrometers with Flat Response

- Saturated detector = un-usable region
- D-alpha line from deuterium lamp
Solutions for Spectrometer Saturation

• Application
  - Spectrometer

• Features
  - Anti-blooming (saturation control)
  - Horizontal pixels: 2048
  - Vertical pixels: 128, 256, 512
  - Low noise type: S1014x-01
  - High speed type: S1324x
  - Large full well: 500ke-
    (3 times larger than conventional)

Quantum efficiency [%]

(Wavelength (nm))

(Non-cooled type) TE-cooled type

(Typ. Ta=25 °C)
Solutions for Saturation Control and Flat Response

• **Application**
  - Spectrometer

• **Benefits**
  - Readout bright portions of the spectrum, while allowing weaker signal to accumulate longer.
  - Saturation Charge ~ 180pC

CMOS image sensor with variable integration capabilities
Suppressed fringe of spectral sensitivity

Suppressed the fringe of spectral sensitivity curve over a wide wavelength range.

Application (example)

- Absorption spectroscopic measurement (Liquid chromatograph)

<table>
<thead>
<tr>
<th>Wavelength[nm]</th>
<th>Quantum efficiency[%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td></td>
</tr>
</tbody>
</table>

S1012X-03
CMOS ~ Difference between PPS and APS

**Active Pixel Sensor**
The APS is a method with the amplifier in each pixel.

**Passive Pixel Sensor**
The PPS is a method with only one amplifier at the end of video line.
Buried Photodiode technologies

Surface PD structure

Buried PD structure

Enhanced sensitivity by minimizing capacitance of charge integration area
Higher sensitivity CMOS-APS with Buried PD

• **Features**
  – Higher pixel in size (14x200um)
  – Higher sensitivity with buried PD
  – APS (Active Pixel Sensor)
  – Sensitivity 1300V/lx s
    (8 times higher than conventional type)
  – Electronic shutter

• **Application**
  – Spectrometer

• **Specification**
  – 14um x 200um, 2048ch

Almost same as CCD
# CCD vs CMOS Image sensors

<table>
<thead>
<tr>
<th></th>
<th>CCD</th>
<th>CMOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output (pixel)</td>
<td>charge</td>
<td>voltage</td>
</tr>
<tr>
<td>Amplifier</td>
<td>1-amp for multi pixels</td>
<td>1-amp for single pixel</td>
</tr>
<tr>
<td>Output (chip)</td>
<td>voltage (analog)</td>
<td>digital/analogue</td>
</tr>
<tr>
<td>Charge transfer</td>
<td>from pixel to pixel</td>
<td>inside of pixel</td>
</tr>
<tr>
<td>Fabrication</td>
<td>specialized process for CCD</td>
<td>common LSI process</td>
</tr>
<tr>
<td>Input bias</td>
<td>multiple, high, voltage</td>
<td>single, low, DC</td>
</tr>
<tr>
<td></td>
<td>clocking</td>
<td></td>
</tr>
<tr>
<td>Onchip circuit</td>
<td>Very difficult</td>
<td>possible</td>
</tr>
<tr>
<td>External circuit</td>
<td>complicated</td>
<td>simple</td>
</tr>
</tbody>
</table>
CCD vs CMOS image sensors

CCD image sensor
- Signal charges are transferred in Si.
- Charges are converted to voltage "after" transferring.

CMOS image sensor
- Signal voltage is transferred in the metal.
- Charges are converted to voltage "before" transferring.

Q⇒V

V-shift register
H-shift register
CDS, ADC, etc.
UV – Visible (SWIR) Summary (190nm-1100nm)

• Spectrometers & Image Sensors
  ✓ CCD based solutions excellent for low light levels.
  ✓ CMOS-APS spectrometers, portable implementations for middle range.
  ✓ CMOS-PDA spectrometers with variable integration time and huge dynamic range. Absorption applications with bright light, detecting small changes.
NIR Image Sensors and Spectrometers (900-2500nm)
# NIR Spectrometers

<table>
<thead>
<tr>
<th>Photo</th>
<th>C14486GA</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Spectral range [nm]</th>
<th>950 to 1700 (NIR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution [nm]</td>
<td>5.0 typ</td>
</tr>
<tr>
<td>Image sensor</td>
<td>InGaAs</td>
</tr>
<tr>
<td>N of pixel</td>
<td>256</td>
</tr>
<tr>
<td>W x D x H [mm]</td>
<td>80 x 60 x 12</td>
</tr>
<tr>
<td>Weight [g]</td>
<td>88</td>
</tr>
</tbody>
</table>
Compound Semiconductors for IR sensors

Wavelength

0.6 1 2 4 10 20 μm

- P b S
- P b S e
- H g C d T l
- I n G a A s

P b, H g, C d : Hazard Material

Good candidate to replace
InGaAs image sensor spectral response
For wide wavelength spectrometer
2 types InGaAs in 1PKG

InGaAs Hybrid Linear image sensors
- Single video line 512ch
- High speed readout 5MHz max.
- 255ch(0.95-1.7um)&255ch(1.4-2.2um)
Market Demand ~ “Perfect” Spectrometer

- **Stray Light Corrections**

Simple spectral stray light correction method for array spectroradiometers

Yuqin Zong, Steven W. Brown, B. Carol Johnson, Keith R. Lykke, and Yoshi Ohno

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**Fig. 3.** Representative LSFs spanning the test spectrograph’s detector array.
Market Demand ~ “Perfect” Spectrometer

- Linearity Corrections

Figure 7. Pixel intensities (counts) versus integration time (ms). A single line represents data from one pixel. Data from 200 representative pixels (equally spaced between 400–800 nm) are shown. All data lines appear to be linear up to 50,000 counts and then deviate strongly from the ideal line.
MOEMS Technologies
New Technology creates new solutions ..... Micro-Spectrometers
New development for NIR Mini-Spectrometer

Grating design has some limitation to make smaller and cheaper

- Have to use a very expensive Image sensor
- Very difficult to get higher resolution in limited space
- Difficult to design wide wavelength spectrometer

How to realize small and cheap NIR spectrometers?

Not Grating type but
“Interference Spectrometer using Actuator“
Focusing on Portable Implementations

- Mini-spectrometer SMD series (640 to 1050 nm)
- MEMS-FPI spectrum sensor (e.g., 1550 to 1850 nm)
- Compact FTIR engine (1100 to 2500 nm)
Hamamatsu Contributions to Industry

Industry
- incoming test
- Process control
- Wet process analysis

Agriculture

Recycle

Infrastructure

Functional group of Near infrared region

Wavelength range of FTIR engine

700nm  1000nm  1500nm  2000nm  2500nm
FTIR (Fourier transform infrared spectrometer) – Principle –

Michelson interferometer

- Beam Splitter (BS)
- Detector
- Measured light
- Dispersion compensation plate
- Fixed mirror
- Movable mirror

Interference signal

Optical path difference

Fourier transform

Spectrum

Intensity

Wavelength
Optical configuration for the interferometer

Features:

➢ Integrated MEMS chip and beam splitter prism
➢ Manufactured with less optical adjustment

Requirement:
➢ High relative angle accuracy
   - a movable mirror and a fixed mirror
• SNR improvement by NEW FTIR Engine (vs old model)

<table>
<thead>
<tr>
<th></th>
<th>New FTIR Engine C15511-01</th>
<th>Old MEMS-FTIR C12606-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror size</td>
<td>3mm dia.</td>
<td></td>
</tr>
<tr>
<td>Spectral range</td>
<td>1100 to 2500 nm</td>
<td>1150 to 2050 nm</td>
</tr>
<tr>
<td>SNR *1</td>
<td>10,000 : 1 (40dB)</td>
<td>1,000 : 1 (30dB)</td>
</tr>
<tr>
<td>Resolution</td>
<td>25cm⁻¹ 5.7 nm (1533nm)</td>
<td>29cm⁻¹ 6.8nm (1533nm)</td>
</tr>
<tr>
<td>Size</td>
<td>57 x 49 x 76 mm (212,000mm³)</td>
<td>100 x 75 x 27 mm (202,500mm³)</td>
</tr>
</tbody>
</table>

- Expanded spectral range up to 2500 nm
- Improved sensitivity about 100 times (*2)

*1: The SNR values are on conditions optimized to each type.
*2: The graph on the right shows the sensitivity improvement by 100 times, whose measurements are on conditions optimized to C15511-01. (i.e. too weak light for C12606-02)
Compact FTIR engine - design concept

φ3.0 mm movable mirror
(Flat/Large diameter)

- High SNR (by large mirror size)
- High resolution (by flat optical surface)

Comb tooth electrode
Torsion spring
• Optical system of FTIR engine (cross-sectional view)

➤ Two interferometers separated by a dichroic mirror
➤ Passive alignments are applied with positioning pins
Compact FTIR engine – Test sample –

Actuator chip (Si)

Movable mirror

Fixed mirror

Dispersion compensation (Glass)

【MEMS chip】

【Compact FTIR engine】

VICSEL

Si-PD

InGaAs-PD

Fiber connector

MEMS chip + Trapezoidal BS

32 mm

28 mm

58.5 mm
Compact FTIR engine – Evaluation result –

- Wavelength region: 1.15~2.5 μm
- Resolution: 11 nm@1.5 μm
- Max SNR: 46dB
Compact FTIR engine application: degradation of mortar

Wavelength (nm)

1100 1300 1500 1700 1900 2100 2300 2500

0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6

1450nm: OH stretch overtone
1410nm: Ca(OH)₂
2200nm: OH stretch + SiOH stretch combination
2250nm: Chloride
2340nm: CaCO₃

Freeze-melt cycles

Degradation

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Near infrared alcohol absorption spectrum

- Transmission measurement
- 1mm quartz cell
- Light source = Halogen

Estimation of alcohol concentration using information in a region of 2300 nm
The absorption peaks of glucose, sucrose and fructose can be found by the FTIR engine C15511-01, which is correspondent with the data by the desktop FTIR instrument.
MEMS-FPI Spectral sensor –Lineup–

- **C14272**
  - 1350~1650nm
  - Water

- **C14273**
  - 1750~2150nm
  - Protein • Lipid • Carbohydrate

- **C13272-02**
  - 1550~1850nm
  - Plastic Fiber
  - Alcohol

- **NEW**
  - MEMS-FPI Spectral sensor
  - Lineup
  - Wavelength
Non-Grating IR Spectrometer

**MEMS-FPI**

A tunable filter that adjusts transmission wavelength by controlling the applied voltage.

**Upper Mirror (Membrane)**

**Lower Mirror**

**Incident Light**

**Air gap**: \( \frac{m\lambda}{2} \)

**Transmission wavelength to be tuned by this air gap**

**FPI (Fabray-Perot Interferometer)**

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

![Graph showing transmission wavelength vs. control voltage](graph.png)
MEMS-FPI Spectral sensor – Tunable filter –

A tunable filter that adjusts transmission wavelength by the applied voltage.
Structure of **MEMS-FPI**

**MEMS-FPI**

- **Spacer**
- **IR Detector**
- **Wiring Substrate**

**Feature**

- Small PKG : TO-5
- Super lightweight : 1g
- Hermetic PKG
- Single InGaAs-PD included
- Thermistor included
- Band pass filter included
MEMS-FPI spectral sensor – Characteristics –

**Peak transmission wavelength**
- Filter control voltage

**Resolution (FWHM) – nm**

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**Wavelength resolution**
- Peak transmission wavelength

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MEMS FPI: Wavelength transmission response

FPI Type: C14273 (1750～2150 nm)

(Ta=25°C, incident light’s line spectrum resolution (FWHM)=3 nm max., Incidence angle=0°, photosensor NA=0.09)
MEMS-FPI Spectral sensor - Evaluation kit -

- USB connection
- 16 bit ADC
- Gain: Low / High
- Evaluation software bundled

MEMS-FPI Spectral Sensor

InGaAs PD
Thermistor
MEMS-FPI Tunable filter

Gain: 2 step (High/Low)
I-V Amplifier
ADC
ADC
FPGA
USB Controller

DC/DC Converter
DAC

USB Interface

Evaluation kit C13294-02

C13294-02
MEMS-FPI spectrum module features

- **Compact • Thin**
  - Size: 74×32×16mm

- **MEMS-FPI spectrum sensor built-in**
  - 3 types C15712, C15713, C15714 are available

- **USB2.0 bus-power operation**

- **Transmission wavelength compensation**
  - Transmission wavelength shift by ambient temperature (Max. 0.9nm/°C) can be compensated by circuit

- **High speed measurement**
  - <1 sec/scan is possible (at 1 nm step between 300 or 400nm wavelength range)

- **Built-in lamp**
  - Reflection measurement is available
  - Transmission measurement is also available with Lamp OFF

- **Software**
  - In addition to evaluation software, DLL can be provided soon

- **Option**
  - SMA fiber attachment (option) is available.

It will be released on Spring, 2020

**Operating temperature**: -5~+50°C

**Spectral resolution (FWHM)**
- C15712: 18nm
- C15713: 20nm
- C15714: 22nm
MEMS-FPI spectrum module application example

- **Plastics**
  - Measured by reflection
  - Material identification by spectrum differences

- **Fabrics**
  - Measured by reflection
  - Material identification by spectrum differences

- **Graphs**
  - Absorbance vs. Wavelength (nm)
  - PET, PVC, PS, wool, polyester, cotton
# FPI & FTIR Summary Table

<table>
<thead>
<tr>
<th>Item</th>
<th>MEMS-FPI spectral sensor</th>
<th>Compact FTIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>Fabry-Perot interferometer Tunable filter</td>
<td>Michelson interferometer FTIR</td>
</tr>
<tr>
<td>Wavelength length region</td>
<td>1.35-1.65μm, 1.55-1.85μm, 1.75-2.15μm</td>
<td>1.15-2.5μm</td>
</tr>
<tr>
<td>Wavelength resolution</td>
<td>18nm@1.65μm, 20nm@1.85μm, 22nm@2.15μm</td>
<td>11nm@1.5μm</td>
</tr>
<tr>
<td>Detector</td>
<td>InGaAs PIN PD single element</td>
<td>InGaAs PIN PD</td>
</tr>
<tr>
<td>Light incident method</td>
<td>Window</td>
<td>Optical fiber (SMA)</td>
</tr>
<tr>
<td>Product form</td>
<td>Sensor component or module Module – Temperature Compensation Component – User calibrate</td>
<td>Module</td>
</tr>
</tbody>
</table>
Market Demand – Move the instrument to the sample

Pocket Spectrometer for Color Analysis
Components for Mini & Micro-Spectrometers

Optical slit on the same CMOS image sub.

Color Filter on CMOS image sensor

Master Lens for Replication

800nm Blazed Grating by Nanoimprint

1st Gen. Mini-Spectrometer

CMOS image sensor
Input slit

Concave grating

2nd Gen. Micro Spectrometer

CMOS image sensor
Input slit
Air gap

Concave grating

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Strategy for much smaller Spectrometer

MOEMS spectrometer

Micro spectrometer

Spectrometer inside smartphone!
Optical design

Micro spectrometer

Input slit

CMOS

Concave Grating

SMD-type

CMOS

Mirror

Input slit

Down sizing

CMOS

Concave Grating

Window glass

CMOS Image sensor

light
Components of MOEMS Spectrometer

3rd Gen. Micro Spectrometer

- ⑤ High sensitivity/speed CMOS image sensor
- ④ Concaved blazed grating
- ③ 2nd mirror for collimate
- ② 1st mirror for collimate
- ① Input slit

- Integrated slit and mirror to CMOS
- Formed grating and mirror on concave
Micro-spectrometer SMD type—C14384MA—

- **Feature**
  - Grating type
  - Ultra compact, light weight
  - Thin type, Side looker
  - Wavelength: 640 ~ 1050nm
  - High sensitivity, high speed
  - Flexible cable connection

- **Target market**
  - food, agriculture, environment monitor

**weight**: <0.3g  
**FPC length**: 18mm

The smallest size as a grating type spectrometer!
# Mini-spectrometer SMD series - Characteristics -

## Construction / Optical characteristic

<table>
<thead>
<tr>
<th>Item</th>
<th>C14384MA</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral response range</td>
<td>640-1050</td>
<td>nm</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>256</td>
<td>pixels</td>
</tr>
<tr>
<td>Clock pulse frequency</td>
<td>5</td>
<td>MHz</td>
</tr>
<tr>
<td>Slit size</td>
<td>15×300</td>
<td>μm</td>
</tr>
<tr>
<td>NA</td>
<td>0.22</td>
<td>-</td>
</tr>
<tr>
<td>Spectral resolution (FWHM)</td>
<td>20(Max.)</td>
<td>nm</td>
</tr>
<tr>
<td>Wavelength temperature dependence</td>
<td>±0.1</td>
<td>nm/℃</td>
</tr>
<tr>
<td>Wavelength reproducibility</td>
<td>±0.5</td>
<td>nm</td>
</tr>
<tr>
<td>Spectral stray light</td>
<td>-23</td>
<td>dB</td>
</tr>
</tbody>
</table>
Line-up of spectrometers using MOEMS grating

- **C10988MA-01**: Good stability
- **C11708MA**: High reliability
- **C12666MA**: Low price, Rough analysis, Surface mount, Side input
- **C12880MA**: SMD-swNIR

Wavelength [nm] from 300 to 1000

- **200kHz**
- **5MHz**

MOEMS spectrometer
Micro spectrometer
SMD-type
Grating type compact spectrometer series

**MS series**
weight: 9g
C10988MA(340~750nm)
C11708MA(640~1050nm)

**Micro series**
weight: 5g
C12666MA(340~780nm)
C12880MA(340~850nm)

**SMD series**
weight: <0.3g
C14384MA(640~1050nm)

volume: 1/40
MOEMS Spectrometers

Size (Cost)

Small

Conventional grating-type

Ultra-compact grating type spectrometer

Very small

MEMS-FPI (300 to 400nm range x 3 types)

Compact FTIR engine

Wavelength

VIS (640 nm)  NIR (1050 nm)  NIR (1700 nm)  NIR (2500 nm)
Summary

- Optical MEMS (MOEMS) devices to enrich sensor information remarkably, which will make “real-time, on-site measurements in various fields” possible.

- Downsizing, cost reduction of the devices
  → to be utilized in more and more handy products
  → to be utilized in more and more production lines
  → to be utilized in our daily lives more and more
Join Us for 10 Weeks of FREE Photonics Webinars (17 Topics)

<table>
<thead>
<tr>
<th>Week #</th>
<th>Weekly Topics</th>
<th># of Talks</th>
<th>Talk #1 Date</th>
<th>Talk #2 Date</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Introduction to Photodetectors</td>
<td>2</td>
<td>26-May-20</td>
<td>28-May-20</td>
</tr>
<tr>
<td>2</td>
<td>Emerging Applications - LiDAR &amp; Flow Cytometry</td>
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<td>Using SNR Simulation to Select a Photodetector</td>
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