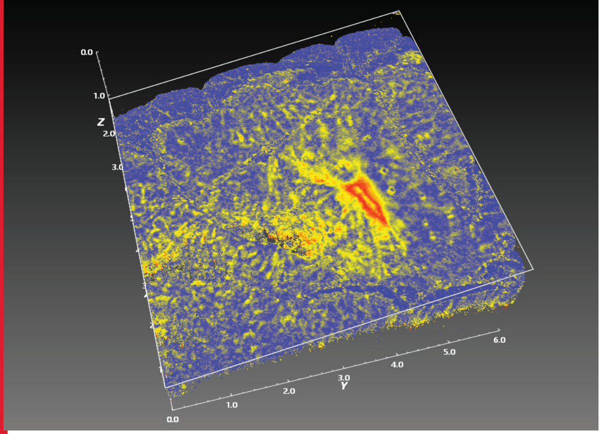
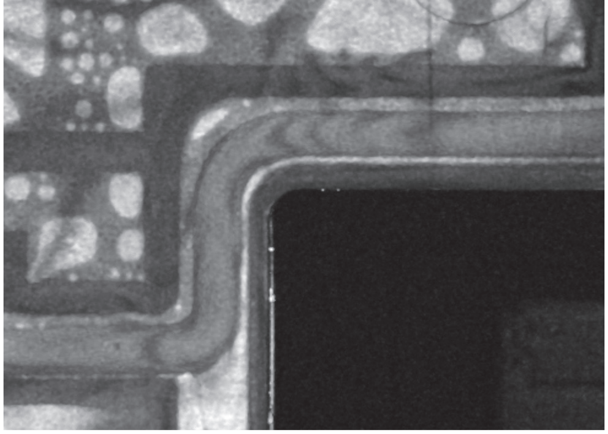
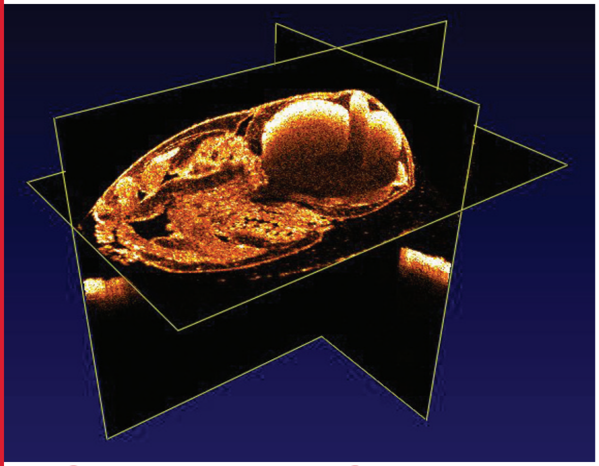
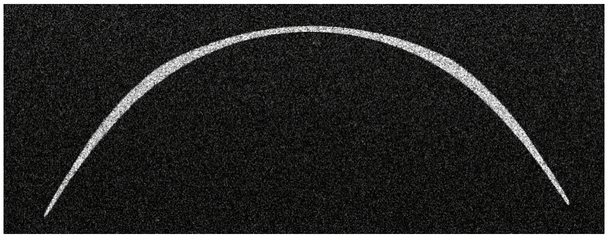
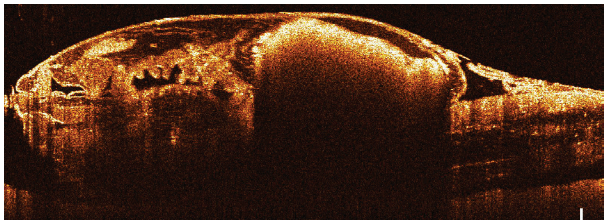
OCT











Optical Coherence Tomography

Thorlabs meets the unique and often complex requirements of each OCT imaging application by manufacturing modular OCT components that are designed to be configured into highly customizable systems. Our systems enable not only cross-sectional imaging of specimens but also real-time volumetric and micron-level imaging. Particle motion, flow, and vascular imaging are accomplished through Doppler and speckle variance OCT, and this information can be overlaid on the respective cross-sectional images.

The engine of each modular system is the OCT base unit, which includes the light source, detection optics, and hardware. Thorlabs offers a variety of OCT base units based on spectral domain and swept-source approaches, as well as a selection of beam scanning systems and scan lens kits. Modular designs, flexible configurations, high-performance data acquisition software, and a wide variety of components and accessories allow these OCT systems to meet specific requirements and be seamlessly integrated into a wide range of applications and environments.

Алматы (7273)495-231
Ангарск (3955)60-70-56
Архангельск (8182)63-90-72
Астрахань (8512)99-46-04
Барнаул (3852)73-04-60
Белгород (4722)40-23-64
Благовещенск (4162)22-76-07
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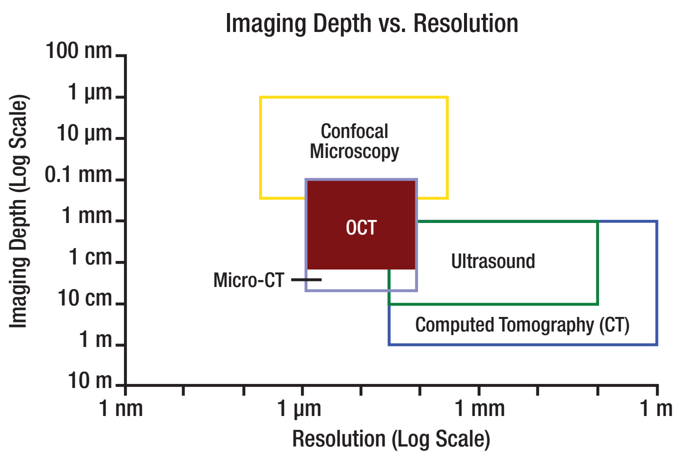
OCT Basics



Optical coherence tomography (OCT) is a non-invasive and non-destructive imaging technique that provides real-time, cross-sectional (2D) and sub-surface volumetric (3D) imaging of structural features with micron-level resolution. OCT bridges the gap separating the resolution and imaging depth capabilities of confocal microscopy and ultrasound imaging.

OCT images are generated by analyzing light backscattered from the different features in the sample. To collect a 1D depth scan, often called an A-Scan, the light emitted by the OCT light source is focused to a small diameter spot, positioned on the specimen, and held stationary. OCT imaging is ideal for samples that are partly transparent to this light probe, allowing the light to penetrate into the sample. The OCT system collects and measures the light backscattered by the surface and sub-surface features located along the path of the probe. The backscattered light and a reference light beam form an interference pattern that is Fourier transformed to produce a 1D depth profile.

2D and 3D images are obtained by scanning the OCT light probe across the surface of the sample while collecting the measured A-Scans into datasets. The 2D scan that produces a cross-sectional image is called a B-Scan. OCT measurements can also be used to perform qualitative and quantitative motion detection through Doppler and speckle variance OCT.

Thorlabs' Modular OCT System Design

Thorlabs' modular OCT systems consist of an OCT base unit, beam scanning system, scan lens kit, and user-selected accessories. Each system component is chosen to best meet the requirements of the application. As there are interdependencies among the various performance specifications in OCT systems, no single system can meet the needs of all applications. The purpose of OCT system design is to optimize key parameters while ensuring good overall system performance.

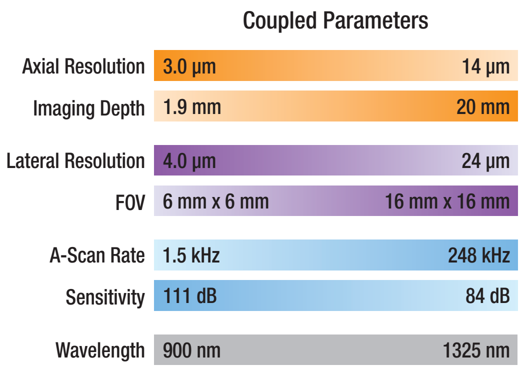
The OCT Base Unit and Scan Lens Kit are Key to OCT System Performance

Significant performance characteristics, including the axial resolution, A-Scan rate, and imaging depth, are entirely or strongly dependent on the design of the OCT base unit. The choice of scan lens kit determines other parameters, such as lateral resolution and the field of view (FOV). Thorlabs offers a variety of OCT base units and scan lens kits that provide foundations for systems with a wide range of capabilities.

Balancing Coupled Performance Parameters

In all optical systems, including OCT systems, interrelationships exist among optical parameters. Significant performance parameters that are coupled in OCT systems are shown to the right. Optimal OCT systems balance these parameters to achieve the best performance for an application.

- Improving axial resolution contracts the maximum possible imaging depth.
- Improving lateral resolution contracts the field of view.
- A faster A-Scan (i.e., 1D depth scan) rate results in reduced sensitivity.
- A shorter wavelength improves lateral resolution but increases scattering from small features in tissue and other media.



Updated Features in the SD-OCT Family

We have updated our Ganymede™ , Telesto®, and Telesto PS OCT systems with new features that simplify image capture and data gathering.

New Scanner Assembly with Integrated Micrometer Screw

Updated SD-OCT Scanner

The OCTG Scanner for SD-OCT systems now includes a micrometer at the top of its housing. This allows for fine adjustments of the reference arm's optical path length so it matches the optical path length of the sample light precisely without compromising the housing's light-tight seal.

Triggering Functionality

The SD-OCT base units feature a fully configurable trigger that is extensively programmable using our ThorImage®OCT software. The connector can be operated as either an input, responding to external signals, or an output, generating trigger signals. Trigger signals can be sent at the start of each A-, B-, or volume scan, as well as after an arbitrary number of scans.

Hardware Diagnostics

The cases of the SD-OCT base units have integrated LED indicators on their front panels, which help monitor the systems' general health, interlocks, and superluminescent diodes (SLD). This provides a means to quickly troubleshoot and resolve system issues, minimizing downtime.

Synchronous Analog Data Gathering

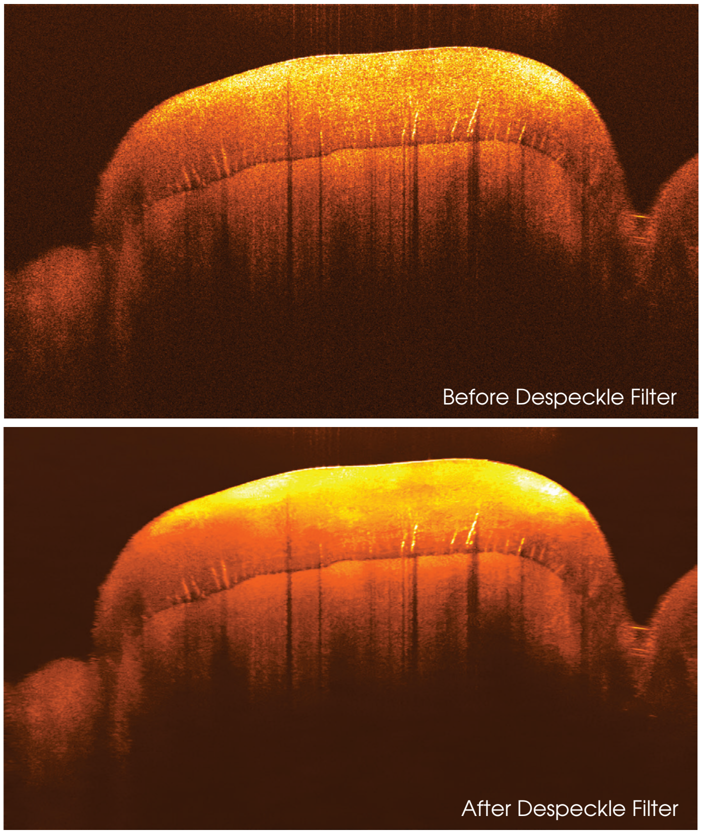
Two analog inputs on the back of the SD-OCT base units allow OCT image acquisition to be synchronized with information gathered from other imaging modalities. Analog data can be overlaid on OCT images to create informative composite images.

Post-Processing Filters

Backscattered reflections from a sample's randomly oriented surfaces lead to variations in the intensity of collected light, manifesting themselves in speckle noise across an image. The image to the upper right shows a B-Scan of a human tooth, which exhibits speckling across the imaged area. Below it is the same image after our despeckle filter has been applied. This filter has been designed to reduce speckle noise without blurring details of the imaged structure.

Reflecting surfaces near the deepest extreme of a scan can lead to aliasing artifacts that appear as spikes along the bottom of a B-Scan. By using our undersampling filter, these artifacts can be partially compensated for, giving a cleaner image.

ThorImage®OCT can also integrate user-defined post-processing algorithms. OCT datasets can be exported and modified in a third-party program, including ImageJ, and then reimported back into the ThorImageOCT software. This functionality allows for fast and customized modifications of OCT images, while still using the dataset management of the ThorImageOCT software.



OCT Image of a Human Tooth Before (Top) and After (Bottom) Despeckle Filtering.

Thorlabs' Modular OCT System Architecture

Building a Complete OCT System

Every OCT system is built from an OCT base unit, beam scanning system, and scan lens kit. Optional components include additional beam scanning systems and/or scan lens kits, as well as Z-spacers and accessories. We encourage you to contact

OCT System Core Components


Base Unit

OCT Base Unit

The OCT base unit includes a desktop computer with pre-installed software and an enclosure such as the one shown to the left, which houses the optics, electronics, light source, and detection unit. The OCT base unit measures the raw signal from the specimen and processes it to produce 1D depth profiles, 2D cross-sections, and 3D volumetric images. Our four series of OCT base units are called Atria®, Vega™, Telesto®, and Ganymede™, and each is optimized for different parameters.

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OPTICAL INSTRUMENTS
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Standard Scanner

Beam Scanning System

The beam scanning system scans the light beam across the back aperture of the scan lens, which enables 1D cross-sectional (A-Scan), 2D cross-sectional (B-Scan), and 3D volumetric imaging of the specimen. Scanners for Telesto and Ganymede base units require a reference arm of the interferometer needed to generate the raw measurement; the reference arms for the Vega and Atria base units are built into the base unit. All of our beam scanners include a built-in high-resolution video camera. Surrounding the exit aperture of the scanner are white-light LEDs, which are not used for the OCT measurement but can be used to provide illumination for the video feed. The beam scanner types are interchangeable, making it possible to choose the best option for a given application.

Standard (OCTG) Scanner

The standard assembly, which offers stability and ease of use, is ideal for general-purpose OCT imaging applications. Packaged in a rugged, light-tight housing, the standard scanner prevents misalignment of the scanning beam.

User-Customizable (OCTP) Scanner

For users who require flexibility in configuring the optical beam path in their OCT imaging system, the user-customizable models are built with Thorlabs' SM1 and 30 mm cage system components to support customization.


Customizable Scanner


Lens Kits

Telecentric Scan Lens Kit

Our OCT scan lens kits are designed for optimal image quality across a large field of view. These telecentric objective lenses direct the OCT light beam to a specific point on the sample and collect the backscattered light. These easily interchanged scan lens kits include a telecentric objective scan lens, IR card, illumination tube, and calibration target.

Preconfigured Systems

VEG210C1
Preconfigured OCT System

Thorlabs offers a number of preconfigured systems for each OCT series. Preconfigured systems ship with the three essential components: a base unit (including the PC), a scanning system, a scan lens kit, as well as two accessories: a scanner stand and a translation stage. These systems are optimized for out-of-the-box performance in most typical applications.

Preconfigured system specifications are strongly tied to the base unit and lens kit used in each system, which are given in the table to the right.

Specifications

Series Name	Preconfigured System Item #	Included Base Unit Item #	Included Scan Lens Kit Item #
Ganymede™	GAN111C1	GAN111	OCT-LK3-BB
	GAN311C1	GAN311	OCT-LK3-BB
	GAN321C1	GAN321	OCT-LK2-BB
	GAN611C1	GAN611	OCT-LK3-BB
	GAN621C1	GAN621	OCT-LK2-BB
Telesto®	TEL211C1	TEL211	OCT-LK4
	TEL311C1	TEL311	
	TEL221C1	TEL221	OCT-LK3
	TEL321C1	TEL321	
Telesto PS-OCT	TEL211PSC1	TEL211PS	OCT-LK4
	TEL221PSC1	TEL221PS	OCT-LK3
Vega™	VEG210C1	VEG210	OCT-LK4
	VEG220C1	VEG220	
Atria®	ATR206C1	ATR206	OCT-LK4-BB
	ATR220C1	ATR220	

Options and Accessories

OCT-IMM4

OCT-IMM3

Immersion-Type Z-Spacers

OCT-AIR3

Ring-Type Z-Spacer

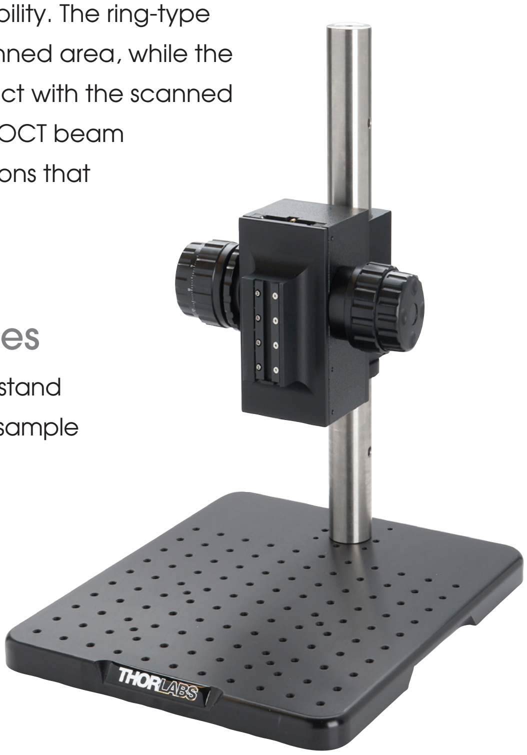
Sample Z-Spacers Provide Imaging Stability

Thorlabs' Sample Z-Spacers enable optimal positioning of a beam scanning system relative to the sample. Fine adjustments can be made to their height, and then they can be locked into place for increased stability. The ring-type spacer contacts the sample away from the scanned area, while the immersion types press a glass window into contact with the scanned area. This can result in better penetration of the OCT beam into the sample by reducing strong back reflections that often occur at the sample's surface.

Convenient Imaging Accessories

Leveraging Thorlabs' long history of optomechanical design expertise, we offer a stand for mounting our standard and user-customizable beam scanning systems and a sample positioning stage, which provides X and Y translation as well as 360° rotation.

OCT-XYR1(/M)
Sample Positioning Stage



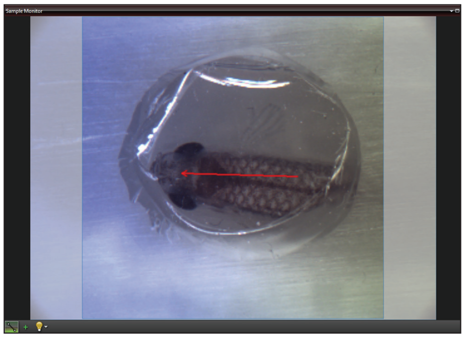
OCT-STAND(/M)
Stand for Scanning System

ThorImage® OCT Software

The high-performance ThorImage® OCT software is included with all Thorlabs OCT systems and is capable of data acquisition and processing, scan control, and OCT image display and manipulation. Features include:

- Interactive Scan Position Control through Video Display (Draw and Scan)
- Versatile Scan and Acquisition Control
- Despeckle Filtering
- Two Analog Input Channels for Combining Data from Different Image Modalities (Only Ganymede™ and Telesto® Series)
- External A-Scan and B-Scan Trigger for Synchronization of External and OCT Experiments (Only Ganymede and Telesto Series)

Additionally, National Instuments®’ LabVIEW® and C-based Software Development Kits (SDKs) are included.



Draw and Scan 2D Guide Line on Video Image

Scan Control

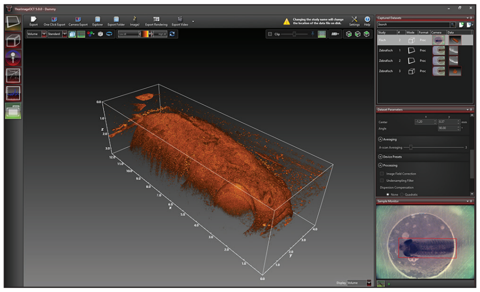
The integrated camera provides a live video feed viewable in the software. The “Draw and Scan” feature defines the scan line for 2D scans or the area for 3D scans. Additionally, the software sets processing and averaging parameters, speed, and sensitivity.

2D Imaging Mode

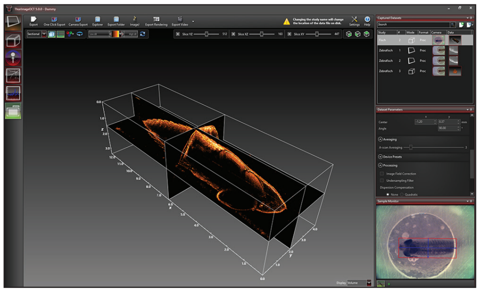
The beam scans in one direction and the OCT system acquires a cross-sectional image (B-Scan), which is displayed in real time. B-Scan averaging can be specified as well as A-Scan averaging before or after the Fourier transform.

3D Imaging Mode

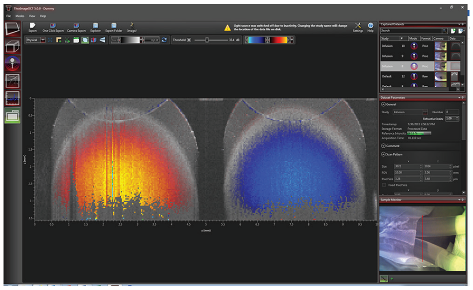
3D datasets can be viewed as volume renderings, or the content in orthogonal cross-sectional planes can be selected for exclusive display in 3D sectional views. The 3D view can be rotated as well as zoomed in and out. The fast volume rendering feature can be used to display real time lower-resolution volume images. These preview images can be helpful when a user is selecting a region of the sample over which to acquire a subsequent high-resolution volume scan.



3D Rendering View



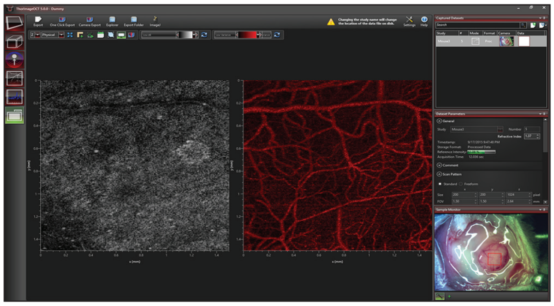
3D Sectional View



Doppler Image Showing Velocity of Rotated Plastic Stick with Opposite Flow Directions.

Doppler Mode

This mode measures movement occurring relative to the axis of the OCT probe beam. Doppler information can be overlaid on the OCT images in the form of a color map. The color coding indicates whether the flow occurred in a forward or backward direction, relative to the OCT beam.



OCT Image on Left; Speckle Variance Image of Blood Vessels of a Mouse Brain on Right

Speckle Variance Mode

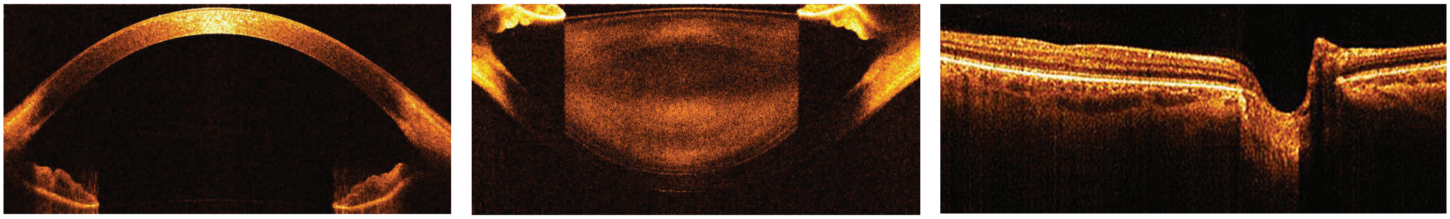
By monitoring speckle patterns, this mode can highlight locations of particle movement and flow, although information about the direction of movement cannot be determined. Using this mode, significant blood flow is not required to visualize 3D vessel trees. Speckle variance images can be overlaid on the OCT image.

OEM System Development

Our engineering teams have developed a catalog of turnkey OCT systems tuned to answer a variety of imaging needs. Our vertically integrated production allows us to modify our catalog units or build custom units from the ground up to create targeted application solutions.

Thorlabs has manufactured OCT systems for OEM customers in research, medicine, and metrology. A dedicated engineering team will work with you to evaluate your project's needs and select the parameters required to successfully image your subject. Form factor adjustments can be made to reduce the scanner size or modify the footprint and appearance of the base unit housing for better integration into a laboratory or factory floor.

Optical elements, mechanics, and internal electronics of our OCT components can be customized to adjust the system's lateral resolution, field of view, and operational wavelengths.



OCT images of a human eye. From left to right: cornea, lens, and retina. Taken with a customized system operating at 1060 nm.

Configuration Options

Light Sources

- Superluminescent Diodes
- MEMS-VCSEL Swept Source Lasers

Housing

- Footprint
- Appearance
- Ergonomics

Signal Collection

- Spectrometers
- Balanced Detectors
- Integrated Cameras

Configurable Electronics

- Input/Output Ports
- Power Supplies
- 2D Scanner Drives

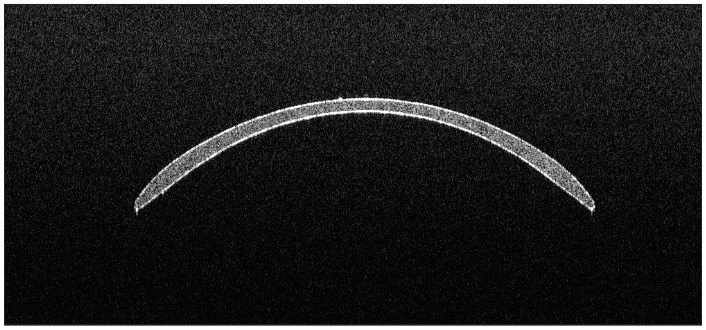
In-house development and production of all necessary sub-components enables us to adapt the system to your needs.

Case Study: Optimec is830

One example of a customized OCT system is the Optimec *is*830, which is an instrument Optimec® Systems developed in close collaboration with Thorlabs. This instrument was designed to evaluate contact lenses in air or in aqueous solution for quality control purposes. The OCT measurements are used to determine parameters that include:

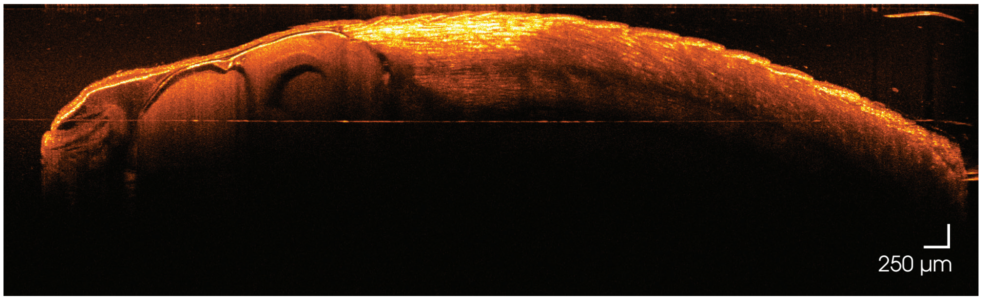
- Sagittal Height
- Diameter
- Curvature
- Thickness

This customized system operates in the 830 nm wavelength range and uses a custom compact OEM scanner.

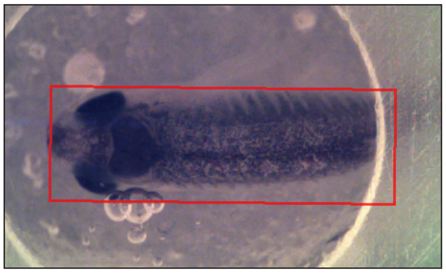


A 2D cross section of a contact lens acquired with the Optimec is830 system.

In Vivo Imaging



2D Cross-Section of the Zebrafish, in which the Vertical Axis is Depth into the Specimen

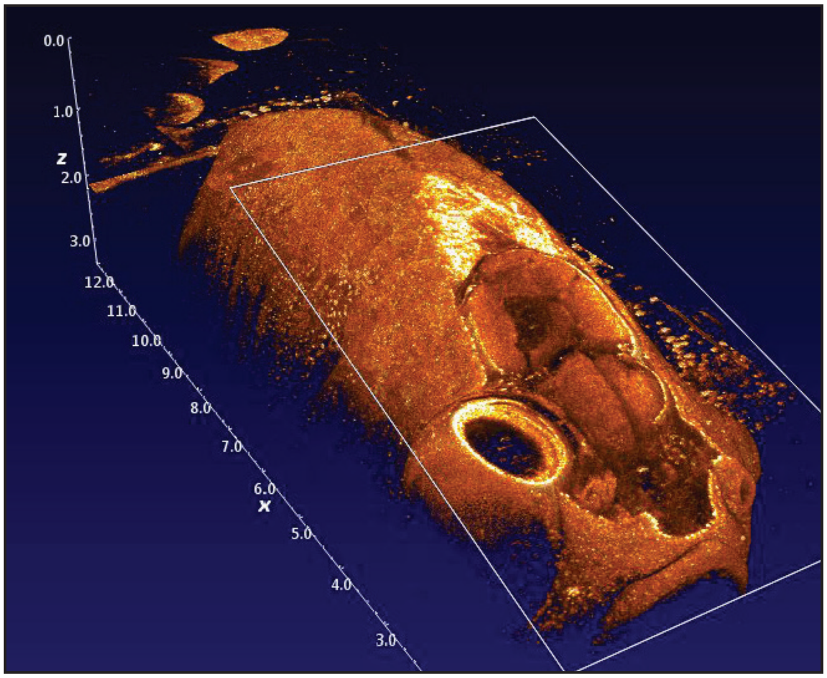


Still from the Live Video Feed of the Zebrafish Showing Area of Acquisition

The zebrafish (*danio rerio*) is a model organism used in various fields, including cancer research and neuroscience. The images shown here were captured using a standard beam scanning system and the Telesto® base unit.

OCT imaging allows the inner organs of the same organism to be non-invasively examined and then re-examined, *in vivo*, at different stages of development.

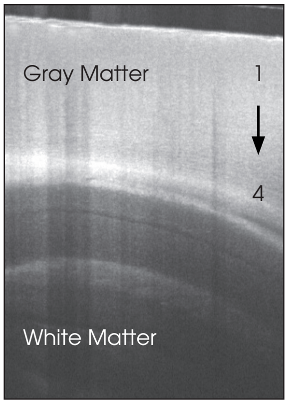
The camera and white-light LEDs integrated into the beam scanning system can be used to view a live video feed. Video is not recorded, but stills may be acquired. The video image is displayed in the ThorImage® OCT software and can be used to select an area over which to perform the 3D acquisition.



Sectioned 3D Image of the Zebrafish
Dimensions: 12 mm (X Axis), 4 mm (Y Axis), 3.6 mm (Z Axis)

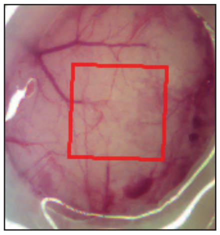
Sectioning the volume image at a user-selected plane gives a view of the interior of the subject. Post-processing the volume dataset allows cross-sectional images to be viewed in all three orthogonal planes, independent of the orientation in which the data were acquired. The view can also be rotated as well as zoomed in and out.

Vascular Imaging

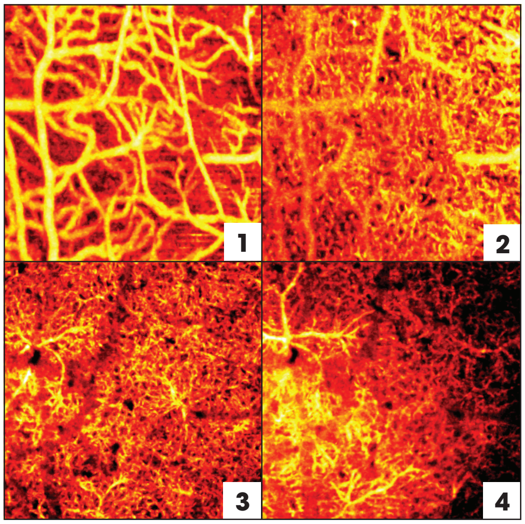


OCT Cross-Sectional Image of the Brain (B-Scan Depth Profile)
Dimensions: 2.6 mm x 1.5 mm

Vascular imaging in a mouse brain can be used to monitor the evolution of a disease or a stroke. An OCT cross-sectional image of the brain is shown on the left (B-Scan depth profile). These OCT images were acquired through a cranial window using the standard beam scanning system and the Telesto base unit.



Still from the Live Video Feed Showing Area of Acquisition



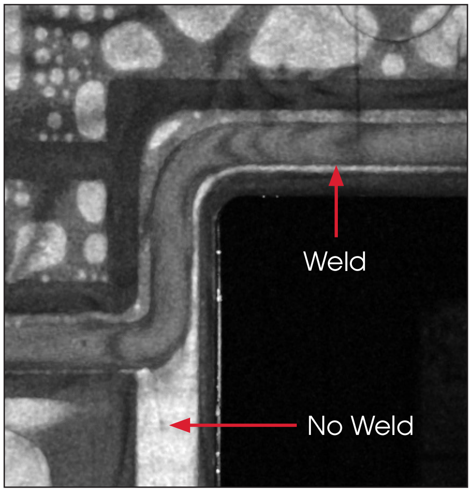
These blood vessel images were acquired using speckle variance OCT and are shown in *en face* view. Thick blood vessels are found at the top of the brain, and thinner capillaries are located deeper.
Dimensions: 1.5 mm x 1.5 mm

Images Acquired in Collaboration with MacVicar Lab, University of British Columbia

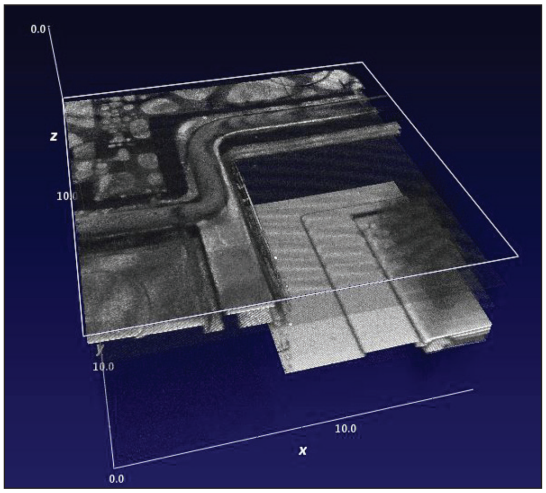
Non-Destructive Testing and Quality Control

Plastic welds are used in many industries to join individual plastic pieces. OCT imaging with the Vega™ base unit and a standard beam scanner were used to inspect the welds made by the laser transmission welding technique. These images show a good quality weld and an intentionally weld-free region in a printer ink cartridge.

Standard beam scanning systems were paired with a Telesto® base unit for weld inspection (lower left) and a Ganymede™ base unit to evaluate foil layer thicknesses (lower right), as described below. The stability and ease of use of our standard beam scanning system is well suited for these applications, which require 2D cross-sectional B-Scans to be acquired.



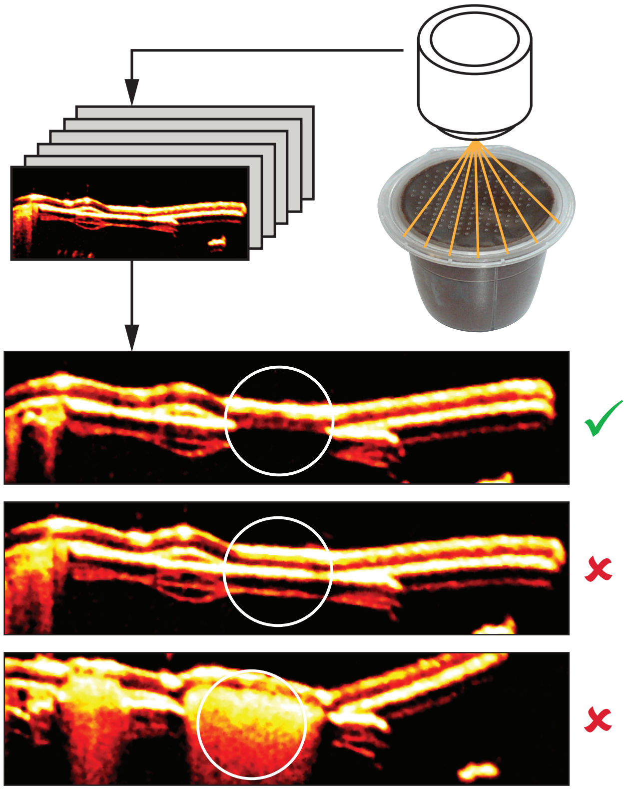
Post-Processed Image Composed of Several *En Face* Cross-Sections Viewed Together
Dimensions: 16 mm x 16 mm



3D Volumetric Rendering of a Region of the Ink Cartridge
Dimensions: 16 mm (X Axis), 16 mm (Y Axis), 11 mm (Z Axis)

Plastics Weld Inspection

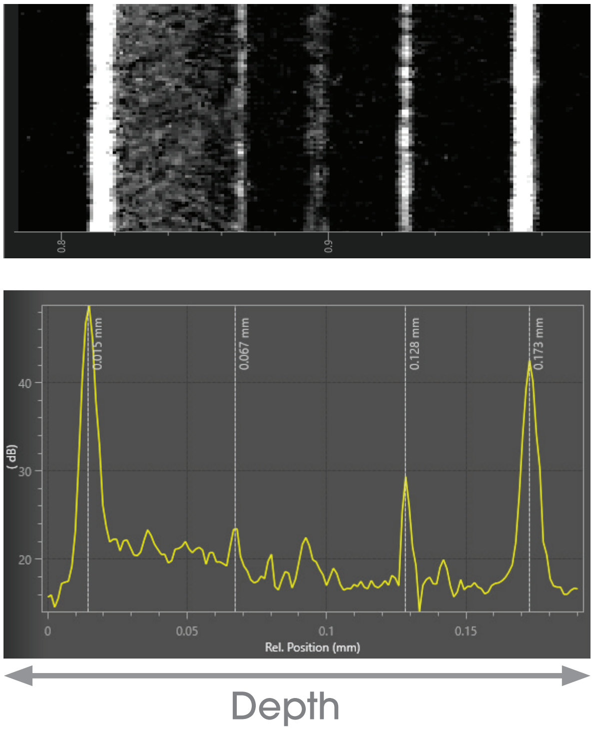
The welded seam of a coffee capsule is inspected at different positions by analyzing cross-sectional OCT images. Faulty regions can be detected by automated OCT image processing.



OCT imaging shows interfaces, such as between air and plastic. In the case of a successful weld, no air interface is visible between the underside of the foil and the top of the capsule.
Dimensions: 5.5 mm x 1 mm

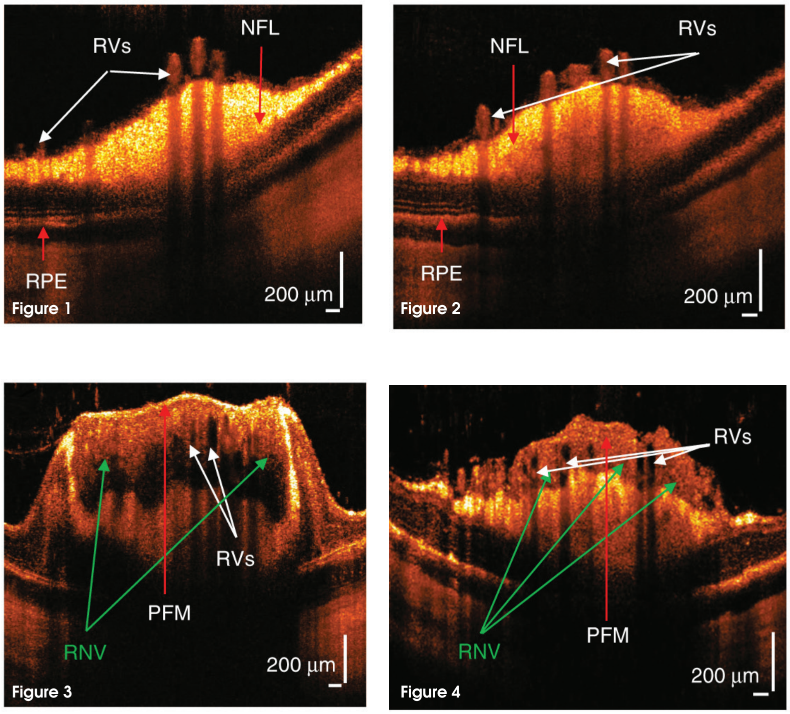
Thickness Control

In-line thickness control of a multi-layered foil. The fixed scan head constantly acquires depth-resolved information from the moving foil. The film thickness parameters are extracted continuously and in real time through OCT image processing.



ThorImageOCT provides a real-time view of multi-layer foils (top) while measuring each layer's depth (bottom) using peak detection.

Ophthalmology Research with a User-Customized Scanner



Using a high-resolution Ganymede™ system, researchers highlighted how retinal neovascularization (RNV) affected the structure of the eye. Figure 1 shows a normal retina in an albino rabbit. Figure 2 shows a normal retina in a pigmented rabbit. Figure 3 shows an albino rabbit with RNV. Figure 4 shows a pigmented rabbit with RNV. Retinal vessels (RV), the nerve fiber layer (NFL), and the preretinal fibrovascular membrane (PFM) were labeled as well.

This ophthalmologic application called for a multimodal imaging system. Our OCTP-900 Customizable Scanner served as a nexus to combine photoacoustic imaging from a pulsed optical parametric oscillator (OPO) with optical coherence tomography (OCT) and fluorescence microscopy (FM) imaging signals.

Whereas photoacoustic imaging and fluorescence microscopy mainly visualize the position and structure of retinal blood vessels (RV), OCT imaging allows for visualization of individual retinal layers, such as nerve fiber layers (NFL) and retinal pigment epithelium (RPE), as well as additional structures from the eye, such as the choroid and the sclera.

By funneling all three imaging modalities through the OCTP-900 scan head, researchers were able to co-register the images and capture an *in vivo* view of the retina to explore the impacts of retinal neovascularization as the disease developed in albino and pigmented rabbits. Because all imaging modalities were nondestructive and noninvasive, progression could be tracked safely without interrupting or otherwise adversely affecting the experiment.

User-Customized OCTP-900 Beam Scanning System

The OPO laser was coupled into the cage-based OCTP-900 via an additional dichroic mirror, such that it could be focused on the same spot as the OCT beam. For retina imaging, an additional objective lens was inserted after the OCT scan lens.

The backscattered OCT signal and the emitted fluorescence signal were collected by the same lens system and separated by a selective filter. The photoacoustic signal was measured via an ultrasound transducer that was placed in contact with the sclera.

Zhang, W., Li, Y., Nguyen, V.P. *et al.* High-resolution, in vivo multimodal photoacoustic microscopy, optical coherence tomography, and fluorescence microscopy imaging of rabbit retinal neovascularization. *Light Sci Appl* **7**, 103 (2018).
https://doi.org/10.1038/s41377-018-0093-y
Image adapted from original.

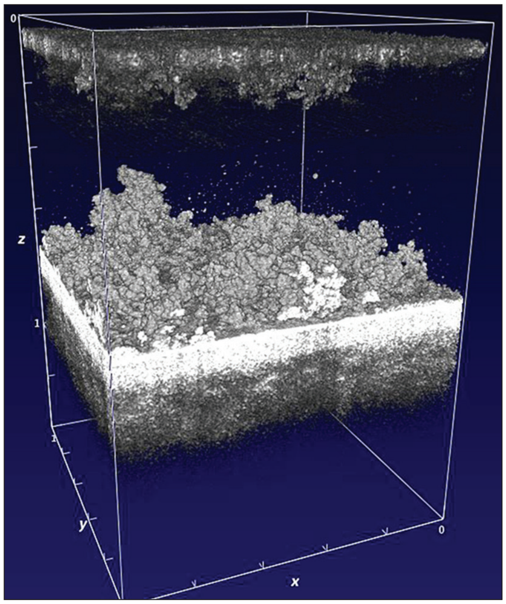
Biofilms and Biofouling

Biofilms grow under harsh conditions and on various surfaces. OCT imaging is a powerful tool for investigating and understanding the growth and morphology of biofilms at the mesoscale. Particularly helpful to this study is the ability to perform real-time imaging of the biofilms under water flow.

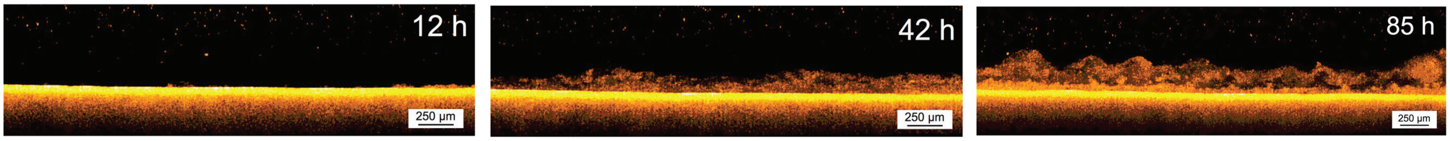
The OCT images shown on this page were obtained while the biofilms were in water, and the resulting visualizations reveal the morphology and fine structure of the biomass.

The ThorImage®OCT software enables examination from all angles by allowing the user to rotate and zoom the view. The volume data sets may also be post-processed to show cross-sectional or sectional views, in which multifaceted slices of the volume are shown by specifying the locations of the three orthogonal planes. This is illustrated by the images shown below.

The biofilm image on the right was acquired using a Ganymede™ OCT base unit and a standard beam scanning system. The GAN311 and GAN611 base units are recommended for biofilm imaging. The volumetric image dimensions are 1 mm x 1 mm x 1.4 mm (X axis x Y axis x Z axis).



This OCT image shows the complex structure of a biofilm cultivated on a flat sheet membrane. Courtesy of Michael Wagner, Chair of Water Chemistry and Water Technology, Karlsruhe Institute of Technology.

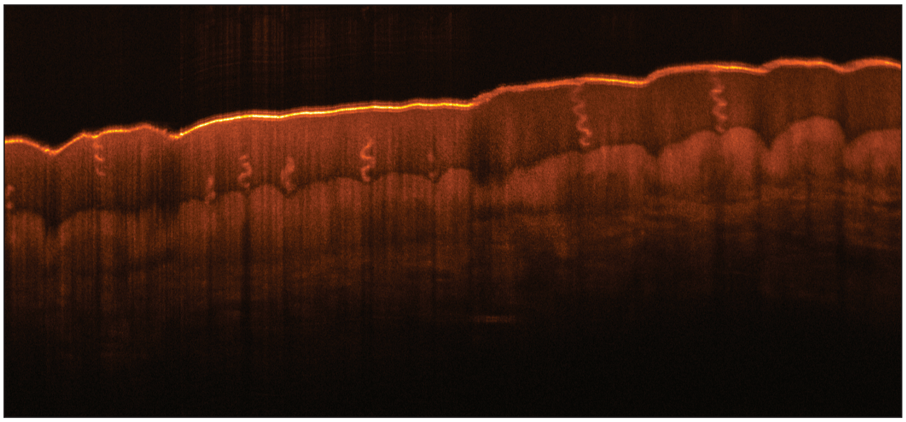


Growth of biofilm on a membrane over several days. The accumulation of biofilm on a membrane leads to a significant reduction in performance and is therefore of interest in many industrial applications. L. Fortunato, S. Jeong, T.O. Leiknes, *Sci. Rep.*, **7**, 15 (2017). Images licensed under a Creative Commons Attribution 4.0 International License. Image adapted from original.

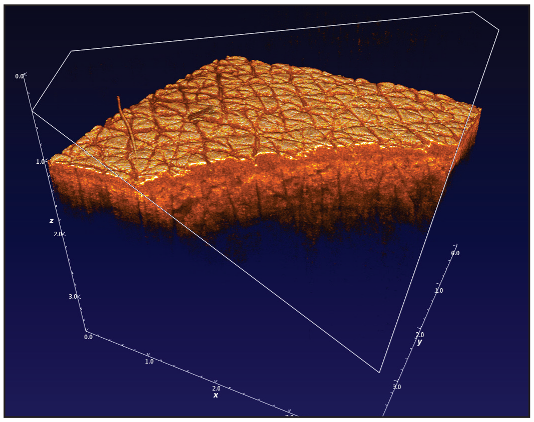
Skin Imaging

OCT imaging can be used to monitor the thickness of skin layers, detect wrinkles, and differentiate between fake and real fingerprints. Scans can be taken quickly and easily with minimal interaction with the subject.

These images were acquired using a standard beam scanner and the Telesto® high-resolution base unit. Stable *in vivo* imaging is facilitated by the use of spacers to minimize motion artifacts, such as the OCT-AIR3, OCT-IMM3, or OCT-IMM4 spacers for standard scanning systems.



In this 2D cross-section of a fingertip, the sweat ducts in the epidermis top layer are clearly visible, as is the underlying dermis.
Dimensions: 6 mm x 3 mm



3D Volumetric Image of a Forearm
Dimensions: 4 mm (X Axis), 4 mm (Y Axis), 3 mm (Z Axis)

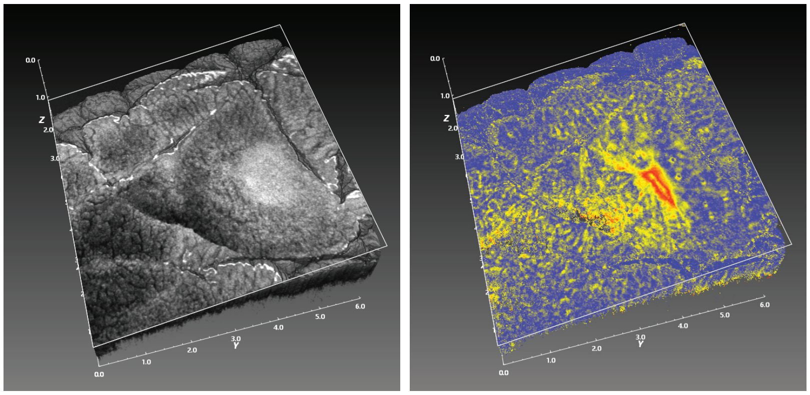
Polarization-Sensitive Imaging

Polarization-sensitive OCT (PS-OCT) systems use a polarization-maintaining design with specialized optics to enable measurement of polarization information in samples. Thorlabs' robust PS-OCT systems do not require calibration and are easy and intuitive to use.

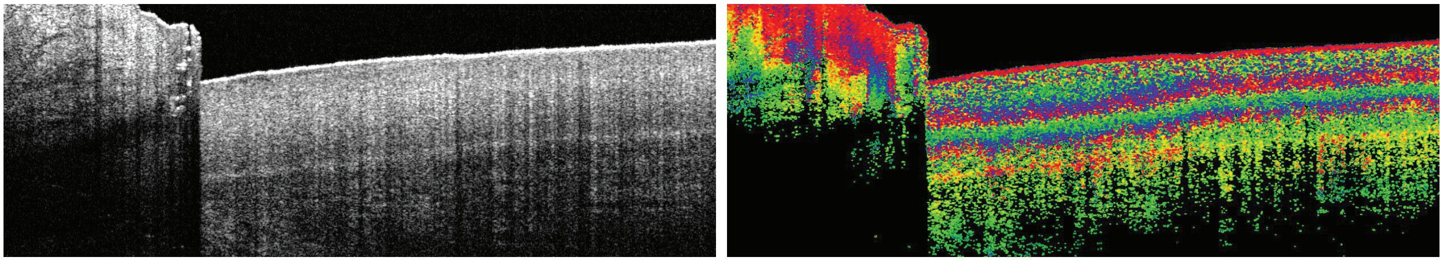
The examples shown here demonstrate the multifaceted capabilities of this cutting-edge technology, as measured using our Telesto® PS-OCT system. The grayscale images combine the intensity recorded by the twin detectors. Since each detector measures orthogonal linear polarizations of light, this eliminates banding that would occur in a traditional OCT system from birefringence in the sample.

For comparison to the grayscale intensity image of each sample, each colored image displays a mode for interpreting the polarization information, i.e., cumulative retardation, optic axis, or degree of polarization uniformity (DOPU). The mode ideal for each application depends on the birefringence properties of the sample.

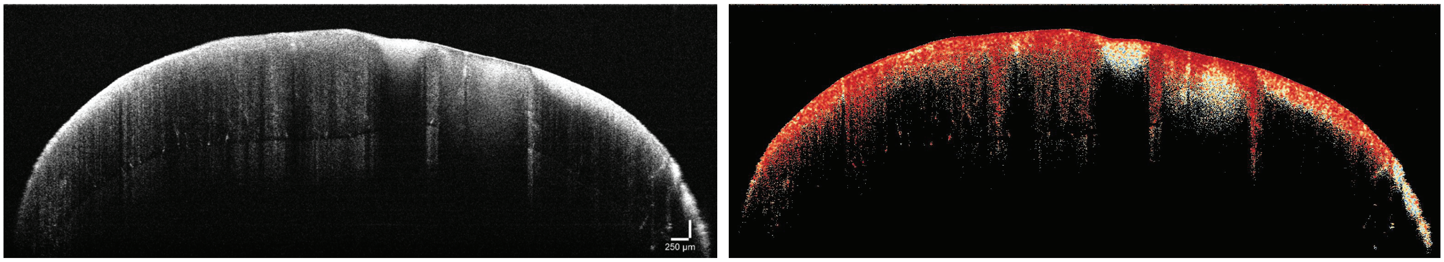
For example, the scar tissue (right) and fingernail (below) cause a distinct change in polarization made visible by the cumulative retardation and optic axis modes, respectively. The tooth (bottom of the page), on the other hand, causes depolarization as the sample scatters the polarized light back as non-polarized light. This effect is clearly visualized in the DOPU image, but would not be observed in either of the other two polarization modes.



In the total intensity OCT image (left), both scarred and unscarred skin appear indistinguishable. In the cumulative retardation image (right), however, the unscarred skin tissue gives a uniform signal while the scarred tissue is easily distinguished by the change in collagen structure causing retardation.
Dimensions: 6 mm (X Axis), 6 mm (Y Axis), 3.5 mm (Z Axis)



Skin is on the left and fingernail is on the right in both the intensity (left) and polarization (right) images of this nail bed. Compared to the skin tissue where only certain interfaces induce a change in the optic axis, the regularly oriented structure of the fingernail leads to a continuous change in the optic axis signal, appearing as strata.
Dimensions: 4.5 mm x 1.5 mm

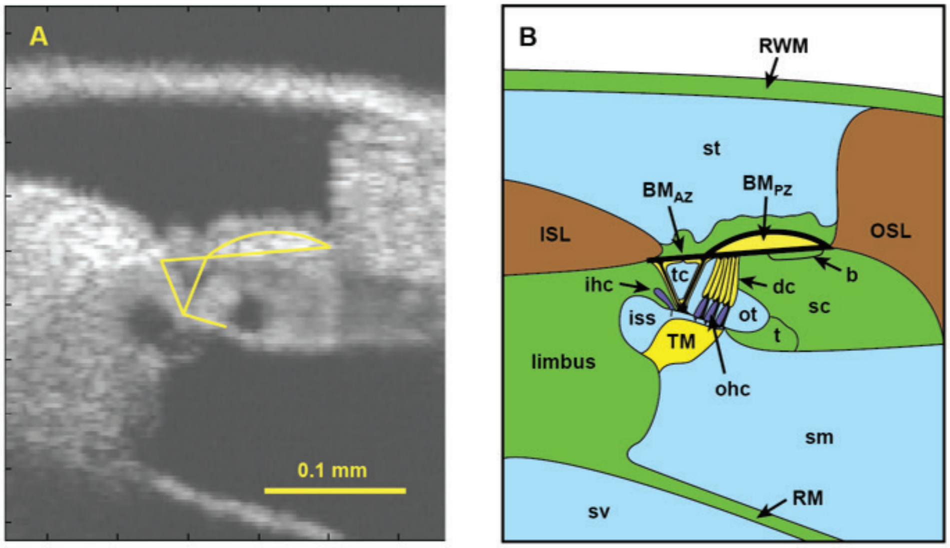


Caries lesions in the enamel of a tooth cause a destruction of the ordered structure. Although similar in intensity (left), light reflected off the lesion becomes depolarized compared to healthy enamel, as seen in the DOPU image (right).
Images Taken in Collaboration with H. Schneider, University Medical Center Leipzig, Germany
Dimensions: 10 mm x 3.5 mm

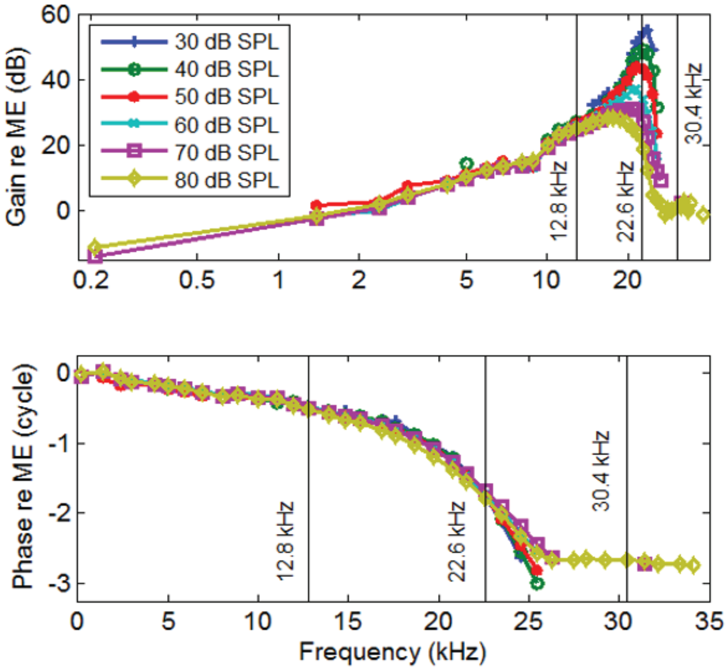
Vibrometry

Several of the biomechanical mechanisms underlying the function of the mammalian inner ear have not been well understood because of difficulties in the microscopic scale of the structures and *in vivo* accessibility. The imaging depth and high speed offered by Thorlabs' new OCT systems facilitate new avenues of investigation into micromechanics, such as in this application. While a Telesto® system was used in this experiment, the Ganymede™ system offers even higher speeds at much finer resolution, opening up further opportunities for OCT research. Both Ganymede and Telesto OCT systems can be externally triggered using TTL pulses to align external excitation with OCT detection, as was done in this experiment with an acoustic stimulation system and a Telesto system.

Operating at a central wavelength of 1300 nm, the Telesto system provided cross-sectional and axial images at a sampling rate of 111.6 kHz. Cooper, et al. were able to image the inner cochlea of a gerbil with unprecedented spatial resolution by going through the round window. As shown in the images to the right, the cross-sectional intensity image of a living, intact gerbil cochlea could be directly mapped onto known anatomical structures.



Cross Section of the Gerbil Cochlear Partition: *In Vivo* OCT Image (Left) and Schematic Diagram (Right); Key Visible Structures: Basilar Membrane (BM), Round Window Membrane (RWM), Inner/Outer Spiral Lamina (ISL/OSL), Tectorial Membrane (TM), and Reissner's Membrane (RM). Images Courtesy of N.P. Cooper, A. Vavakou, and M.V.D. Heijden, Nature Communications **9,** 3054 (2018)



Basilar Membrane Tuning Measured by OCT Vibrometry Shown as Magnitude and Phase Curves, Normalized by Stapes Motion. Data Courtesy of Marcel van der Heijden of Erasmus MC Rotterdam.

Vibration measurements (M-scans) were taken at specific loci in the XY plane guided by the intensity images. M-scans are axial OCT images taken at a single spot over time. At each locus, a series of about 1.5 million M-scans were recorded, so the movement of each structure could be determined in response to the input sound wave, normalized for the motion of the stapes. By analyzing the phase of the OCT signal instead of the intensity, a much higher axial resolution can be achieved, enabling vibrometry measurements with noise-floors down to ~3 pm/√Hz in the middle ear.

The magnitude of the vibration response in the basilar membrane is shown in the top-left graph. Since both the sound generation and vibration detection were triggered at the same time using TTL pulses, the phase shift between excitation and response of the cochlea could be analyzed (see bottom-left graph).

About Swept-Source OCT

Long-Range Imaging at High Scan Rates

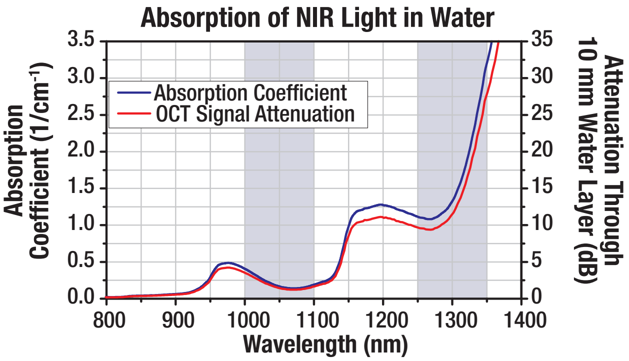
Swept-source OCT (SS-OCT) base units achieve an impressive imaging depth range while delivering high A-Scan rates. Swept-wavelength laser sources emit a narrow linewidth laser beam with long coherence length. During operation, the center wavelength of this single mode emission is quickly tuned across a broad spectral range. As the wavelength sweeps, a detector records the backscattered intensity from the sample as a function of time (wavelength).

Because the laser's power is always concentrated at a single wavelength, instead of spread across a wide spectral width, it produces a stronger backscattered signal at each wavelength than is possible with a broadband source possessing comparable total output power.

Note that optical absorption and scattering effects of the specimen frequently limit the depth to which the light probe can penetrate. For an OCT system to provide valid measurements over the full quoted imaging depth range, the light probe must be able to penetrate the sample to a depth equal to the imaging depth.

Thorlabs' Vega and Atria systems use embedded swept-wavelength laser sources.

Selecting a Wavelength

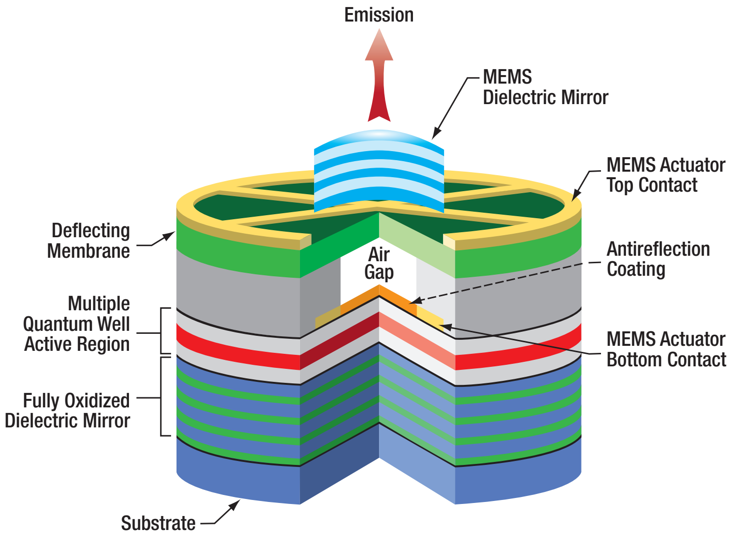


Samples in solution are often difficult to image due to water absorption bands. The Atria systems have a center wavelength 1060 nm, which exhibits much lower absorption compared to the 1300 nm center wavelength of the Vega systems.

MEMS-VCSEL Source for OCT

The swept laser source is a vertical cavity surface emitting laser (VCSEL) that possesses a micro-electromechanical (MEMS) mirror and a single-longitudinal-mode cavity. The laser operates mode-hop-free throughout its entire tuning range, which is in excess of 100 nm.

The laser was developed by Praevium Research in collaboration with Thorlabs and MIT. It overcomes the modest output power and wavelength tuning ranges that characterize other VCSELs through its low mass MEMS mirror and the use of a semiconductor optical amplifier (SOA), which also makes the output more uniform across the spectrum.

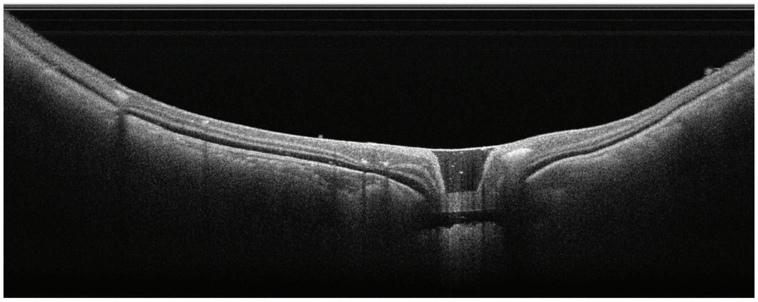


Atria® and Vega™ Series OCT Base Units

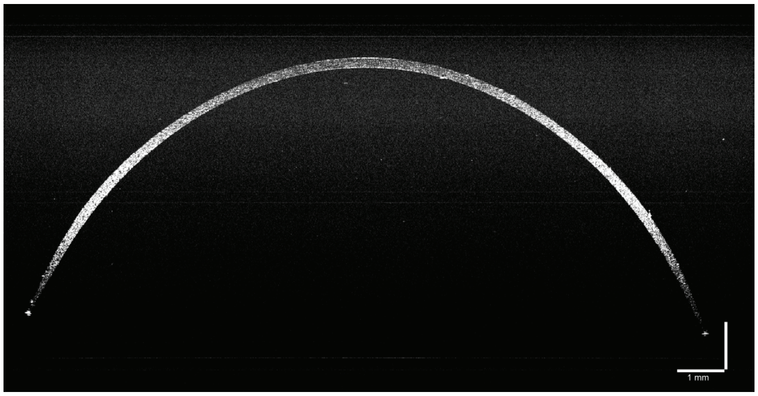
Long-Range Imaging at High Resolution

We offer an array of SS-OCT base units that are tuned for either imaging depth or imaging power. Our ATR206 base unit offers the deepest imaging capabilities of all Thorlabs OCT systems at 20 mm in air. The faster 200 kHz A-Scan rate of the ATR220 base unit reduces the imaging depth to 6.0 mm in air. Both Atria units operate at 1060 nm which exhibits relatively little attenuation through water compared to other near-IR wavelengths, making them well suited for aqueous samples like the vitreous fluid of an eye or contact lenses suspended in water.

Vega base units provide lower imaging depths but operate at a higher power. This allows the VEG210 and VEG220 base units to produce high contrast images, depending on the sample in question. Both the Atria and Vega base units offer the benefits of a swept source laser source. Choosing the right system depends on the sample of interest.



An image of model human retina highlighting the connection of the optical nerve.

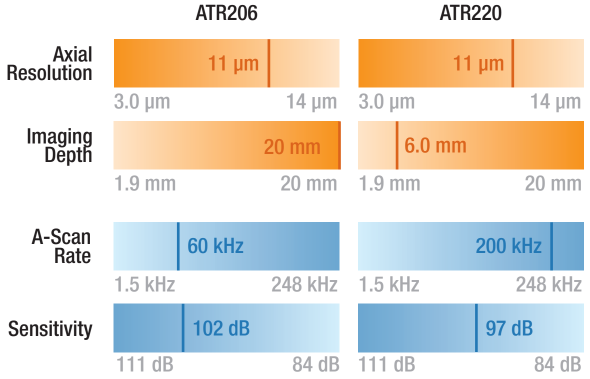


An image of a contact lens submerged in 7 mm of water; OCT can be used to examine lenses like this for shape and manufacturing errors.

Specifications

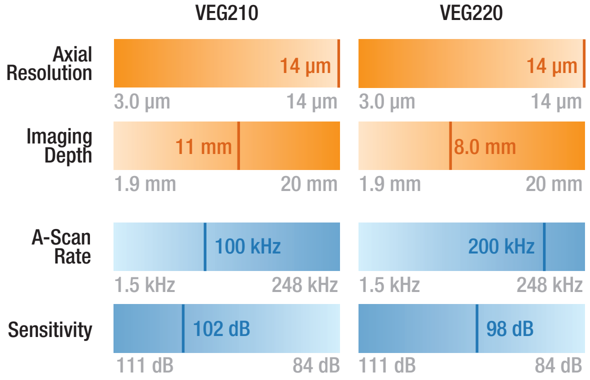
Long-Range Imaging at High Resolution

OCT Base Unit	ATR206	ATR220
Center Wavelength	1060 nm	
Light Source	Swept-Wavelength MEMS VCSEL	
Axial Resolution (Air/Water)	11 µm / 8.3 µm	
Imaging Depth (Air/Water)	20 mm / 15 mm	6.0 mm / 4.5 mm
A-Scan Line Rate	60 kHz	200 kHz
Sensitivity	102 dB	97 dB



Deep Imaging in Scattering Media

OCT Base Unit	VEG210	VEG220
Center Wavelength	1300 nm	
Light Source	Swept-Wavelength MEMS VCSEL	
Axial Resolution (Air/Water)	14 µm / 10.6 µm	
Imaging Depth (Air/Water)	11 mm / 8.3 mm	8.0 mm / 6.0 mm
A-Scan Line Rate	100 kHz	200 kHz
Sensitivity	102 dB	98 dB



Telesto® Series OCT Base Units

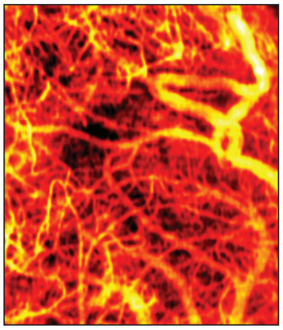
Deep and High-Resolution Imaging in Scattering Media

Deep imaging in scattering media is enabled in part by having the Telesto® light sources operating at center wavelengths of 1300 nm or 1325 nm, as scattering effects are less pronounced at longer wavelengths. In general, axial resolution is better when the OCT light source possesses a higher bandwidth. Because of this, all of our spectral domain OCT base units include superluminescent diodes (SLDs) with broad spectral widths.

The 1325 nm SLD sources in the Telesto long-range OCT base units (TEL211 and TEL311) achieve deep imaging in scattering media, such as tissue. The Telesto high-resolution OCT base units (TEL221 and TEL321) adapt the Telesto design to achieve even finer resolution. This is done in part by coupling the emission of two SLDs with offset center wavelengths, which further increases the bandwidth of the OCT light source.

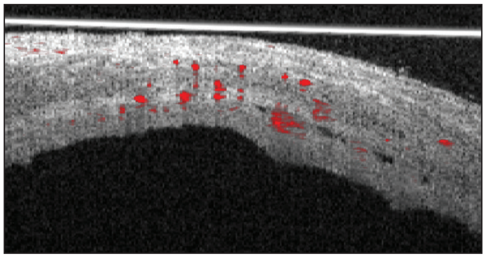
The most significant difference between the two Telesto high-resolution OCT base units, as well as between the two Telesto deep imaging versions, is the maximum A-Scan rate. A-Scan rates of up to 76 kHz can be specified for the standard versions, and rates up to 146 kHz can be achieved by the high-speed versions. The standard and high-speed versions for each model produce equal image quality when the two operate at the same speed.

Sensitivity improves as the A-Scan rate decreases. The user can tune the sensitivity of each Telesto OCT base unit by adjusting its A-Scan rate; decreasing the A-Scan rate increases the sensitivity of the OCT system by enabling longer integration times.



The *en face* view at left shows the vascular system of a sheep's ovary produced using speckle variance OCT and a TEL221 base unit. *Dimensions: 2.3 mm x 2.6 mm*

The 2D OCT profile view (B-Scan) below shows red vascular highlights located using speckle variance OCT and overlaid on the OCT image. Scans were acquired using the OCT-IMM3 Z-Spacer to achieve deeper imaging into the sample.
Dimensions: 2.4 mm x 1.5 mm



Images Acquired in Collaboration with Vassilis Sboros from Heriot-Watt University and Colin Duncan at the MRC Centre for Reproductive Health, The University of Edinburgh

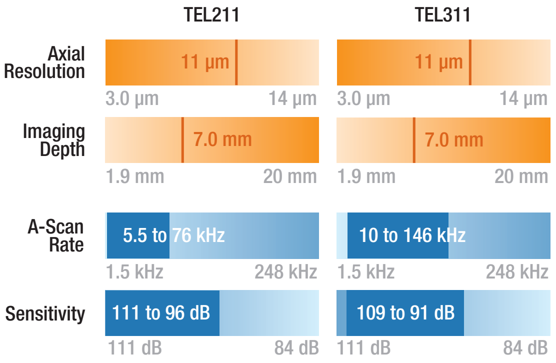
Specifications

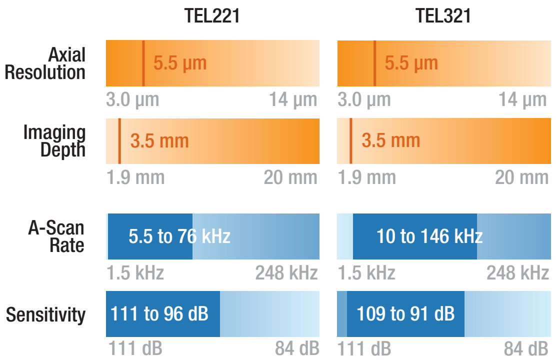
Deep Imaging in Scattering Media

OCT Base Unit	TEL211	TEL311
Center Wavelength	1325 nm	
Light Source	Single SLD	
Axial Resolution (Air/Water)	11 µm / 8.3 µm	
Imaging Depth (Air/Water)	7.0 mm / 5.3 mm	
A-Scan Rate	5.5 kHz to 76 kHz	10 kHz to 146 kHz
Sensitivity	96 dB - 111 dB (76 kHz - 5.5 kHz)	91 dB - 109 dB (146 kHz - 10 kHz)

High Axial Resolution in Scattering Media

OCT Base Unit	TEL221	TEL321
Center Wavelength	1300 nm	
Light Source	Dual SLD, Extended Bandwidth	
Axial Resolution (Air/Water)	5.5 µm / 4.2 µm	
Imaging Depth (Air/Water)	3.5 mm / 2.6 mm	
A-Scan Rate	5.5 kHz to 76 kHz	10 kHz to 146 kHz
Sensitivity	96 dB - 111 dB (76 kHz - 5.5 kHz)	91 dB - 109 dB (146 kHz - 10 kHz)





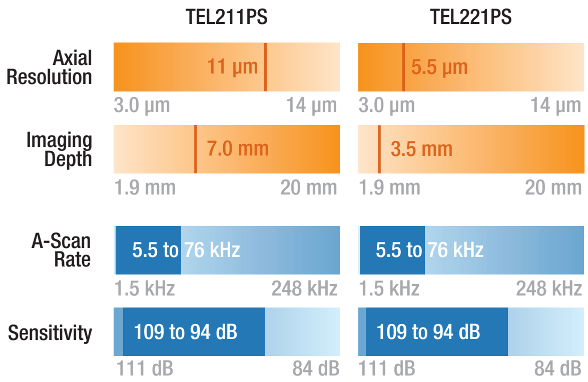
Telesto® Series PS-OCT Base Units

Polarization-Sensitive OCT (PS-OCT) Imaging

The Telesto® PS-OCT base units (TEL211PS and TEL221PS) build on the basic Telesto design, incorporating a dual-detector design and specialized optics to enable the capture of polarization information as well as high-quality intensity images. This polarization information can be characterized as cumulative retardation, optic axis, or degree of polarization uniformity (DOPU), providing an additional layer of contrast to a standard OCT image. The additional contrast may reveal typically unobserved features that result from the internal microstructure of samples (e.g. tissue, plastic, or crystals).

Specifications

OCT Base Unit	TEL211PS	TEL221PS
Center Wavelength	1325 nm	1300 nm
Light Source	Single SLD	Dual SLD, Extended Bandwidth
Axial Resolution (Air/Water)	11 µm / 8.3 µm	5.5 µm / 4.2 µm
Imaging Depth (Air/Water)	7.0 mm / 5.3 mm	3.5 mm / 2.6 mm
A-Scan Rate	5.5 kHz to 76 kHz	
Sensitivity	94 dB – 109 dB (76 kHz – 5.5 kHz)	



Complete PS-OCT System

A complete PS-OCT system consists of one base unit, a scanning system, and a scan lens kit, as described by the schematic diagram to the right. The base unit houses the superluminescent diode (SLD) broadband source and polarization-sensitive detection module, while the scanning system contains both arms of the interferometer, including two quarter-wave plates.

Starting with the linearly polarized light from the SLD, the quarter-wave plate in the reference arm orients the light returning to the beamsplitter at a 45° angle relative to the input light. The quarter-wave plate in the sample arm causes circularly polarized light to be incident on the sample. At the detection module, the light from both arms is split into its two orthogonal linear polarization components, sending one orientation to Sensor 1 and the other to Sensor 2.

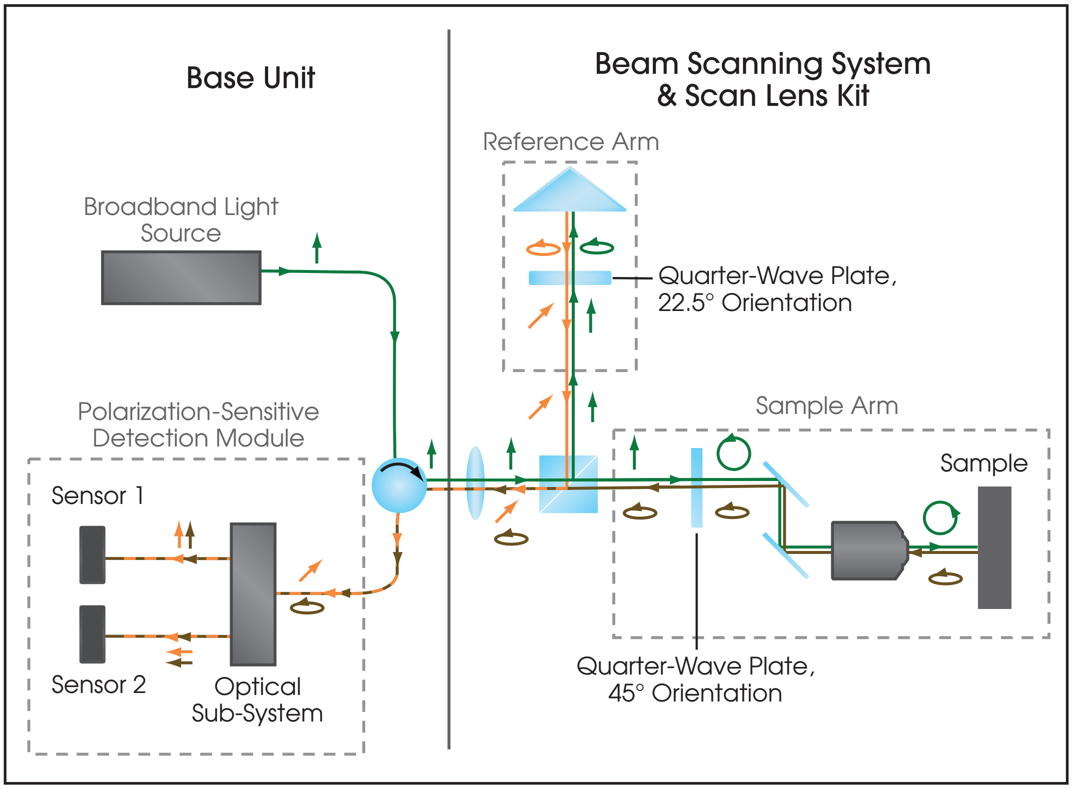


Diagram of Complete Telesto PS-OCT System, including Base Unit, Scanning System, and Lens Kit

The interference of the components from each arm provides the polarization information which the PS-OCT system can use to calculate the Stokes vectors for each image point, which are the basis for the special polarization modes of this OCT system. The dual-detector system also removes birefringence-induced extinction banding effects from intensity images.

Ganymede™ Series OCT Base Units

High-Resolution Imaging

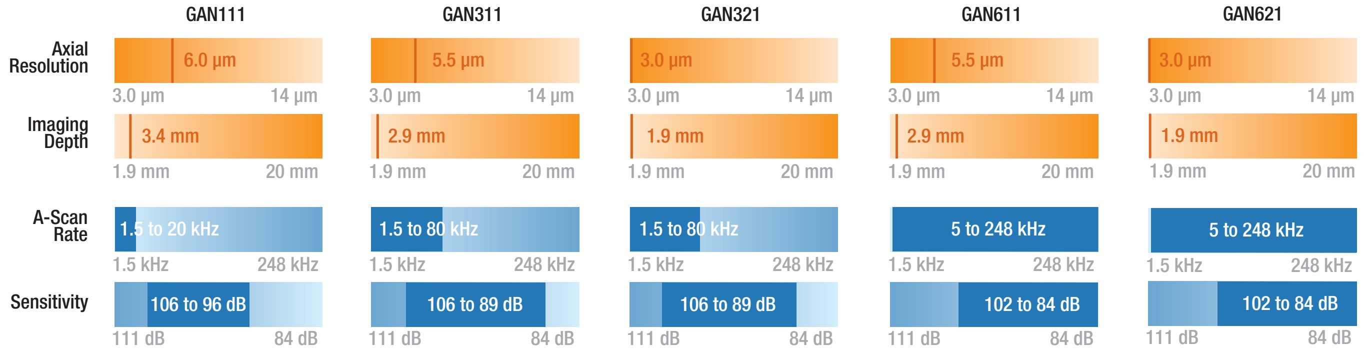
Our GAN321 and GAN621 very-high-resolution base units feature Thorlabs' highest resolution OCT imaging capability and operate at a center wavelength of 900 nm. The 3.0 µm axial resolution in air translates into even better resolution in more optically dense media, such as tissue. This performance is achieved through optimized system design, operation around 900 nm, and use of an extended bandwidth light source.

The GAN311 and GAN611 high-resolution units operate at a center wavelength of 930 nm, while the GAN111 unit operates at a center wavelength of 880 nm. It is possible to tune the sensitivity of these base units by adjusting the A-Scan rate; decreasing the A-Scan rate increases the sensitivity of the OCT system by enabling longer integration times. Due to the low absorption of water at 900 nm, the Ganymede OCT base units are our recommended choice for imaging samples in water.

Specifications

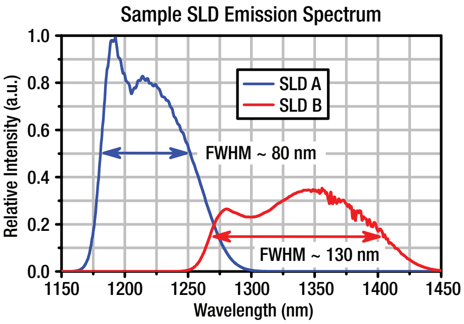
High Axial Resolution

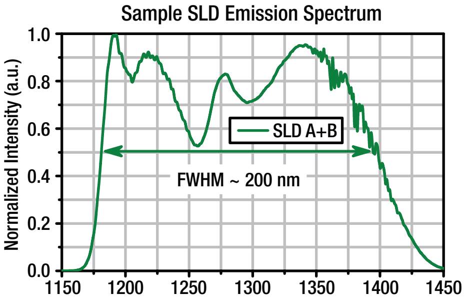
OCT Base Unit	GAN111	GAN311	GAN321	GAN611	GAN621
Center Wavelength	880 nm	930 nm	900 nm	930 nm	900 nm
Light Source	Single SLD	Single SLD	Dual SLD, Extended Bandwidth	Single SLD	Dual SLD, Extended Bandwidth
Axial Resolution (Air/Water)	6.0 µm / 4.5 µm	5.5 µm / 4.1 µm	3.0 µm / 2.2 µm	5.5 µm / 4.1 µm	3.0 µm / 2.2 µm
Imaging Depth (Air/Water)	3.4 mm / 2.5 mm	2.9 mm / 2.2 mm	1.9 mm / 1.4 mm	2.9 mm / 2.2 mm	1.9 mm / 1.4 mm
A-Scan Line Rate	1.5 kHz to 20 kHz	1.5 kHz to 80 kHz		5 kHz to 248 kHz	
Sensitivity	96 dB – 106 dB (20 kHz – 1.5 kHz)	89 dB – 106 dB (80 kHz – 1.5 kHz)		84 dB – 102 dB (248 kHz – 5 kHz)	



Extended-Bandwidth Sources for High-Resolution Imaging

The extended-bandwidth sources in our very-high-axial-resolution 900 nm Ganymede (GAN321 and GAN621) and 1300 nm Telesto (TEL221, TEL221PS, and TEL321) spectral domain OCT base units combine the emission of a pair of hand-picked SLDs. The extended-range light source used in the TEL221, TEL221PS, and TEL321 has a spectrum similar to that of the combined A and B SLDs, shown in the graphs below. In contrast, the Telesto long-range systems use SLDs with emission spectra similar to SLD B.





OCT System Component Overview

OCT Base Units[a]

Item #	**Atria ATR206**	**Atria ATR220**	**Ganymede GAN111**	**Ganymede GAN311**	**Ganymede GAN611**	**Ganymede GAN321**	**Ganymede GAN621**
OCT System Type	Swept Source		Spectral Domain				
Key Performance Feature(s)	High Resolution		High Resolution	High Resolution		Very High Resolution	
	Ultra-Long Range	Long-Range		High Speed			
Center Wavelength	1060 nm		880 nm	930 nm		900 nm	
Light Source	MEMS-VCSEL		Single SLD	Single SLD		Dual SLD	
Optical Bandwidth	>100 nm		>70 nm	>100 nm		>170 nm	
Axial Resolution (Air/Water)	11 µm / 8.3 µm		6.0 µm / 4.5 µm	5.5 µm / 4.1 µm		3.0 µm / 2.2 µm	
Imaging Depth[b] (Air/Water)	20 mm / 15 mm	6.0 mm / 4.5 mm	3.4 mm / 2.5 mm	2.9 mm / 2.2 mm		1.9 mm / 1.4 mm	
A-Scan Rate	60 kHz	200 kHz	1.5 – 20 kHz	1.5 – 80 kHz	5 – 248 kHz	1.5 – 80 kHz	5 – 248 kHz
Sensitivity	102 dB	97 dB	96 to 106 dB (20 to 1.5 kHz)	89 to 106 dB (80 to 1.5 kHz)	84 to 102 dB (248 to 5 kHz)	89 to 106 dB (80 to 1.5 kHz)	84 to 102 dB (248 to 5 kHz)

Item #	**Vega VEG210**	**Vega VEG220**	**Telesto TEL211PS**	**Telesto TEL221PS**	**Telesto TEL211**	**Telesto TEL311**	**Telesto TEL221**	**Telesto TEL321**
OCT System Type	Swept Source		Spectral Domain					
Key Performance Features	Long-Range Imaging		Polarization-Sensitive Imaging		Long-Range Imaging		High Resolution	
	General Purpose	High Speed	High Imaging Depth	High Resolution	General Purpose	High Speed	General Purpose	High Speed
Center Wavelength	1300 nm		1325 nm	1300 nm	1325 nm		1300 nm	
Light Source	MEMS-VCSEL		Single SLD	Dual SLD	Single SLD		Dual SLD	
Optical Bandwidth	>100 nm		>100 nm	>170 nm	>100 nm		>170 nm	
Axial Resolution (Air/Water)	14 µm / 10.6 µm		11 µm / 8.3 µm	5.5 µm / 4.2 µm	11 µm / 8.3 µm		5.5 µm / 4.2 µm	
Imaging Depth[b] (Air/Water)	11 mm / 8.3 mm	8.0 mm / 6.0 mm	7.0 mm / 5.3 mm	3.5 mm / 2.6 mm	7.0 mm / 5.3 mm		3.5 mm / 2.6 mm	
A-Scan Rate	100 kHz	200 kHz	5.5 – 76 kHz			10 – 146 kHz	5.5 – 76 kHz	10 – 146 kHz
Sensitivity	102 dB	98 dB	94 to 109 dB (76 to 5.5 kHz)		96 to 111 dB (76 to 5.5 kHz)	91 to 109 dB (146 to 10 kHz)	96 to 111 dB (76 to 5.5 kHz)	91 to 109 dB (146 to 10 kHz)

a. The OCT base units include a high-performance desktop computer, monitor, and necessary cabling.

b. Optical absorption and scattering can limit the penetration of the light probe into a sample. For an OCT system to provide valid measurements over the full quoted imaging depth range, the light probe must be able to penetrate the sample to a depth equal to the imaging depth.

Scan Lens Kits

Item #	**OCT-LK2**	**OCT-LK3**	**OCT-LK4**	**OCT-LK5**
Compatible Scanner	Standard: OCTG13[a], OCTG13PS[b], or OCTG-1300NR[c] User-Customizable: OCTP-1300(/M)[a], OCTP-1300PS(/M)[b], or OCTP-1300NR(/M)[c]			Standard: OCTG-1300NR[c] User-Customizable: OCTP-1300NR(/M)[c]
Design Wavelength	1300 nm / 1325 nm			
Lateral Resolution[f]	7 µm	13 µm	20 µm	41 µm
Focal Length	18 mm	36 mm	54 mm	110 mm
Working Distance	3.4 mm[g]	24.9 mm[g]	41.6 mm[g]	92.9 mm
Field of View	6 mm x 6 mm	10 mm x 10 mm	16 mm x 16 mm	30 mm x 30 mm
Item #	**OCT-LK2-BB**	**OCT-LK3-BB**	**OCT-LK4-BB**	**OCT-LK5-BB**
Compatible Scanner	Standard: OCTG9[d] and OCTG11NR[e] User-Customizable: OCTP-900[d] and OCTP11NR[e]			Standard: OCTG11NR[e] User-Customizable: OCTP11NR(/M)[e]
Design Wavelength	880 nm / 900 nm / 930 nm / 1060 nm			
Lateral Resolution (900 nm/930 nm)[f]	4 µm	8 µm	12 µm	24 µm
Lateral Resolution (1060 nm)[f]	5 µm	9 µm	13 µm	26 µm
Focal Length	18 mm	36 mm	54 mm	110 mm
Working Distance	3.4 mm[g]	24.9 mm[g]	41.6 mm[g]	92.9 mm
Field of View	6 mm x 6 mm	10 mm x 10 mm	16 mm x 16 mm	30 mm x 30 mm

a. Compatible with Telesto Base Units

b. Compatible with Telesto PS Base Units

c. Compatible with Vega Base Units

d. Compatible with Ganymede Base Units

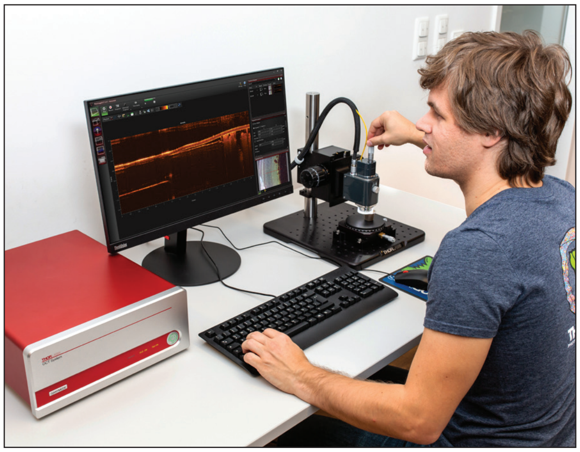
e. Compatible with Atria Base Units

f. 1/e^2 Beam Diameter at Focus

g. The working distance is limited due to the illumination tube, which can be removed.

Thorlabs' OCT products are for research purposes only.

Application Support


A Ganymede™-Based OCT System in our Lübeck, Germany Demo Room

Modular designs, flexible configurations, and a wide variety of components and accessories allow Thorlabs' OCT systems to be seamlessly integrated into any laboratory, research and development, or industry environment. We encourage customers to partner with our dedicated OCT application engineers to identify the optimal system configuration that meets their individual imaging requirements.

Additionally, we have dedicated lab space in our Sterling, Virginia and Lübeck, Germany facilities where our engineers can configure an ideal OCT system and test it under specific application conditions. After testing, we provide comparative data to further guide the decision-making process. For larger feasibility studies, Thorlabs offers extensive support to validate OCT imaging processes and provides statistical data for larger sample quantities. Please contact us to discuss such potential projects.

We have implemented OCT imaging solutions for a wide range of applications in various fields with different levels of customization. The solution for your application will be based on our extensive experience in designing and manufacturing hundreds of active systems in the field.

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