HAMAMATSU

PHOTON IS OUR BUSINESS

Hamamatsu products for

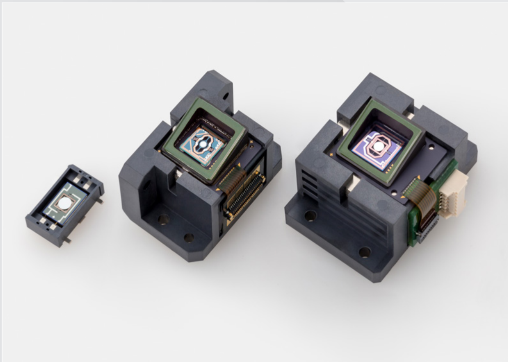
OCT applications

CONTENTS

July 2023

Hamamatsu offers diverse products for OCT applications

Hamamatsu offers a variety of components for SD (spectral-domain) OCT, including compact MEMS (micro-electro-mechanical system) mirrors, high-speed image sensors, and image sensor circuits/modules. For related applications, we offer balanced detectors, supercontinuum sources, and super luminescent diodes.



MEMS mirrors

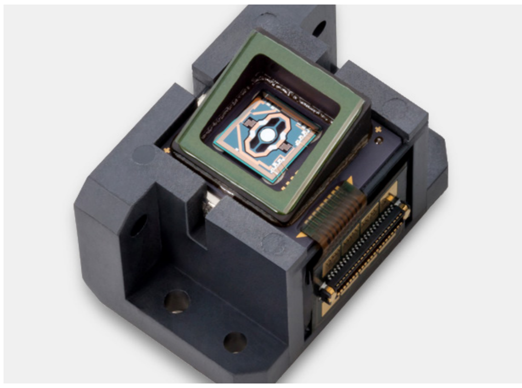
Image sensors and modules

Balanced detectors

Broadband near-infrared laser

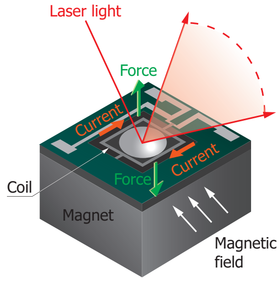
MEMS mirrors (electro-magnetic drive)

The MEMS (micro-electro-mechanical system) mirrors offer a wide optical deflection angle, high mirror reflectivity, and low power consumption. Their compact size is attained by arranging the magnet beneath the mirror.

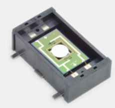


FEATURES

- Compact
- Wide optical deflection angle
- Low voltage drive
- High stability (2D resonant/linear mirror)
- Linear mode type available (1D, 2D)



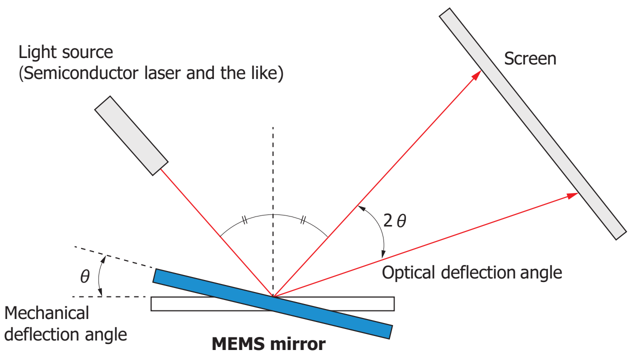
Lineup

Parameter	2D resonant / linear	2D linear	1D linear
	S13989-01H	S13124-01	S12237-03P
Photo			
Scan mode	Raster (2 axes)	2-axis linear	1-axis linear
Mirror size (mm)	ϕ1.2	ϕ1.95	ϕ2.6
Optical deflection angle	±20° / ±12°	±10° / ±10°	±15°
Operation frequency	29.3 kHz / 100 Hz max.	90 Hz max.	100 Hz max.
Mirror coating	Al*1	Al*1	Al*1
Window	Yes*1	Yes*1	No
Evaluation circuit*2	C13884HC	C15087	C15087

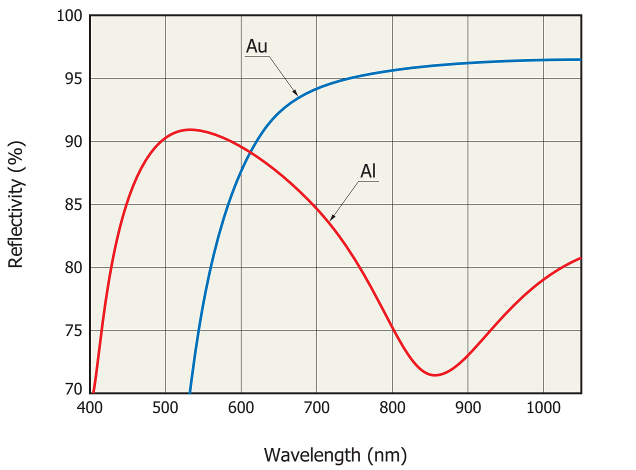
**1 Please consult a Hamamatsu representative for the availability of Au mirror coating and a window optimized for an NIR region.*

**2 Sold separately*

Relationship between optical and mechanical deflection angles



Reflectivity vs. wavelength (Al vs. Au)



Q&A

Q: What are the main differences between MEMS mirrors (electro-magnetic) and galvano mirrors?

A: The advantages of the MEMS mirrors are 2 axes capability, compactness, and low cost. These features can allow the creation of new markets.

Parameter	MEMS mirror	Galvano mirror
Drive method	Electro-magnetic (Lorentz force)	Motor (Lorentz force)
Optical deflection angle	Good	Very good
Mirror size	Up to a few mm	Large
Device size	Compact	Bulky
Cost	*Low*	*High*
2 axes capability	*Yes* *(2 axes mirror available)*	*No* *(2 units needed for 2 axes)*
Controllability	Requires know-how *Hamamatsu develops dedicated drivers.	*Established*

Q: Are dedicated driver boards available?

A: Yes, evaluation circuits C15087 (for S12237-03P and S13973) and C13884HC (for S13989-01H) are available. For the low cost mass-production type board, feel free to consult with a Hamamatsu representative. We can customize driver boards after understanding the requirements for your application.

■ Driver software options

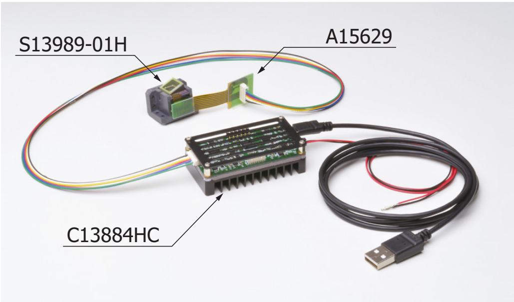
a) The evaluation circuit can be used as is.

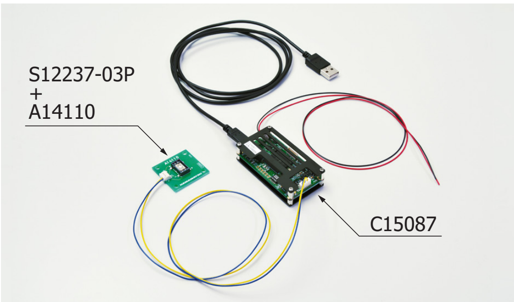
b) The evaluation circuit could be modified in the following examples.

- Serial communication (currently USB communication)
- Support for development languages (currently C# samples are distributed)

c) For S13989-01H (raster scan mirror), an application software can be developed by a user with the driver ASIC (high-speed axis back EMF feedback circuitry) developed by Hamamatsu.

d) All driver circuit and software can be designed by a user.





Q: Is it possible to enlarge a mirror's size?

A: It is possible. However, there are various factors involved. There are trade-offs in the mirror size, deflection angle, and frequency.

■ Simulated performance examples

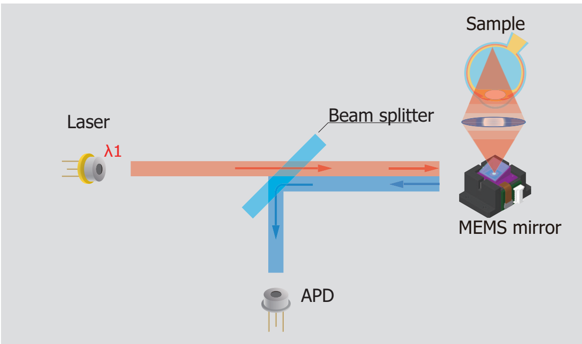
Parameter		Mirror size	Optical deflection angle	Frequency
Raster (2 axes)	S13989-01H	ϕ1.2 mm	±20° / ±12°	29.3 kHz / 100 Hz max.
	Option - 1	ϕ2.0 mm	±22° / ±14°	10.0 kHz / 60 Hz max.
	Option - 2	ϕ5.0 mm	±10° / ±10°	to 100 kHz

Option - 1:
- Sine wave, 10kHz high-speed operation is possible.
- Stable operation by suppressing air resistance due to hermetic package
- Low aberration reflective mirror with unique beam structure

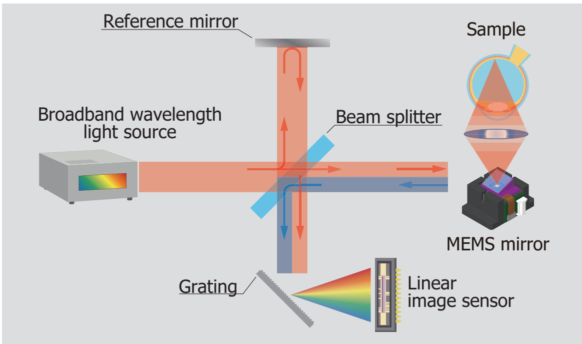
Option - 2:
- Scanning speed corresponding to A-scan rates up to 100 kHz
- Maximum reflection size to take advantage of MEMS mirror features (low cost, low price)
- Deflection angle equivalent to that of galvanometer mirrors

■ Application

Option - 1: SLO (scanning laser ophthalmoscope)
The object is scanned with a laser beam to acquire an image of the surface.



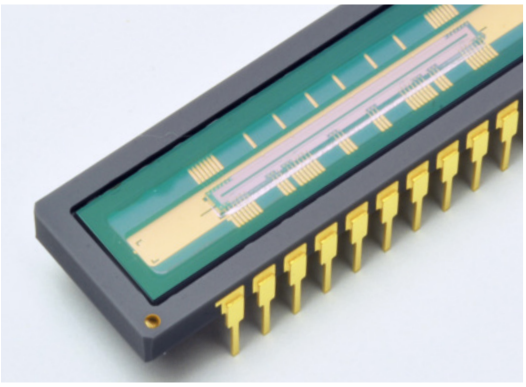
Option - 2: OCT (optical coherence tomography)
Acquire a tomographic image of the object using the coherence of light.



Please consult a Hamamatsu representative for the development time and cost.

CCD/CMOS image sensors for SD-OCT

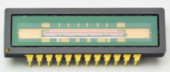
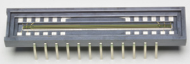
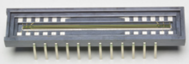
The CCD/CMOS image sensors with enhanced sensitivity in the NIR region are suitable for SD-OCT. The circuit modules are also available.



FEATURES

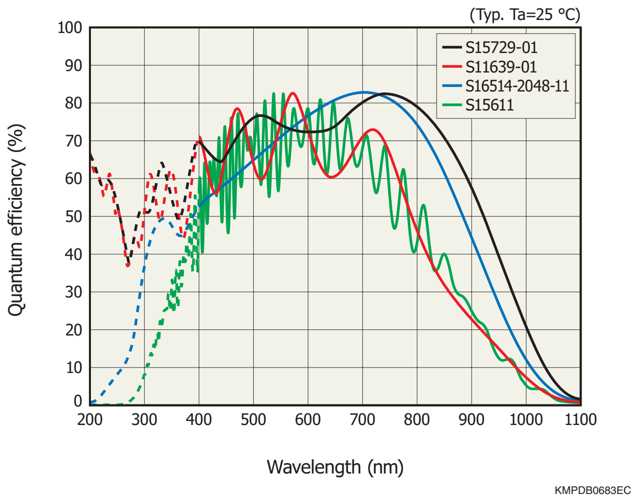
- NIR sensitivity
  High sensitivity from 800 nm to 900 nm is required.
- High line rate
  To reduce inspection time, image sensors with high line rate are required.
- Rectangular pixels
  To achieve fast and accurate inspection, more light needs to be collected, which requires rectangular pixels.

Lineup

Parameter	S15729-01	S11639-01	S16514-2048-11	S15611
Photo				
Type	CCD	CMOS	CMOS	CMOS
Pixel size (μm)	*10 x 180*	*14 x 200*	*14 x 200*	*7 x 200*
Number of pixels	*2048*	*2048*	*2048*	*1024*
Line rate (kHz)	70	4.6	4.6	34
Quantum efficiency [at 900 nm]	*54%*	*24%*	*45%*	*25%*
Output	Analog	Analog	Analog	Digital
Circuit*1	C15821-2351 C15821-2151	C13015-01	C13015-01	Demo kit

**1 Sensor is sold separately*

Spectral response

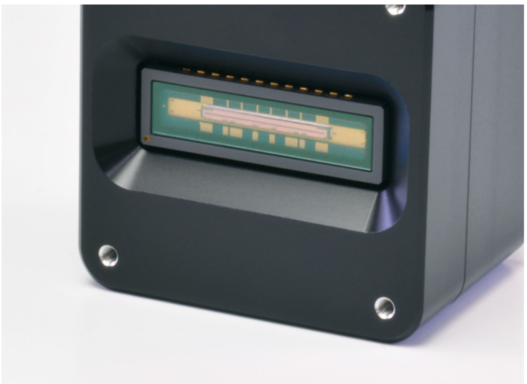


Demo kit for S15611

** Demo kit for loan only*

CCD/CMOS image sensor modules

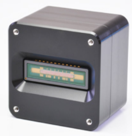
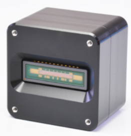
FEATURES



C15821-2351, C15821-2151
- Image sensor module with a built-in CCD linear image sensor
- High line rate: 70 kHz
- Number of pixels: 2048 pixels (512 pixels × 4 taps)
- High NIR sensitivity (>60%, λ=850 nm)
- Interface: CameraLink (C15821-2351), USB 3.1 Gen 1 (C15821-2151)

C16605
- Driver circuit developed for Hamamatsu CMOS linear image sensor
- Built-in 16-bit A/D converter
- Compact sensor circuit board that is easy to install in optical systems
- External synchronization capability

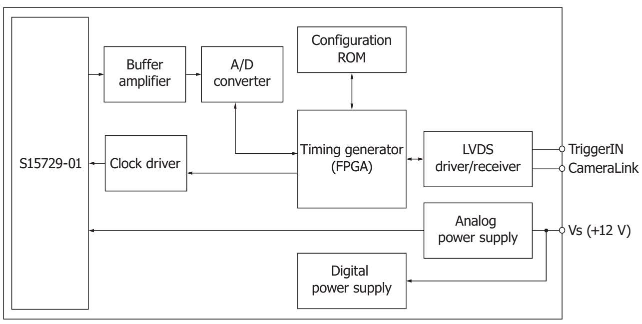
Lineup

Parameter	C15821-2351	C15821-2151*1	C16605
Photo			
Image sensor	CCD image sensor*2 S15729-01		CMOS image sensor S11639-01, etc.*3
Line rate (kHz)	70		4*3
A/D resolution (bit)	10 or 12		16
Dimensions (mm)	60 × 60 × 45.82	60 × 60 × 43.3	Sensor board: 41.6 × 20 × 2.2 Interface board: 50 × 38 × 2.2
Interface	CameraLink	USB 3.1 Gen 1	USB 2.0
Supply voltage (V)	+12		+6

*1 Product release date: August 2023 *2 Sensor included *3 Sensor is sold separately. See the C16605 datasheet for applicable sensor and line rate.

Block diagram examples

C15821-2351



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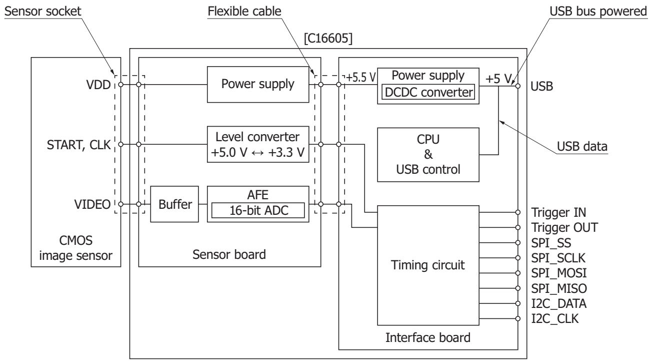
C16605



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Q&A (image sensors & modules)

Q: Is it possible to customize an image sensor?

A: Yes, it is possible. In addition to the development cost and time frame, we would like to collect the following requirements and priorities.

a) Number of pixels

b) Pixel size (pitch, height)

c) Line rate (What is the minimum requirement? Ideally?)

d) Target spectral sensitivity and wavelength range

e) Function (e.g., Do you need an internal A/D converter?)

f) Cost

g) Quantity

Q: Is it possible to customize an image sensor module?

A: Yes, it is possible. In addition to the development cost and time, we would like to collect the following requirements and priorities.

a) Image sensor

*The contents of the above Q&A on image sensors and the basic performance itself

b) Size constraints

c) Interface (CameraLink, Ethernet, USB, etc.)

d) Housing

e) A/D converter resolution (number of bits)

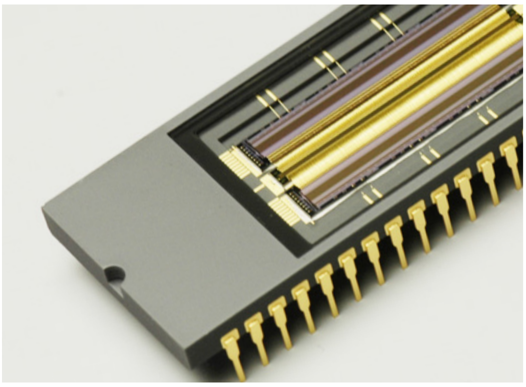
f) Function (external trigger, gain switching, sensitivity compensation, Fourier transform, etc.)

g) Target price

h) Quantity

InGaAs image sensors for SD-OCT (long wavelength)

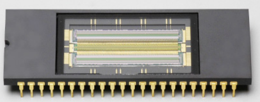
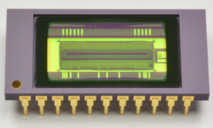
The G10768-1024D and G14714-1024DK are 1024-channel, high speed line sensors suitable for SD-OCT, with high sensitivity in the near-infrared spectrum. Also Hamamatsu provides camera modules, C10854 and C15853-02, for plug-and-play solutions.



FEATURES

- High line rate (40 kHz max.)
- High sensitivity at 1.0 µm and 1.3 µm
- Room temperature operation (no cooling required)

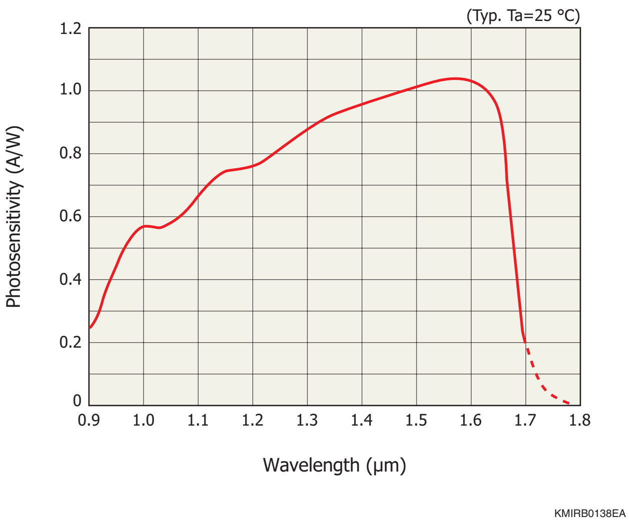
Lineup

Parameter	G10768-1024D	G14714-1024DK
Photo		
Pixel size (µm)	25 × 100	12.5 × 12.5 *
Number of pixels	1024	1024
Line rate max. (kHz)	39	40

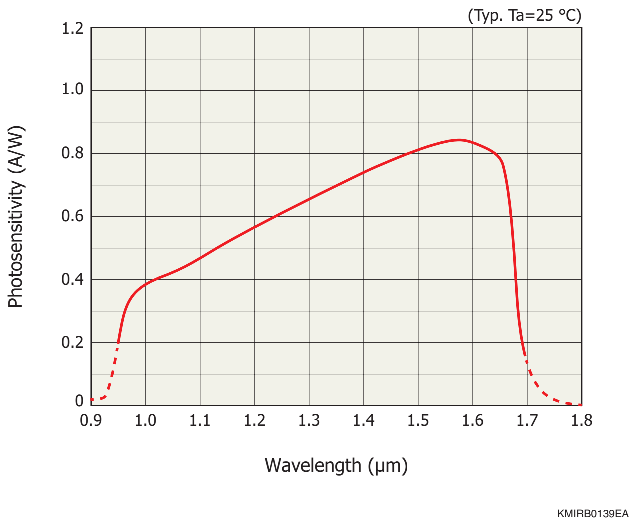
*12.5 × 250 µm pixel size typeis also available (G14714-1024DG) .

Spectral response

G10768-1024D



G14714-1024DK



Dedicated camera modules

■ InGaAs multichannel detector head C10854

- For InGaAs image sensor G10768-1024D
  *Sensor is sold separately
- Line rate: 31.25 kHz
- CameraLink

■ Image sensor module C15853-02

- For InGaAs image sensor G14714-1024DK
  *Sensor included
- Line rate: 40 kHz max.
- USB 3.1 Gen 1

Balanced detectors

The balanced detectors are differential amplification type photoelectric conversion modules that can detect a minute difference by cancelling out common mode noise of two incident light rays.

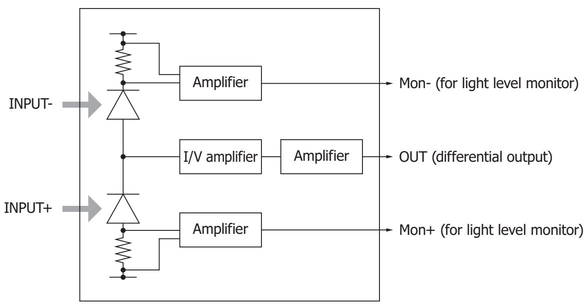
FEATURES

- Employs our unique (patented) structure that reduces multiple reflections at the incident light wavelength of 1.0 μm or 1.3 μm (-01, -02, -03, -04)
- Input section: FC receptacle (APC polished)
  A single-mode fiber with an FC connector can be connected.
- Output section: SMA receptacle

Lineup

Parameter	C12668-01	C12668-02	C12668-03	C12668-04	C12668-05	C12668-06
Photo						
Optimal wavelength band (μm)	1	1.3	1	1.3	1	1.3
Cutoff frequency (MHz)	DC to 200		DC to 400		0.1 to 800	
Common-mode rejection ratio (dB)	35		30		30	
Conversion impedance (kV/A)	15 (50 Ω)		5 (50 Ω)		29 (50 Ω)	
Output noise voltage (mVp-p)	20		20		80	
Supply voltage (V)	±12		±12		±12	
Dimensions (mm)	25 × 54.5 × 65		25 × 78 × 72		18 × 63 × 70	

Block diagram



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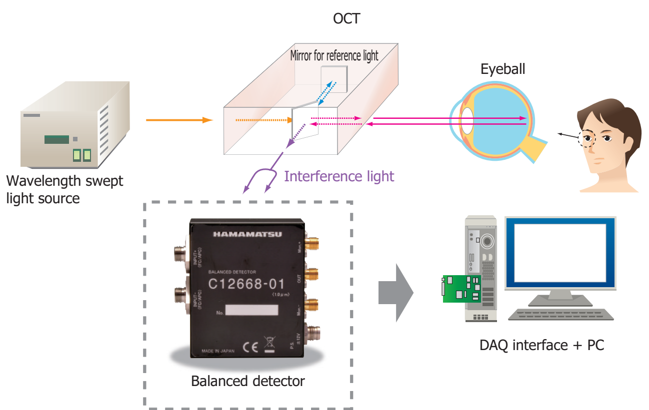
Connection example (opthalmic/medical OCT)



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Supercontinuum light source

The L15077-C7 is a highly stable laser light source that outputs a broadband laser beam centered in the 1700 nm band. It is suitable for measurements of biological samples using the 3rd optical window (1600 to 1800 nm) and enables high-resolution deep imaging of highly scattering biological tissues and materials.

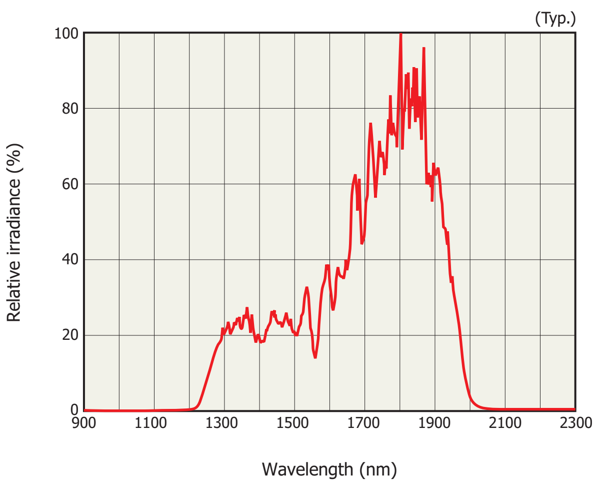
FEATURES

- High stability: ±0.1% typ.
- Broad spectrum: 1300 to 2000 nm
- High brightness: about 20000 times (vs. halogen lamp)

Specifications

Parameter	L15077-C7
Polarization	Linear
Repetition rate (MHz)	50 ± 1
Spectral distribution (nm)	1300 to 2000
Output power (mW)	50
Output stability (%)	± 0.1 typ.
Numerical aperture (NA)	0.07 max.
Fiber output core diameter (μm)	10
Fiber output connector	FC / APC connector

Spectral distribution



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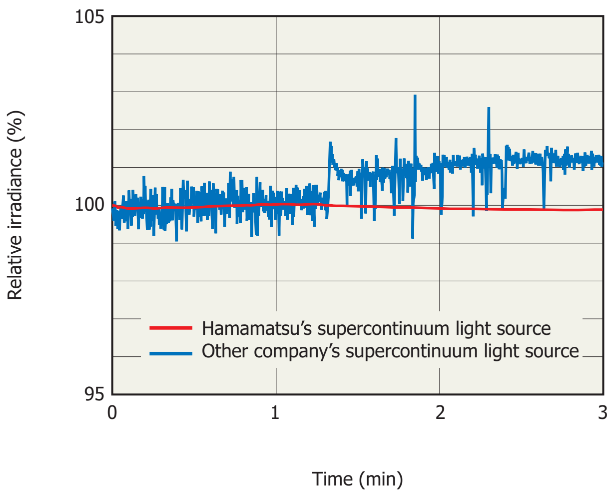
Output stability



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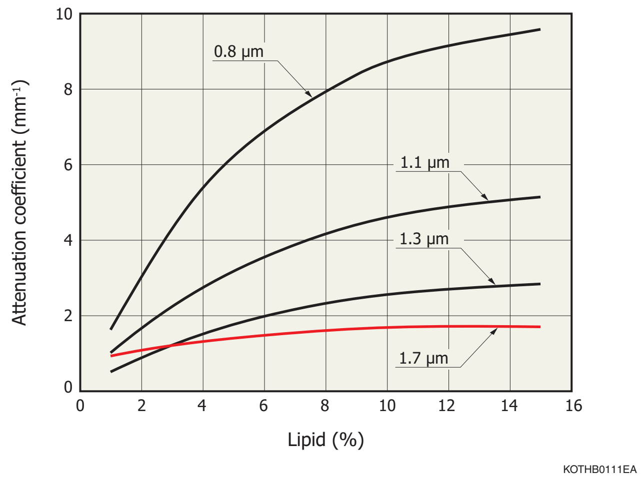
■ Application: SD-OCT at 3rd optical window

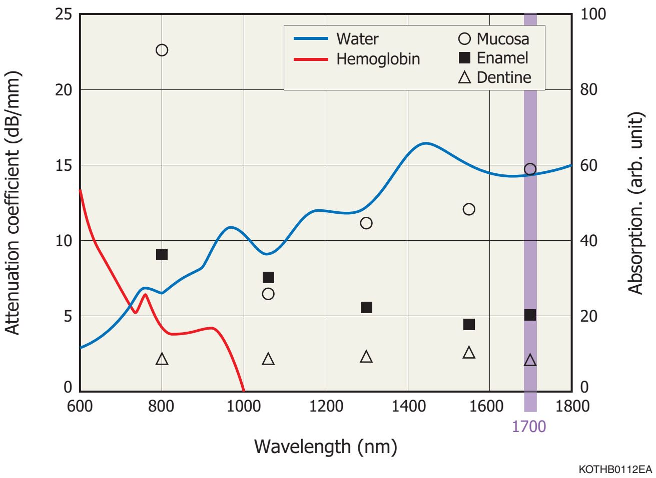
In general OCT, biological tissues containing lipids or hard cells and materials used in industry, such as plastics and magnets, are difficult to observe due to their high light scattering. OCT using broadband light, mainly in the 1700 nm band (3rd optical window), can image deeper regions with higher resolution because the attenuation coefficient for these measurement samples is small, as shown in the figures below.

Lipid



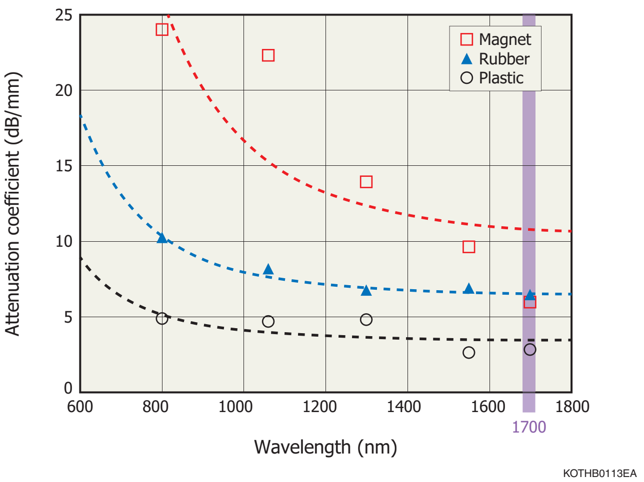
Examples:
Cortex, skin, coronary artery, thyroid gland, trachea, visceral fat

Hard tissue



Examples:
Periodontal, bone tissue

Industrially used materals



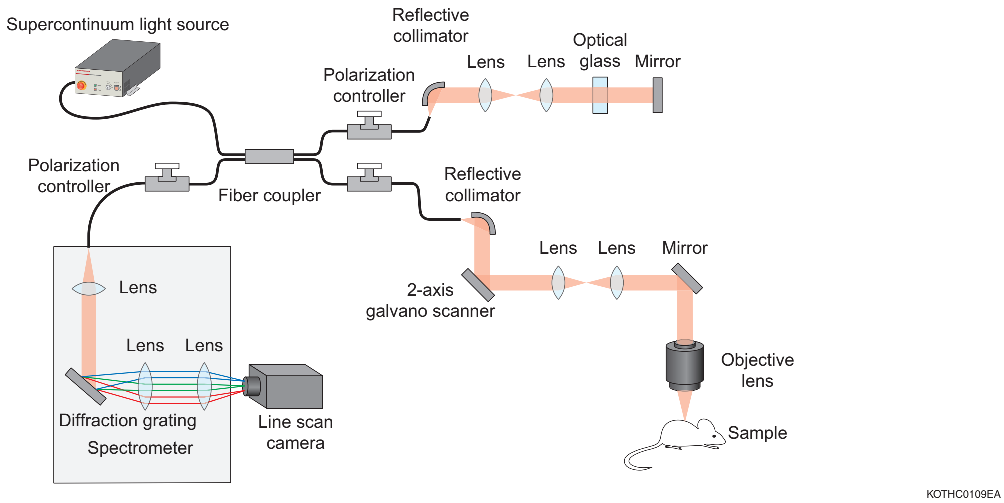
Examples:
Plastic, rubber, magnet

Reference: S. Ishida, et al., Biomed. Opt. Express 3(2) 282-294 (2012), N. Nishizawa, et al., IEEE J. Sel. Top. Quantum Electron. 25(1), 1 (2019)

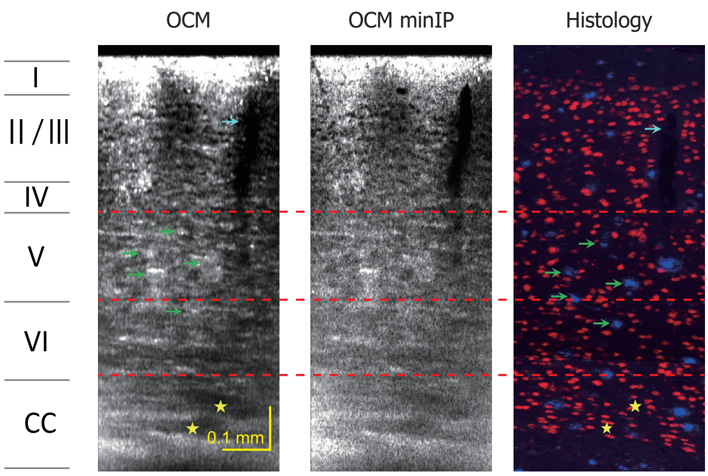
Application example: non-invasive deep brain neuronal imaging

SD-OCT enables non-invasive deep brain neuronal imaging without craniotomy and has been applied to in vivo observation of Alzheimer's lesions. This result shows that imaging of lesions deep in lipid-rich brain neurons has been performed by using the L15077-C7. The demonstrated capabilities of 1700 nm OCT for imaging deep in the brain are promising for deep imaging in other highly scattering, water-rich tissues as well.

■ Measurement system



■ Result



Green arrows: Amyloid-β
Yellow asterisks: demyelination
Red spots: anti-NeuN (Neuron)
Blue spots: FSB (Amyloid-β)

Reference: Zhu, et al., Light: Science & Applications (2021) 10:145

Q&A

Q: How can the supercontinuum light source be evaluated?

A: L15077-C7 is commercially available. A demo unit (L15077-C7, prototype of InGaAs image sensor module suitable for 1600 to 1800 nm) can be arranged, so please feel free to consult with us.

Super luminescent diodes (SLD)

- Suitable for eye inspection -

SLDs feature high radiant flux and combine the high brightness of laser diodes with the low coherence of LEDs. They are suitable for optical measurements and medical imaging.

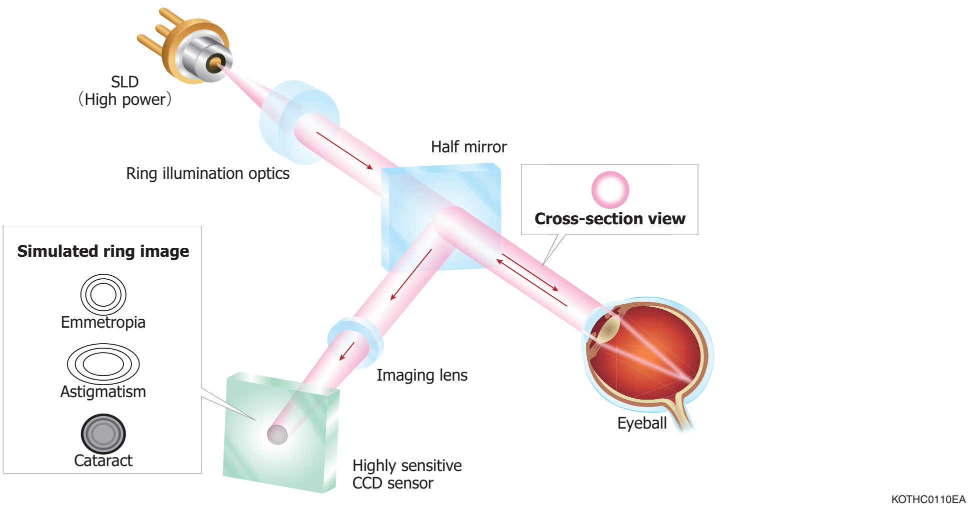
FEATURES

- Non-visible light
- High power: 10 to 30 mW (brighter than LED)
- Narrow spectrum width to avoid interference from other light sources
- No speckle compared to an LD

Lineup

Parameter	L11607-04	L12856-04	Other major SLDs for OCT	
			Example 1	Example 2
Center wavelength (nm)	875 ± 20	830 ± 10	845 ± 25	830 ± 20
Spectrum width FWHM (nm)	10	10	62	15
Radiant flux (mW)	30	10	1 to 2	5
Dimensions (mm)	ϕ9.0 x 12.1		Fiber or can	

Example of use



Q&A

Q: Are these SLDs suitable for OCT?

A: No. We believe these high-intensity SLDs are better suited for ocular surface inspection, rather than OCT. The high-intensity SLD enables high accuracy measurement in ophthalmometers. The number of cataract patients is increasing due to aging, and high intensity is needed to image the clouding of the eye.

- High-intensity SLD*: suitable for ocular surface eye inspection
- Wide-wavelength SLD: suitable for OCT

*Hamamatsu provides high-intensity SLD only, not wide-wavelength SLD.

OCT overview

What is OCT?

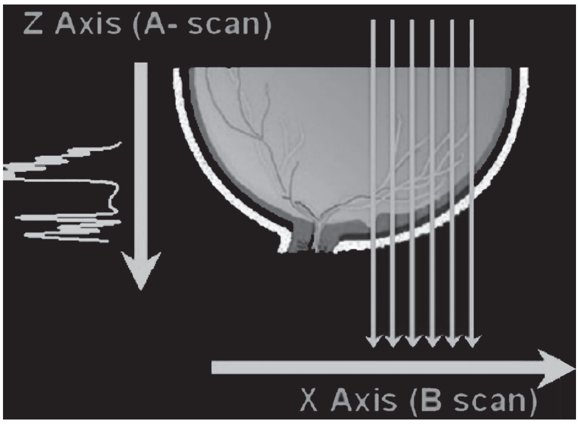
OCT = Optical coherence tomography

- *Advantages*
  - *High speed: instant imaging, reducing patient burden*
  - *High resolution: µm level resolution, improvement in diagnostic accuracy*
  - *Simultaneity / Promptness: real-time imaging*
  - *Non-invasive: radiation-free, friendly to human body*
  - *Low cost: several million yen to a few ten million yen in instrument price spread among private-practice doctors*

Note: Observation area limited to a few µm to a few mm from a surface

Principle

OCT is a technique that can measure distance in the direction of light propagation by utilizing optical interference. When an NIR incident light enters a measurement object, light is scattered backwards and combined with a reference beam in an OCT system to generate optical interference. A 1D signal of the A-scan (depth direction or Z axis) can be obtained with Fourier transform. A tomography image can be obtained by continuously shifting the A-scan along another axis (B-scan).



OCT fundus scan

Types of OCT

SD (spectral-domain) OCT and SS (swept-source) OCT are both called Fourier-domain OCT as optical signals are converted by Fourier transform. In SD-OCT, backward scattering lights from a measurement object are spatially discriminated with a spectrometer as all the wavelengths from a broadband light source like an SLD (super luminescent diode) are utilized simultaneously. In SS-OCT, signal lights are detected by a point detector (ex. balanced detector) serially as each wavelength enters the object in a sequential order by using a swept light source.

■ SS-OCT structure example

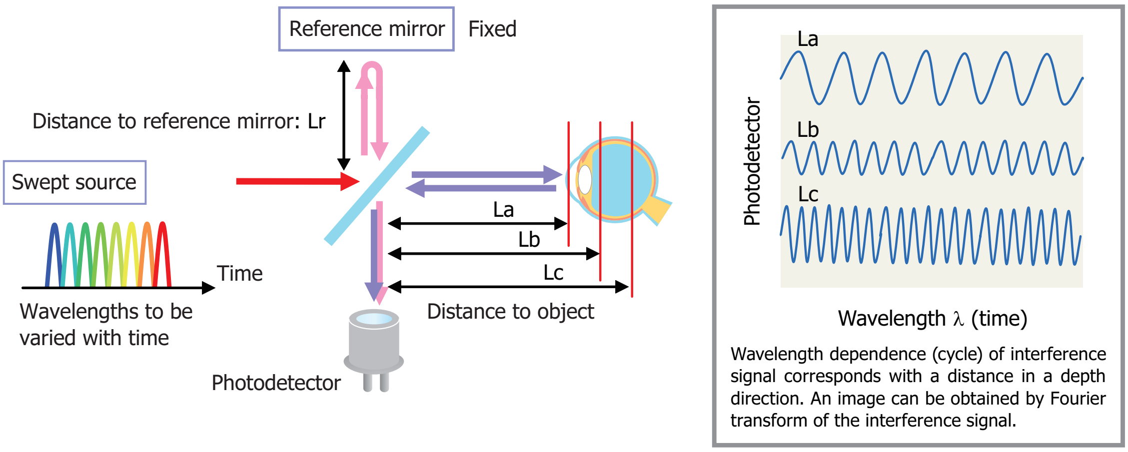
The method below is called SS-OCT.

1. Each wavelength enters a measurement object in a sequential order by sweeping a light source.

2. An optical interference signal between backward scattering and a reference beam is measured with a balanced detector.

3. The interference waveform obtained is converted by Fourier transform to have an image in a depth direction.

A time-resolved spectroscopic analysis of the interference waveforms' wavelength contents is adapted in this method, which is different from SD-OCT.



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■ SD-OCT structure example

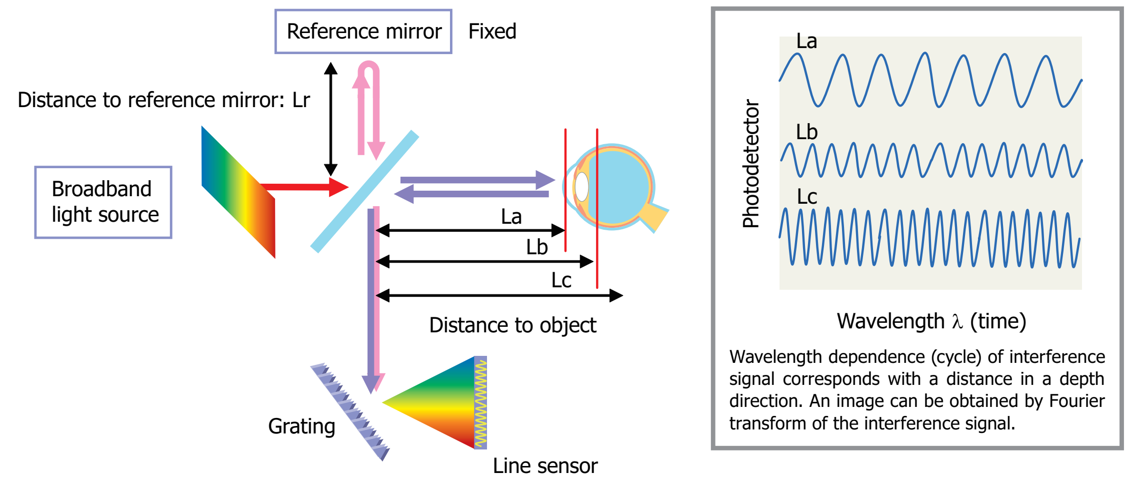
The method below is called SD-OCT.

1. A broadband light source like an SLD emits light onto a measurement object.

2. Backward scattering lights from the object are spatially discriminated with a spectrometer employing a line sensor.

3. The interference waveform obtained is converted by Fourier transform to have an image in a depth direction.

A spectrometer is utilized for measuring the wavelength contents of the interference waveform, which is different from SS-OCT.



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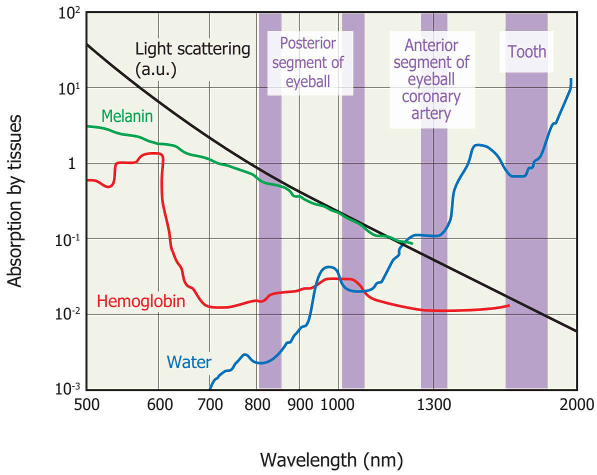
Wavelengths for OCT applications

In biomedical applications, the 800 nm band, 1.0 μm band, and 1.3 μm band are generally utilized because of the smaller influence from water absorption at those wavelengths. Deeper penetration can be achieved using a longer wavelength light due to the decrease of absorption by tissues, but an increase in absorption by water causes less light to reach the tissues (e.g., fundus in ophthalmology), which is a dilemma. For emerging fundus (posterior segment of an eyeball) diagnosis, the use of the 1.0 μm band attracts a great deal of attention because water absorption drops at that long wavelength.



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Information described in this material is current as of July 2023.
Product specifications are subject to change without prior notice due to improvements or other reasons. This document has been carefully prepared and the information contained is believed to be accurate. In rare cases, however, there may be inaccuracies such as text errors. Before using these products, always contact us for the delivery specification sheet to check the latest specifications.
The product warranty is valid for one year after delivery and is limited to product repair or replacement for defects discovered and reported to us within that one year period. However, even if within the warranty period we accept absolutely no liability for any loss caused by natural disasters or improper product use.

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