2010 Volume 1.1

INNER VISION

Revealing inner space like you have never seen before.

Optical Coherence Tomography

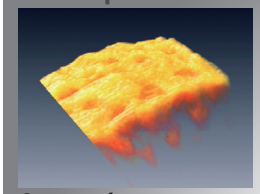
santec

www.santec.com

OCT solutions from santec

Santec is a global photonics engineering company and a leading manufacturer of Tunable Lasers, Optical Test and Measurement Products, and Advanced Optical Components. Santec is a dynamic venture spirited company established in 1979, celebrating more than 30 years in optical innovations. Santec introduced the world's first tunable laser based on external cavity structure and semiconductor laser in 1986.
Santec's advanced tunable laser, the HSL-2000, was developed specifically for OCT applications utilizing patented innovative design and expertise on tunable lasers accumulated over the past 25 years. Featuring high power, wide tuning, fast scan rates and more, the HSL-2000 offers a high specification laser to achieve high resolution 3-D imaging and high resolution real time 2-D imaging. Santec also offers balanced detectors, imaging probes, and a complete OCT system, IVS-2000, which utilizes the HSL-2000.

3D Inspection



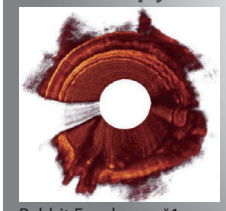
Orange surface

Plastic screw

Biology

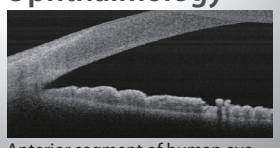
Tadpole

Endoscopy

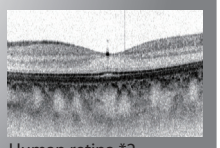


Rabbit Esophagus *1

Ophthalmology



Anterior segment of human eye



Human retina *2

References courtesy of
*1 J. Su, J. Zhang, L. Yu, and Z. Chen (Univ. of California Irvine), Optics Express, Vol. 15, 10390
*2 Y.Yasuno (Tsukuba Univ.), et al, Optics Express, Vol. 15, 6121
(These two images were taken with their own developed SS-OCT system with using santec's HSL-series.)

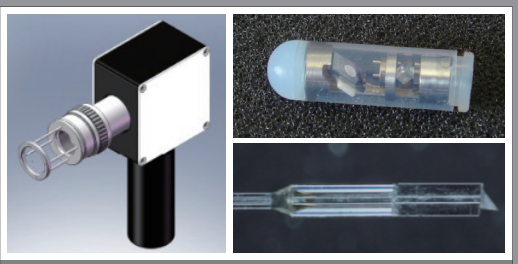
Products

Support

- Technology support for feasibility study in medical, industrial applications
- OEM manufacturing
- Technology transfer

OCT products line up

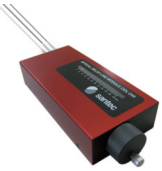
OCT probes



OCT Probes/Catheter
Microscope type, Handheld type, Optically modulated MEMS type, Cardiovascular fiber probe

Interferometer unit

Balanced detector



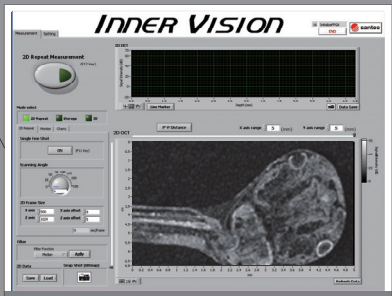
Delay line module

INNER VISION
SS-OCT system
IVS-2000

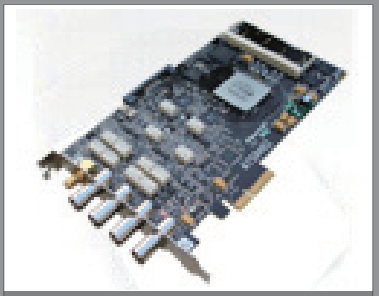
Swept Source

Swept Source Engines HSL series
High power, Low noise, faster scan, wide swept range, long coherence length, high repeatability

SS-OCT process unit



OCT imaging software



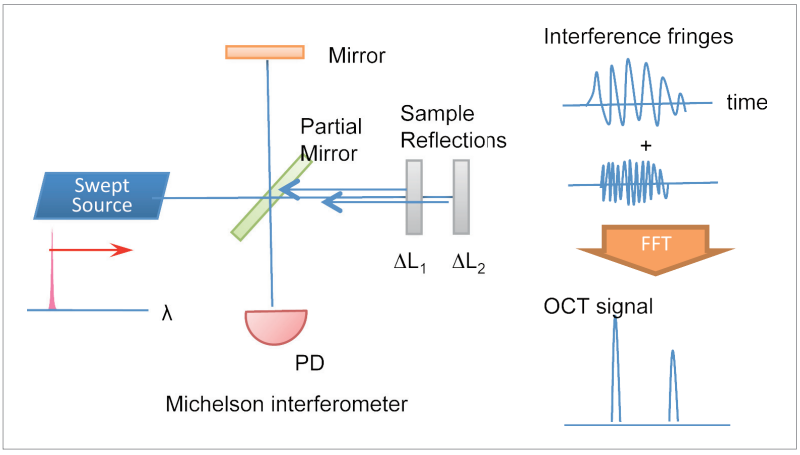
DAQ board for SS-OCT

Background of Swept Source-OCT

OCT is non-invasive imaging technique that was originally introduced in the early 1990's. Diagnosis systems based on this technique are now widely practiced in ophthalmologic applications.
Compared to conventional medical imaging technologies such as Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), X-Ray Computerized Tomography (CT) and Ultrasonography, OCT provides a safe, high resolution solution at a cost point that will enable widespread use in hospitals and clinics. Most of these OCT systems used Time-Domain optical interferometry in which the optical path length difference between the reference mirror and the sample in the Michelson or Mach-Zehnder interferometer is modulated in time. Time-Domain or TD-OCT had opened up the potential of optical biopsy but there are performance limitations for further extension of the applications. First, imaging speed is relatively slow because of mechanical delay modulation. Second, even when higher frequency scanning is possible, detection sensitivity drops because of detection bandwidth in return. Fourier-Domain OCT is a break-through technology which enables high sensitivity and high speed imaging at the same time. FD-OCT relies on analyzing the individual frequency components of backscattered light from the sample or tissue. There are two methods within FD-OCT. One is Spectral-Domain OCT (SD-OCT) which uses a low coherence light source and a spectrometer, where frequency components are spatially analyzed on the CCD array. The fast readout speed of CCD provides high imaging speed, and high signal-to-noise ratio (SNR) gives 20-30dB advantage over conventional TD-OCT.
However, there are also disadvantages. Images gets blurred and degraded when the sample arm motion washes out interference fringes on the CCD during the pixel integration time. Furthermore, unavailability of an InGaAs CCD with higher pixel resolution also limits the application of FD-OCT for in-vivo endoscopic applications.
The other approach is Swept-Source OCT which uses a continuous and repetitively tunable (or "swept") light source where frequency components are analyzed in time with a single photodetector. Each wavelength scan generates depth information; lateral scanning of the laser beam then enables a cross section image to be constructed. This technique has a theoretical sensitivity benefit equal to that of SD-OCT, while overcoming the disadvantages of SD-OCT such as fringe washout, and allowing the use of longer wavelengths, over 1 µm to 1.5 µm range, for endoscopy.
Santec introduced a variety of swept sources that realize high speed, high resolution OCT imaging with extremely high reliability.

SS-OCT principle

Each scan of wavelengths produces an interference pattern signal by the reflections at different depths.
Depth dependent reflection profiles are calculated by Fourier transform of the interferogram. Repeating this A-scan at different locations produces a two dimensional cross section.

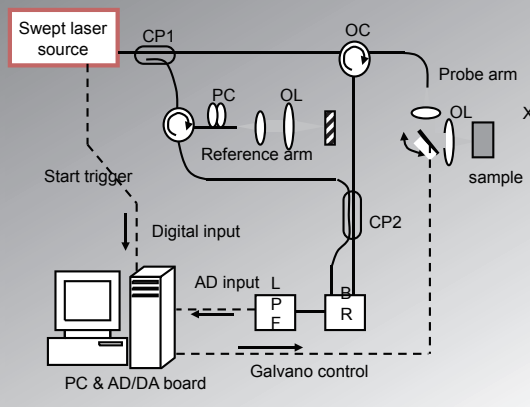


INNER VISION
SS-OCT system
IVS-2000

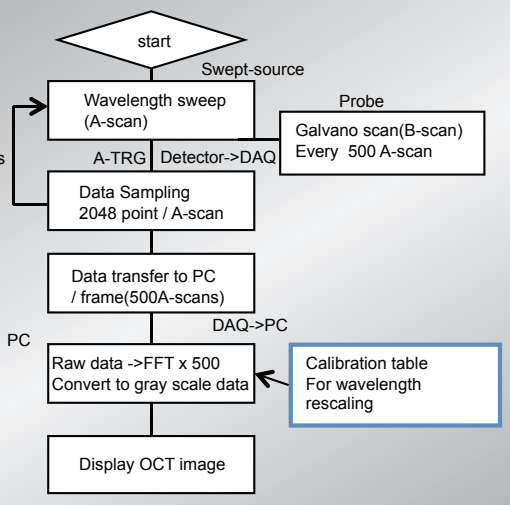
The Santec OCT system, IVS-2000 is designed for general research, feasibility studies and product development in various applications, utilizing the best selling santec HSL series.
You can configure the system by choosing the swept source and probe type from various options.
Santec also supports user's development by disclosing the OCT software.

Typical specifications

parameter	Specification	Notes
Swept source	HSL series	
Interferometer	Mach-Zehnder type Delay line integrated	Other custom available
Probe	Microscope type Handheld type	2D, 3D , CCD included
DAQ board	Special FPGA type 150MHz, 14bit	Real time displaying up to 20-30fps
PC	Quad-core 2.4GHz clock	
Software	OCT software Viewer software	LabVIEW8.6 required VI file can be disclosed by option
Other	PS-OCT available	



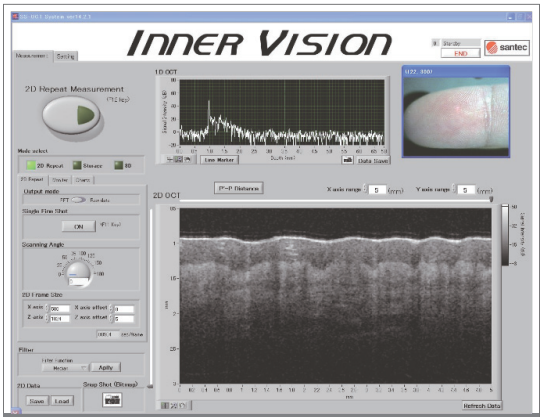
System diagram



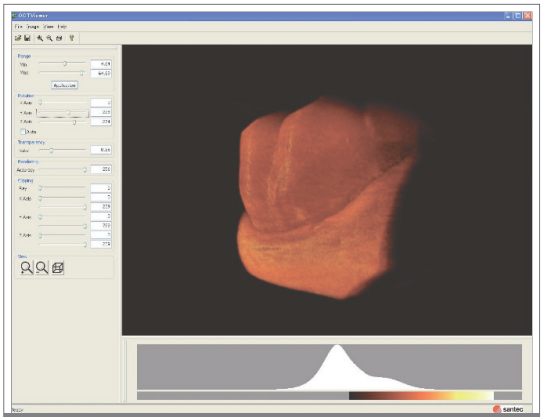
OCT process diagram

Feature of IVS software

- Proprietary rescaling algorithm integrated FPGA DAQ board
- Real time imaging up to 30fps
- 1D, 2D, 3D imaging mode
- Storage mode for time elapsed measurement
- Scan angle setting arbitrary angle scan
- OCT graph capture, Raw data import/export
- Custom settings Viewing area
- Analysis function Point-to-point distance measurement 1D OCT signal line marker
- LabVIEW Sub-VI files, source codes are available as option
- Free 3D viewer attached



OCT imaging software



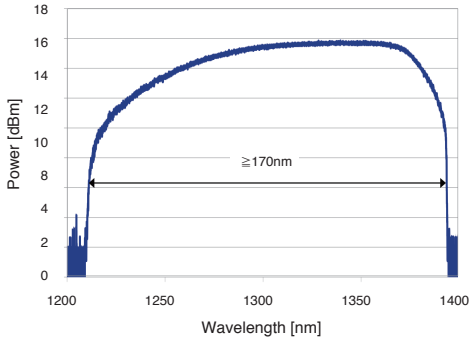
3D viewer software

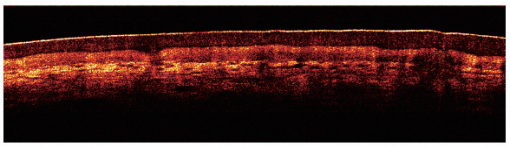
Features of Swept Sources

HSL-2100WR

WIDE

HSL-2100WR guarantees 170nm, the widest swept range for ultra-high resolution OCT imaging. Theoretical axial resolution of about 5 microns is possible with the maximum swept rate of 20kHz.





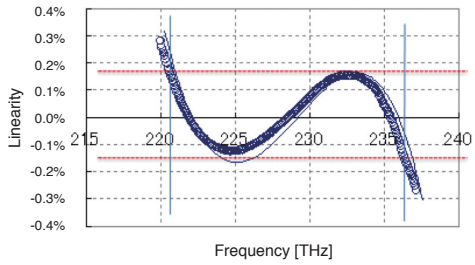
Skin at underside of 1st knuckle joint of ring finger

(Courtesy of MDL, Photo from press release July 28th 2009, www.mdl-ltd.co.uk)

HSL-2100HL

HIGHLY K-LINEAR

The HSL-2100HL model realizes highly linear frequency sweep over 100nm. The Linearity of the sweep is better than ±0.15%. This feature simplifies the OCT calculation process allowing direct FFT(Fast Fourier Transform) on raw sampled interference data. This is a good start for researchers considering SS-OCT implementation in their projects with short turn around.



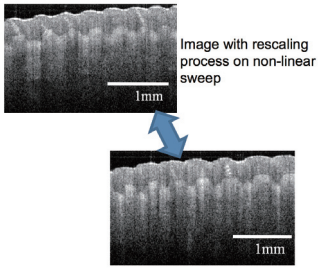


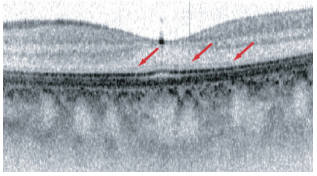
Image with rescaling process on non-linear sweep

Image without rescaling process using high-linearity swept source

HSL-1100

1micron 30kHz

HSL-1100 boasts the widest swept range for the 1mm swept source in the market. This source is suitable for the use in ophthalmology applications. Output power is improved to >10mW for better penetration in the in-vivo eye measurement.



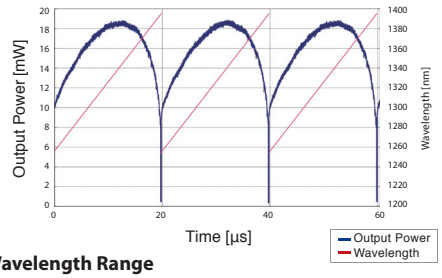
In vivo human macula
In courtesy of Tsukuba Univ.(Op.Ex6121(2007)

HSL-2100HW

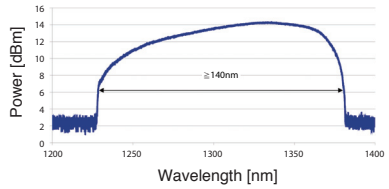
HIGH-SPEED&WIDE

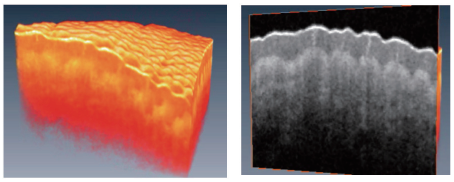
This new model realizes 50kHz, the fastest scan available, while maintaining a wide scan range of over 140nm. This feature provides advantages in ultra high-speed imaging and/or motion-sensitive applications, i.e. ophthalmology and endoscope applications. A polygon-scanner based system with a PMF fiber ring configuration boasts industrial-class high reliability. Santec also supports the integration of the HSL into the customer's system providing numerous options, and the OCT system software.

Transient Characteristics



Wavelength Range



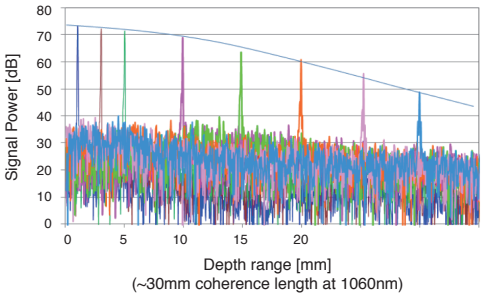


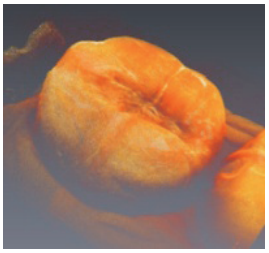
3D OCT image of human finger
250x250x1024 pixel measured within 1.2sec

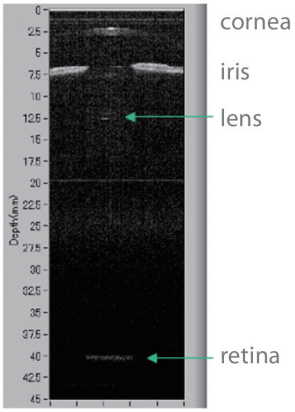
HSL-2100LC

HIGH COHERENCE

HSL-2100LC takes advantage of a Quasi-Phase Continuous Tuning (QPCT) technique (Patent pending) that extends the coherence length to an order of magnitude larger than the conventional swept source for OCT. This new source achieves a 30mm coherence length, suitable for the distance measurement, 3D surface profiling, intraocular distance measurements. The polygon-scanner based system boasts industrial-class high reliability.

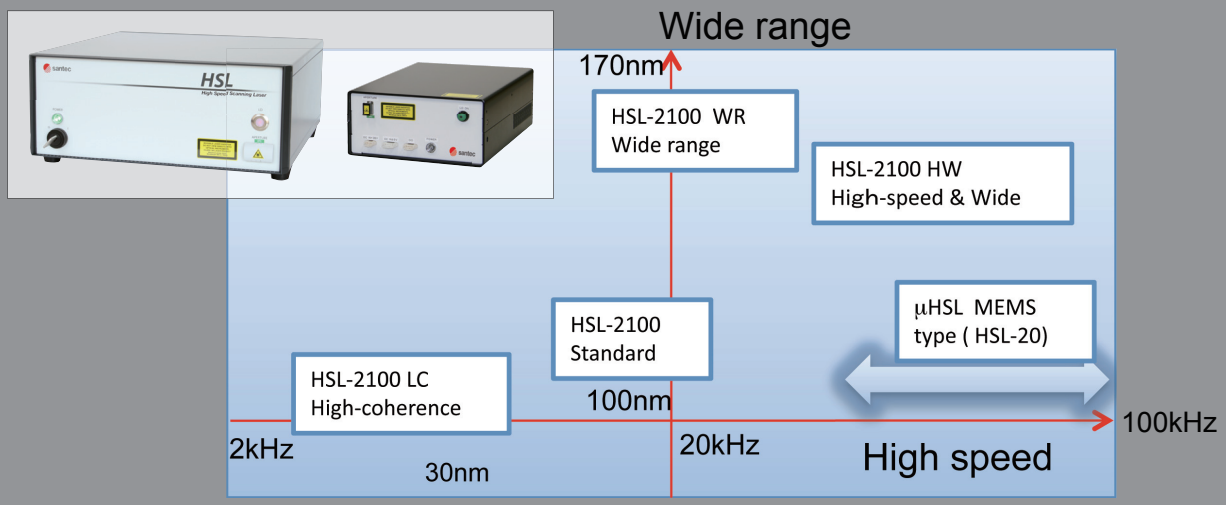






Intraocular structure
(human eye)

Selection Guide for Swept Sources



Parameter		Unit	HSL-2100					
			Standard	High-speed	Wide range	High-linearity	High-speed Wide range	Large coherence
Wavelength scan *1	Center wavelength	nm	1315-1340	1315-1340	1290-1320	1315-1340	1300-1330	1315-1340
	Scan range	nm	≧110	≧80	≧170	≧110	≧140	≧30
Output power *2	Peak	mW	≧20	≧20	≧20	≧20	≧15	≧8
	Average	mW	≧12	≧12	≧10	≧12	≧9	≧5
Scan rate		kHz	20	50	20	20	50	3
Coherence length		mm	≧10	≧6	≧6	≧8	≧6	≧60
Duty cycle		%	≧65	≧90	≧60	≧60	≧65	≧40
Linearity (k-space)		%/100nm	-	-	-	0.25	-	-
Trigger		-	Integrated start trigger					
Output optical fiber		-	SMF					
Output optical connector		-	FC connector,APC polish					
Operation environment	Temperature	℃	15 - 35					
	Humidity	%	<80, no condensation					
Electric power		-	AC100V - 240V±10% , 50/60Hz					
Power consumption		VA	70 @ AC 100 - 120V, 80 @ AC 230 -240V					
Size (W) × (D) × (H)		mm	343 × 376 × 153					
Weight		kg	10					

Parameter		Unit	HSL-1100				
			Standard	High-speed	Wide range	Large coherence	High-speed Wide range
Wavelength scan *1	Center wavelength	nm	1045-1075	1045-1075	1045-1075	1045-1075	1045-1075
	Scan range	nm	≧70	≧70	≧90	≧20	≧80
Output power *2	Peak	mW	≧12	≧12	≧12	≧6	≧12
	Average	mW	≧8	≧8	≧5	≧4	≧5
Scan rate		kHz	30	50	20	3	50
Coherence length		mm	≧6	≧6	≧6	≧60	≧4
Duty cycle		%	≧65	≧90	≧60	≧40	≧90
Linearity (k-space)		%/100nm	-	-	-	-	-
Trigger		-	Integrated start trigger				
Output optical fiber		-	SMF (HI 1060 Fiber)				
Output optical connector		-	FC connector, APC polish				
Operation environment	Temperature	℃	15 - 35				
	Humidity	%	<80, no condensation				
Electric power		-	AC100V - 240V±10% , 50/60Hz				
Power consumption		VA	70 @ AC 100 - 120V, 80 @ AC 230 -240V				
Size (W) × (D) × (H)		mm	343 × 376 × 153				
Weight		kg	10				

OEM solutions

HSL-200/100

HSL-200/100 is an OEM swept source engine based on the same technology used for the bench-top units, HSL-2100/1100. Maintaining the same high performance as the bench-top, the size is miniaturized with an external power supply. It supports RS-232C communication for external control and monitoring by the software in the system. Specifications (ex. scan rate, scan range, coherence length, output power, etc) can be customized to fit to OEM solutions.

Features

- **High reliability**
- **Compact design**
- **Low RIN (Relative Intensity Noise)**

Applications

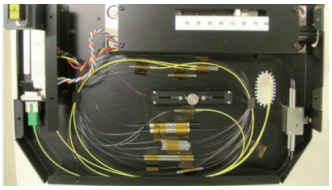
- **OEM source for OCT systems**
- **OEM source for in-line inspection systems**

IFM-200/100

IFM-200/100 is an OEM module using a Mach-Zehnder interferometer. It can integrate a visible LD marker, and an optical delay line with an external control port. Santec's packaging technology for optical subsystems is applied to maintain high quality and high reliability as well as lower cost. Custom configurations, including other interferometer options (e.x. Michelson, Fizeau type) can be designed for an OEM solution.

Features

- **Custom configuration(Michelson, Mach-Zehnder, Fizeau,etc)**
- **Optical delay line, variable attenuator, polarization controller optional integration**
- **PMF type also available**



BPD-200

BPD-200 is a balanced photo detector that outputs the difference of two detector signals. This can be used for reduction of common mode noise due to the laser power fluctuation. In heterodyne detection, as in most OCT applications, it provides a 3dB sensitivity advantage when detecting the signal inverted in phase in between two input signals. Furthermore, its special design significantly reduces the problem of undesired image artifacts, which were a major problem in other balanced detectors. BPD-200 is the best detector ever made specifically for SS-OCT applications.

Features

- **Wide dynamic range(DC to 80MHz)**
- **High reliability and high gain, high linearity**
- **Flat balanced level**
- **Specially designed for artifact-reduction**

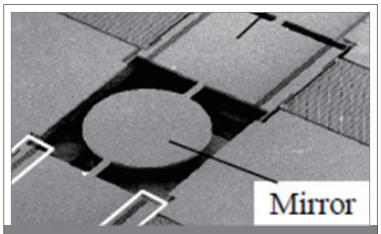
Applications

- **Swept Source -OCT**
- **Heterodyne measurement**
- **OFDR (Optical Frequency Domain Reflectometry)**

OEM

Compact High Speed Swept Source
μHSL HSL-20

HSL-20 is a MEMS scanner based swept source that overcomes the speed limit of polygon scanner-based HSL-2100 series. External cavity design with a diffraction grating ensures high specification performance as a swept source, maintaining low RIN and high repeatability.

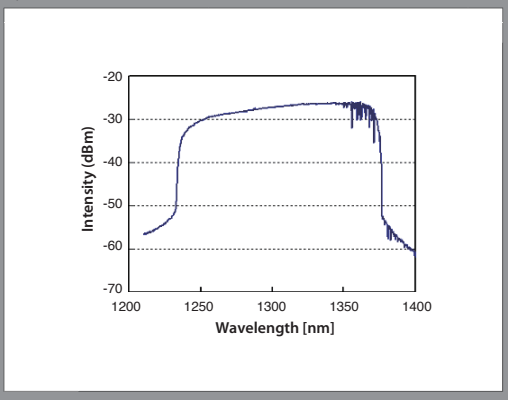


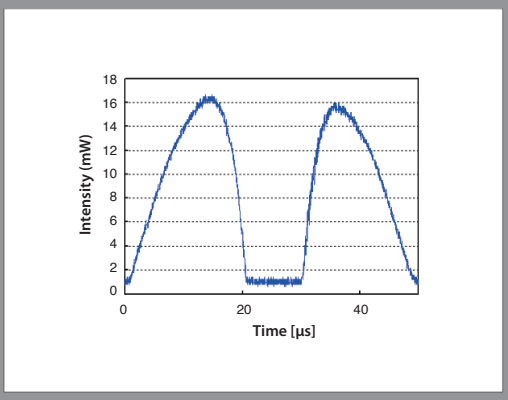
Santec proprietary MEMS design

Features
- High speed up to 100 kHz
- Compact design
- Low RIN (Relative Intensity Noise)
- Low cost

Applications
- OEM source for OCT systems
- OEM source for Point-of-Care applications

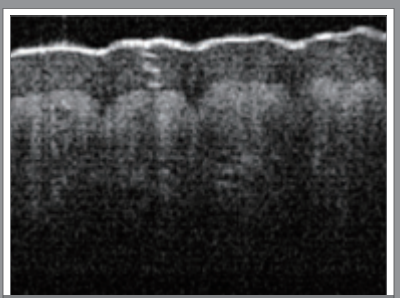
Typical characteristics





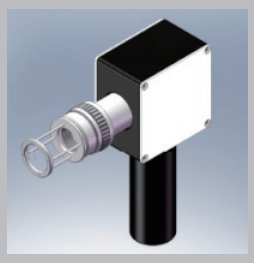
Typical specifications

	Target spec.	Target spec.
Center wavelength	1.3 μm	1.06 μm
Output power	20mW	15mW
Wavelength range	150 nm	120 nm
Sweep rate	50 & 100kHz (bi-directional)	50 & 100kHz (bi-directional)
Coherence length	15mm	15mm
RIN	-120dB/Hz	-120dB/Hz


OCT image measured with μHSL

OCT probes

Handheld probes and small endoscopic probes are available as custom options for SS-OCT systems and OEM solutions.



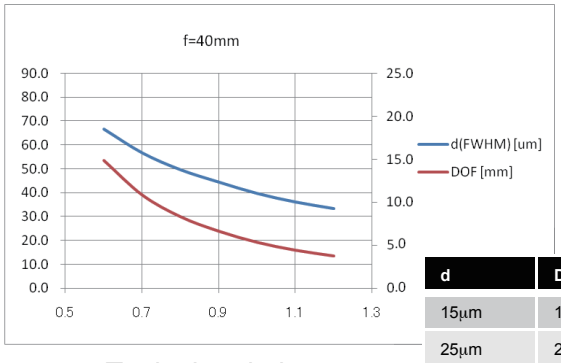
Handheld probes

Handheld probes with a fixing aperture attachment provide 2D and 3D imaging capability which is ideal for oral/dental application as well as for the diagnostics of skin. A Microscope type is also available with integrated CCD camera for target area searching.

TUTORIAL

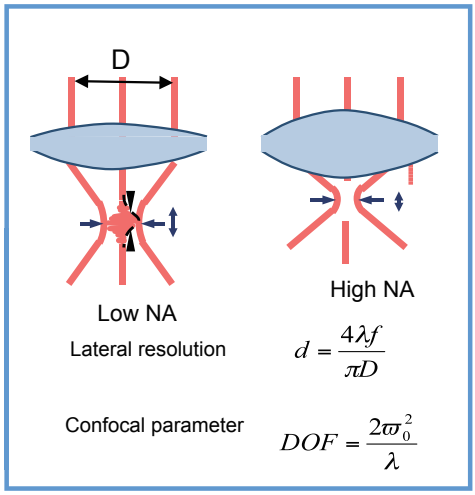
■Lateral resolution and Confocal parameter (Depth of Focus(DOF))

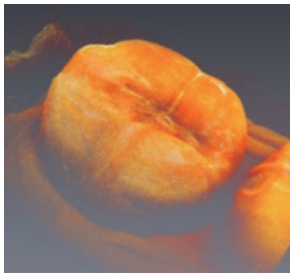
NA (numerical aperture) or focal length, f of an objective lens and beam diameter, D inside the probe determines the spot size(w0), or the lateral resolution and depth of focus (DOF). Graph shows typical relation of these two parameters. If targeting depth range is shallow, DOF can be compromised over small lateral resolution, or vise versa.

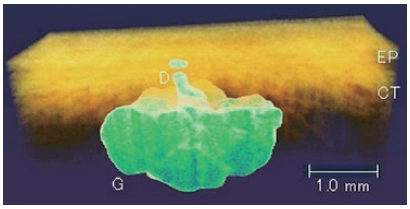


Typical variations

d	DOF
15μm	1mm
25μm	2mm
30μm	4.3mm
40μm	7.7mm







Human labial glands

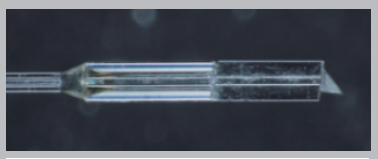
Oral/Dental application

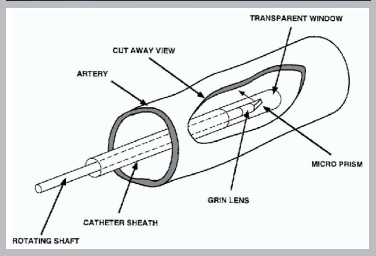
Fiber probes / Catheters

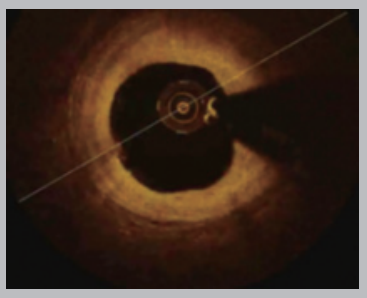
Santec has established expertise in optical component production technology throughout the past 15 years, including optical micro assembly and state-of-the-art MEMS （Micro Electro Mechanical System） for telecom applications. Adapting these technologies, we developed unique OCT fiber catheters for endoscopic applications. Custom designs can be proposed for OEM solutions.

Standard type catheter tip

The probe has a diameter of 0.5mm and angled polished facets on all interfaces so that the back reflection is as small as 60dB or less. Epoxy used for fixing the parts is medical grade that is used for conventional catheter. Small GRIN lens provides about 10 to 20um lateral resolution at 5mm from the optical axis. The collimator structure is rigid enough to be rapidly rotated inside the plastic sheath.





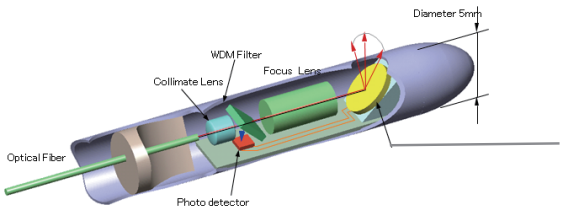


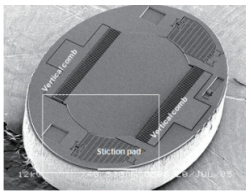
Cardiovascular applications (Image taken from Lighltabs Website)

Optically modulated MEMS fiber probe

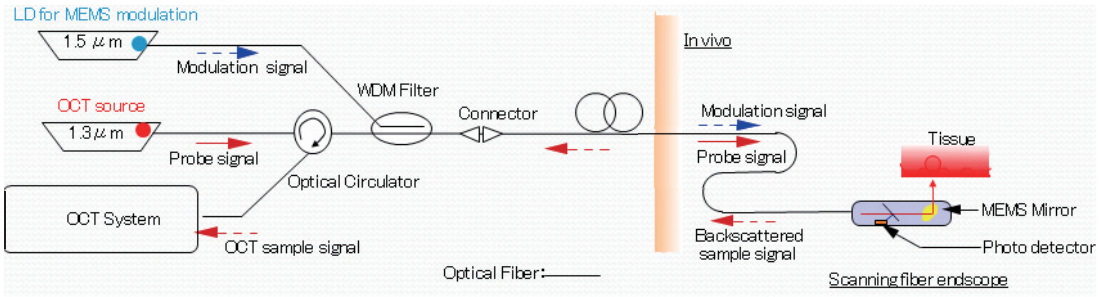
This device is actuated by the light into the fiber probe tip using wavelength division/multiplexing technique. This unique feature provides a hazard-free, EMI tolerant probe, under the multi-modality diagnostic applications in GI endoscopes.

- Power supply-free
- EMI tolerant design
- Compact





MEMS mirror



For OCT manufacturing

Optical Fourier Domain Reflectometry

When manufacturing the OCT system, precise reflection/optical path management is important. For the interferometer it is required to match the optical path length of the reference and sample probe arm. For the optical fiber probe, undesired reflection inside the probe should be suppressed so that it won't interfere with the OCT signal. Optical frequency domain reflectometry (OFDR) is a tunable laser-based frequency domain technique for measuring the length and location of reflection/losses in optical fiber, optical devices in the systems like OCT.

OFDR Lite

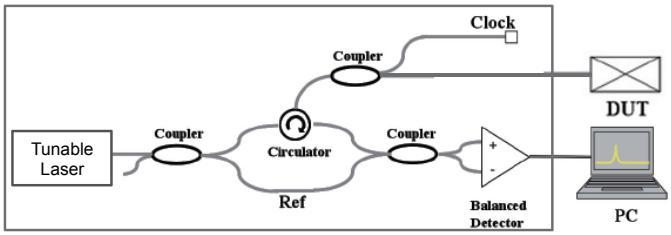
Features

- **High accuracy**
- **O,C or L-band operation**
- **Economical design**

Applications

- **Fiber length management**
- **Waveguide device analysis**
- **Splice fault detection**
- **Fault detection in fiberoptic system**
- **For OCT system assembly**
- **OCT probe/catheter assembly**

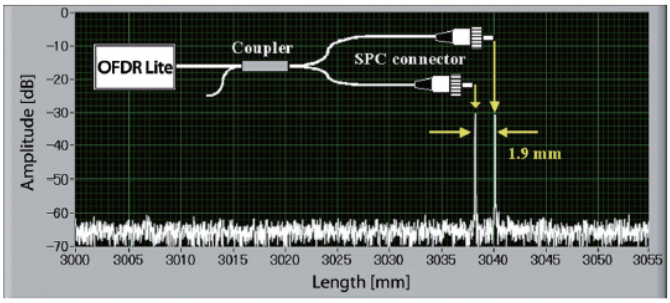
OFDR System configuration



Specifications

Parameter	Specification
Resolution	<30μm
Repeatability	<20μm
Measurement length	5meter max
Dynamic range	70dB

Measurement example



OCT Solutions from Santec
Application examples

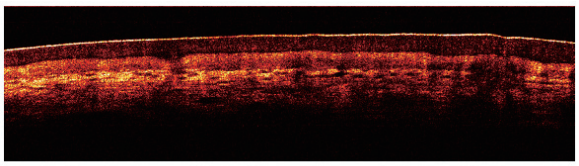
EX 1. Ophthalmology

After clearing approval in Japan, Tomey co. (Nagoya, Japan) released the world first SS-OCT based anterior segment diagnostic system in September 2008. SS-1000 from TOMEY is equipped with Santec's swept source engine, HSL-200-30 with interferometer options. The system scans 3D segment within 2 seconds. It benefits the diagnosis of cataract, glaucoma, and other cornea related diseases.

OEM engine, HSL-200

EX 2. Endoscopy/General clinical use

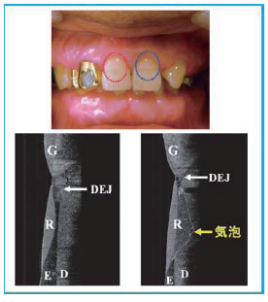
Michelson Diagnostics Ltd. (UK) utilized a wide band type swept source with 160nm scan range for high-resolution OCT imaging. Various clinical studies are ongoing, such as in diagnostics of skin cancer, liver cancer. Their system is available in Europe and North America.



Skin at underside of 1st knuckle joint of ring finger
(Photo from press release July 28th 2009, www.mdl-ltd.co.uk)

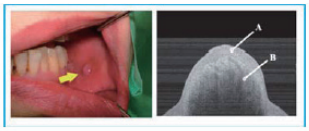
EX 3. Dental/Oral care

Santec has been in collaboration with National Centre for Geriatrics and Gerontrogy （Ohbu, Aichi, Japan） from 2006 in the field of Dental and Oral surgery. Their research works have been widely recognized in Japan. The journal of the Japan Dental Associations features OCT in dental/oral surgery application in 2008 March issue.



❸口腔用 SS-OCT によるレジン充填の評価

赤線で示したレジン充填 OCT 画像（左）では，周囲歯質とレジンの移行的な辺縁と窩底部の良好な界面が確認できた。青線で示したレジン充填 OCT 画像（右）では，レジンが積層充填されており，窩底部には気泡の存在が確認でき，さらに歯内側に過剰充填を認めた（エナメル質（E），象牙質（D），エナメル象牙境（DEJ），レジン充填部分（R），歯肉（G））。

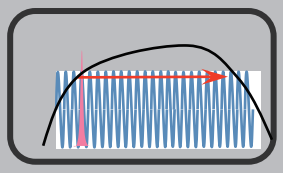


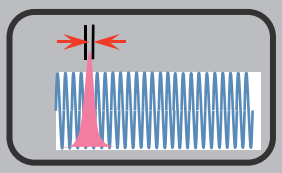
❼口腔用 SS-OCT による頬粘膜線維腫（口腔内写真および OCT 画像）

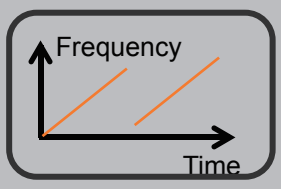
口腔内写真（左）の線維腫（黄矢印）を観察した OCT 画像上（右）では線維腫内部は充実した一様な組織（B）で満たされており，上皮（A）が確認できた。将来病理組織診断にかわる診断法（光 Biopsy）として利用できる可能性がある。

TUTORIAL

Important Parameters in SS-OCT







Swept range ⇔ Axial resolution

$$\delta z = \frac{2\ln 2}{\pi}\frac{\lambda_0^{\,2}}{n\Delta\lambda}$$

Wavelength

Swept range

Coherence length ⇔ Depth range

$$cl = \Delta L \times 2 = \frac{2\ln 2}{\pi}\frac{\lambda_o^{\,2}}{\delta\lambda}$$

Linewidth

Swept rate ⇔Imaging speed

$$Fr = f_{swept} / N_A$$

f_s: Swept rate

N_A: A-lines/frame

Output power

The higher the output power on the sample, the higher the SNR improves in principle. However, maximum permissible exposure on the human tissue is regulated by ANSI(American National Standards Institute) standard. An average power of 0.7mW in the 800nm wavelength range, and about 1mW in the 1060nm wavelength range, at the probe arm, are the maximum allowable exposures for ophthalmic applications. Other tissues can be exposed to >10mW average power in endoscopic applications. At even longer wavelengths, such as 1300nm, higher powers can be used, as the maximum power becomes less critical in terms of ionization of tissue by high power exposure.

Sweep linearity

The OCT signal is processed by time-sampling the backscattered light as the swept source sweeps the wavelength followed by Fourier transform (FFT). Ideally, the sweep should be linear in k space (k=2π/λ). But actual sweep curves of most of the proposed swept sources are non-linear in time, because of the intrinsic tuning mechanism. For examples, the use of Galvano mirror or fiber Fabry-Perot filter imposes sinusoidal sweep due to its driving characteristics. If simply applying FFT on the time-sampled interferogram when this non-linearity is present, the resolution of the signal is blurred and the signal power also decays. So, in general, most SS-OCT systems implement either nonlinear sampling with the use of an optical clock having another set of interferometer and detector, or the post processing approach; the so called "wavelength rescaling process".

Swept rate (scanning speed)

Wavelength swept rate, or scanning speed of the swept source is directly reflected on the imaging speed like the readout speed or refresh rate of the CCD in SD-OCT. Swept rate corresponds to A-line rate in OCT. Increasing A-line rate makes it possible to accommodate more A-lines per frame or increase the frame rate. In practical applications the ability to produce video rate images is of critical importance. This not only removes imaging artifacts that are created by undesired movement, but also enables a large area/volume measurement without compromising resolution, in a short amount of time. Depending on the applications, swept rate of 10 kHz to 100 kHz range are required.

Wavelength range

The choice of wavelength band in OCT is dependent on the water absorption and scattering property of the sample or tissue of interest . In general, 800nm range is used for retinal imaging because of low absorption in vitreous humor , and recently 1060nm range gains attentions because of large penetration in retinal tissue as well as low dispersion property in tissues. In endoscopic applications, the 1310nm range or a longer range is commonly used because of low scattering, resulting in large depth penetration. OCT in the 1310nm range has another benefit: abundant available optical components in this range that were developed for optical fiber telecommunication applications. The spectral width of the OCT signal, i.e. axial resolution, is inversely related to the envelope of temporal power profile via Fourier transforms, and which is given by the equation on the previous page. For example, using this equation: 10um resolution can be achieved by: 30nm at 820nm or 75nm at 1310nm.

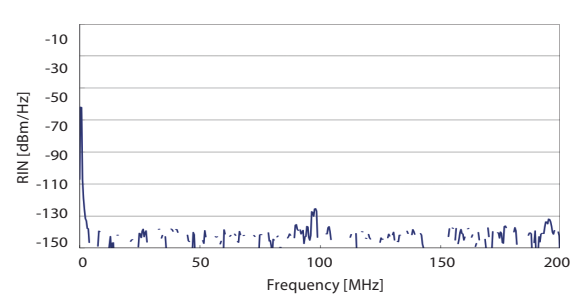
Instantaneous linewidth / Coherence length

Instantaneous linewidth is a terminology very specific to the high-speed swept-source. Sometimes it is called, dynamic linewidth. It doesn't mean the linewidth of a single longitudinal mode as usually referred to in laser oscillation definitions. Most of the swept sources for SS-OCT are partially coherent light sources, and therefore spectral width is the width of the envelope that contains the group of cavity modes. Since instantaneous linewidth is finite and the OCT signal is a convolution of its spectrum and interferogram, its fringe visibility drops for the higher frequency components, i.e. at deeper range. Coherence length is defined as the optical round trip delay or twice of the depth range where fringe visibility drops half or the Fourier-transformed OCT signal drops 6dB compared to the signal power at zero delay.

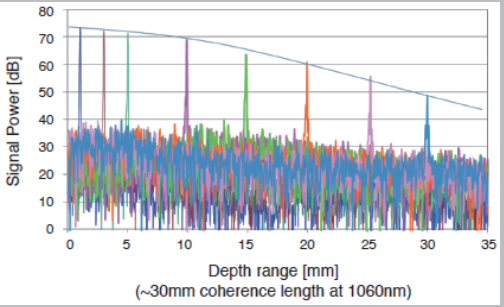
Relative Intensity Noise

Intensity noise of the source at the signal detection band directly impacts on the SNR of the OCT system. Source of the noise attributes to the injection current from the driver circuitry and the cavity mode beating and its harmonics at the frequency equal to the reciprocal of cavity life time. Ripple on the spectral profile of the sweep also influences on the OCT signal as an alias noise. In the OCT system, the source RIN can be reduced if balanced detection is used for common mode noise reduction. RIN can be measured with a photodiode and an electrical spectrum analyzer.

RIN of HSL series



OCT signal of high coherence type HSL



Polarization

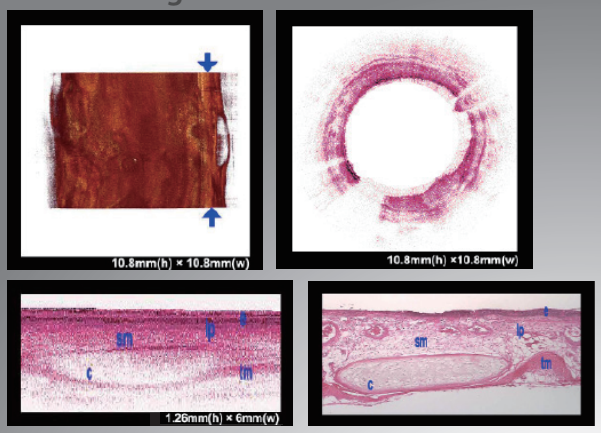
Single polarization output or output with high degree of polarization (DOP) is desired to suppress the effect of PMD in the interferometry system. Single polarization output may be useful when polarization sensitive OCT can be realized by adapting the Muller matrix method.

Reliability

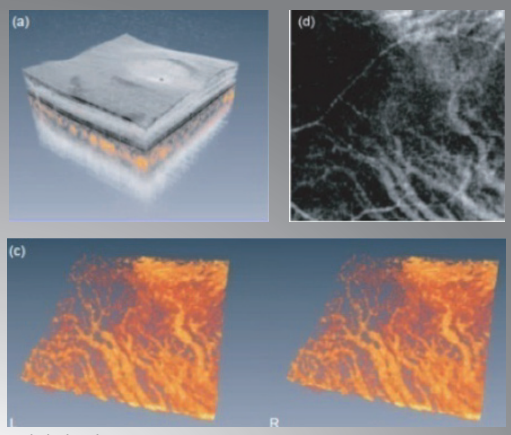
Long term reliability and durability of the source is desired for harsh environmental conditions in clinical use. Meeting EMC/EMI standards is also important so that the instrument doesn't interfere with the other surrounding equipments. In most cases, 5 years product life should apply, corresponding to over average 40,000hrs of continuous usage.

OCT Image Gallery

Medical Diagnostics

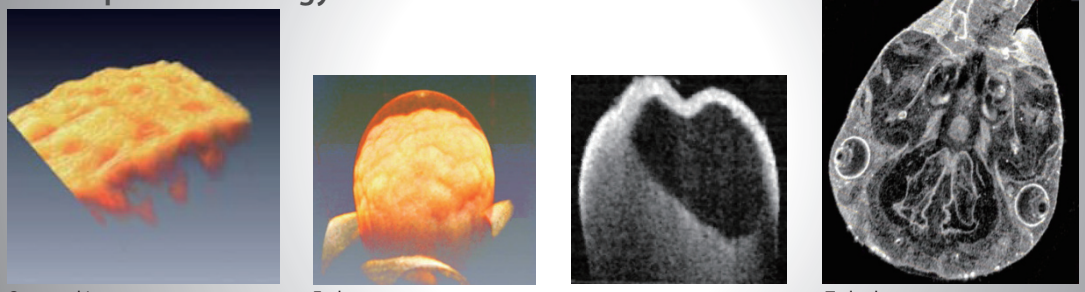


Endoscopy
(In courtesy of Z.P.Chen UC Irvine)



Ophthalmology
(In courtesy of Y.Yasuno, Tsukuba Univ)

Developmental Biology

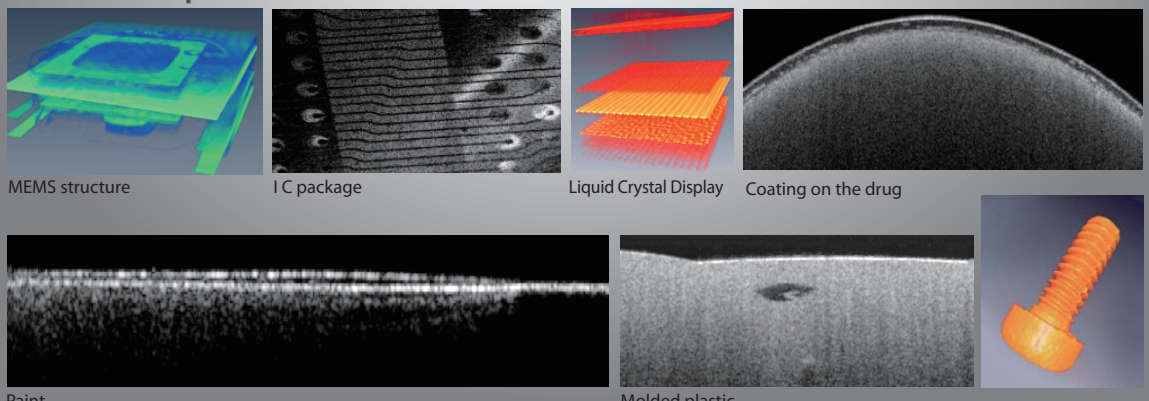


Orange skin

Embryo

Tadpole

Industrial Inspection



MEMS structure

I C package

Liquid Crystal Display

Coating on the drug

Paint

Molded plastic

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Title	Author(s)	Journal	Institue
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In vivo high-contrast imaging of deep posterior eye by 1-μm swept source optical coherence tomography and scattering optical coherence angiography	Yoshiaki Yasuno*1, Youngjoo Hong1, Shuichi Makita1,Masahiro Yamanari1, Masahiro Akiba2, Masahiro Miura1,3 and Toyohiko Yatagai4	14 May 2007 / Vol. 15, No. 10 / OPTICS EXPRESS 6121	Tsukuba Univ.
In vivo three-dimensional microelectromechanical endoscopic swept source optical coherence tomography	Jianping Su,1 Jun Zhang, 2 Linfeng Yu, 2 Zhongping Chen1,2	6 August 2007 / Vol. 15, No. 16 / OPTICS EXPRESS 10390	Univ. of California, Irvine
Three-dimensional and high-speed swept-source optical coherence tomography for in vivo investigation of human anterior eye segments	Yoshiaki Yasuno, Violeta Dimitrova, Madjarova and Shuichi Makita,Masahiro Akiba,Atsushi Morosawa, Changho Chong, Toru Sakai,Kin-Pui Chan,Masahide Itoh and Toyohiko Yatagai	26 December 2005 / Vol. 13, No. 26 / OPTICS EXPRESS 10652	Tsukuba Univ. santec
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Polarization-sensitive swept-source optical coherence tomography with continuous polarization modulation	Masahiro Yamanari, Shuichi Makita, Toyohiko Yatagai, and Yoshiaki Yasuno	Proc. SPIE Vol. 6847, 68471J (Feb. 18, 2008)	Tsukuba Univ.
In vivo 3-D imaging of gastrointestinal tracts by use of an endoscopic swept source optical coherence tomography with a microelectromechanical endoscopic rotational probe	Jun Zhang, Jianping Su, Kenneth Chang, and Zhongping Chen	Proc. SPIE Vol. 6847, 68472Y (Feb. 18, 2008)	Univ. of California, Irvine
Multi-channel Fourier domain OCT system with superior lateral resolution for biomedical applications	Jon Holmes, Simon Hattersley, Nick Stone, Florian Bazant-Hegemark, and Hugh Barr	Proc. SPIE Vol. 6847, 68470O (Feb. 18, 2008)	Michelson Diagnostics Ltd.
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Full range swept-source optical coherence tomography using 3×3 Mach-Zehnder interferometer with unbalanced differential detection,	Youxin Mao,; Flueraru, Costel; Sherif, Sherif; Shoude Chang, Biomedical Imaging: From Nano to Macro	2008. ISBI 2008. 5th IEEE International Symposium on Vol, Issue, 14-17 May 2008 Page (s):1355 - 1358	Ntl Research Council of Canada
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Phase-sensitive swept source optical coherence tomography for imaging and quantifying of microbubbles in clear and scattering media	Ravi Kiran Manapuram,1 Venu Gopal Reddy Manne,1 and Kirill V. Larin1	J. Appl. Phys. / Volume 105 / Issue 10 / SPECIAL TOPIC: APPLIED BIOPHYSICS	Univ. of Houston
In vivo imaging of human labial glands using advanced optical coherence tomography	Nobuyoshi Ozawa, DDS,a Yasunori Sumi, DDS, PhD,b Kazuo Shimozato, DDS, PhD,c,Changho Chong,d and Tohru Kurabayashi, DDS, PhD	Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:425-429	Natl.Gerontology Centr.

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