

Ophthalmic Optical Interferometry Applications of SLDs

Relationship between depth resolution of SD-OCT and
spectrum width of SLD light source

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1 Introduction

SD-OCT (Spectral Domain Optical Coherence Tomography) using optical interferometry is used widely in ophthalmic examination equipment for fundus tomography and measurement of eye-axis length. SLD (Super-Luminescent Diode) light sources with a center wavelength of around 850 nm are used widely in ophthalmic devices due to low absorption of this wavelength by water. This paper begins with a brief explanation of SLD light sources, followed by a discussion of fundus OCT measurement using SLDs, a myopia test examination device, and required key SLD performance.

2 SLD and SD-OCT Overview

An SLD light source has an output power equivalent to an LD (laser diode) and a wide spectrum width equivalent to an LED (Light Emitting Diode), as well as low coherence. It emits oscillation-free light by spontaneous emission. Since light is emitted similarly to an LD from a narrow active layer, it features excellent myocoupling efficiency with optical fiber, and has properties similar to a combination of an LD and LED.

SD-OCT is a technique that uses interference spectra using an SLD light source and spectrometer to acquire interference spectra to image internal structure at high resolution non-invasively.

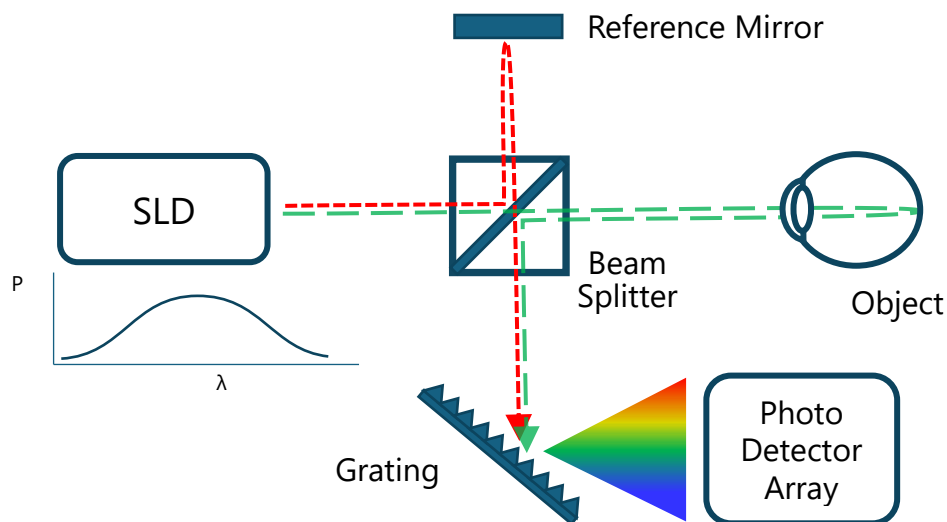


Fig. 2.1 SD-OCT Principle

3 Optical Interferometry Types and Overview

3.1 Fundus OCT

Fundus OCT is used to scan the retina to capture tomography images and diagnose abnormalities. The light penetrates the interior of the fundus, allowing observation of the tomographic structures as well as the surface of the retina. In addition to capturing pictures like a conventional fundus camera, this advanced technology can observe the fundus in three dimensions. Consequently, it is used widely in examination and diagnosis of glaucoma, age-related macular degeneration, etc.

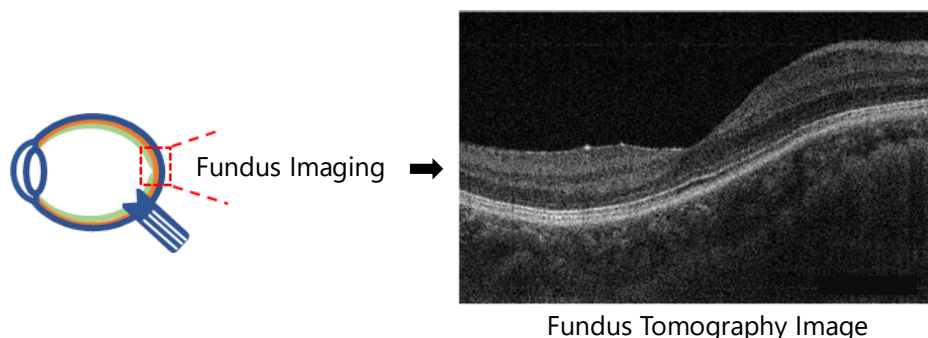


Fig. 3.1 Ophthalmic Measurement of Fundus using OCT

3.2 Eye-Axis Myopia Tester

One cause of myopia is the axial elongation of the eyeball, meaning that the image entering the eye is no longer focused on the retina. Figure 3.2 illustrates the normal vision and myopia conditions. The distance from the surface of the eyeball to the retina is called the "eye-axis length", and the Eye-Axis Myopia Tester evaluates the myopia degree by measuring this length.

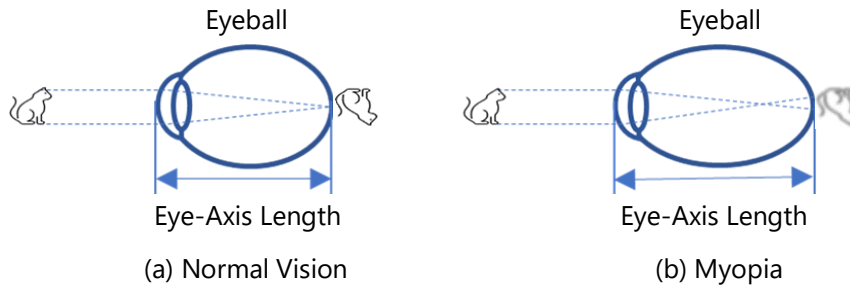


Fig. 3.2 Normal Vision and Myopia

The Survey on Myopia in Children and Students reported by the Japanese Ministry of Education, Culture, Sports, Science and Technology in 2021¹⁾ estimates that the world population of people with myopia will increase to 4.8 billion by 2050. According to various opinions, myopia can be caused and progressed by a combination of genetic factors and by looking closely at smartphones or computer screens, etc., for long hours.

4 Required Depth Resolution of Ophthalmic Inspection Instruments

Fundus tomograms must show isolated fundus cell layers. This section discusses the depth resolution required for fundus OCT using the tomogram image in Fig. 4.1. Scales of 2 mm, 1 mm, 100 μm , and 10 μm are included to compare the thickness of each cell layer. A depth resolution of about 10 μm is required to recognize the thinnest cell layer in this fundus image.

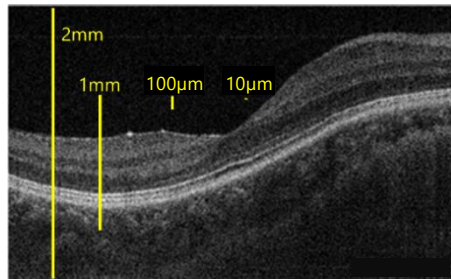


Fig. 4.1 Fundus Tomography Image

What resolution does an eye myopia tester require to measure the eyeball-axis length and examine myopia? Several papers describe the relationship between eye-axis length and myopia^{2),3)}. Although each paper uses different values, this discussion presumes that "1 mm of eye-axis length elongation corresponds to a change from -2.00 D to -2.50 D" where D means diopter, a unit expressing the power of eyeglasses or contact lenses in increments of 0.25. If a 1-mm difference in eye-axis length corresponds to a 2.00 D difference, the value of D changes in 8 steps. Therefore, eye-axis length elongation should be measured with a resolution of at least 1/10 of 1 mm (100 μm) to evaluate the myopia condition. More accurate measurement of eye-axis length is required when replacing the eye lens with an intraocular lens due to cataracts, etc.

This section describes the parameters determining OCT depth resolution. As an example, when using a light source with a Gaussian-distributed spectrum in air, the OCT depth resolution Δz is expressed by the following equation⁴⁾.

$$\Delta z = \frac{2 \ln 2}{\pi} \frac{\lambda_c^2}{n \Delta \lambda}$$

where λ_c is the center wavelength of the light source, $\Delta\lambda$ is the spectrum full width at half maximum (hereafter, spectrum width) of the light source, and n is the refractive index, which is assumed to be about 1.3 because the interior of the eye is assumed to be almost entirely water. Wider half-widths result in a better depth resolution, Δz . The required SLD spectrum width is estimated from this equation.

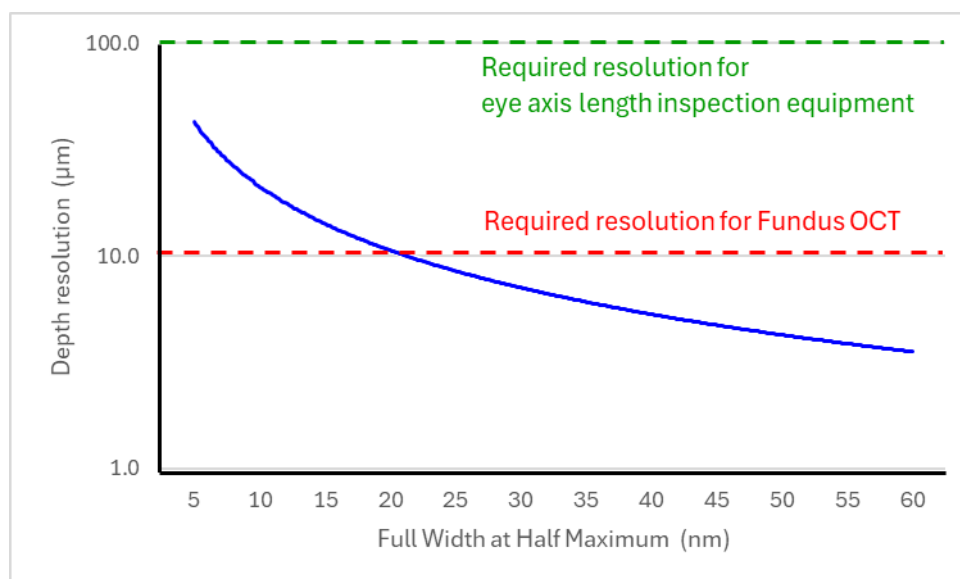


Fig. 4.2 Spectrum Width Dependency of Depth Resolution on OCT

A depth resolution of about 10 μm is considered necessary for fundus OCT. At a center wavelength, λ_c , of 850 nm, the calculated required spectrum width is about 21 nm, and a spectrum width of 50 nm gives a depth resolution of 4.3 μm for even higher-resolution measurements.

To achieve the 100- μm depth resolution required by myopia testers, the estimated spectrum width is 2.5 nm, and a depth resolution of 16.3 μm can be achieved with a spectrum width of 15 nm, which is more accurate than the required resolution.

Table 4.1 Required Resolution and Spectrum Width on Ophthalmic Examination Instruments

Ophthalmic Examination Instruments	Required Depth Resolution	Spectrum Width
Eye-Axis Myopia Tester	100 μm	≥ 2.5 nm
Fundus OCT	10 μm	≥ 25 nm

5 Anritsu's SLD Products

Anritsu supplies a wideband SLD light source for use in SD-OCT and other applications, contributing to the medical and industrial device markets. Our SLDs in cylindrical, CAN, butterfly, and built-in drive-circuit package configurations cover wavelengths in the 0.8, 1.31, 1.55, and 1.65- μm bands. Ophthalmic applications use the 0.8- μm band due to its low absorption by water. We have a wide selection of products in the 0.8- μm band with a spectrum width ranging from 14 to 50 nm. Depending on the application, different packages are available, such as butterfly modules for fundus OCT, CAN modules for myopia testers, and cylindrical modules. Various optical outputs, center wavelengths, and spectrum widths are available.

Table 5.1 0.8- μm Band SLD Products

Main Application	Model	Package	Optical Power (mW)	Center Wavelength (nm)	Spectrum Width (nm)
Eye-Axis Myopia Tester	AS8K215GY30M	CAN	5	830	15
Eye-Axis Myopia Tester	AS8E210GP30M	Cylindrical	1	830	15
Eye-Axis Myopia Tester	AS8B115GT30M	Butterfly	5	830	14
Fundus OCT	AS8B115LT40MA	Butterfly	5	840	50
Fundus OCT	AM8P4005SL45C	Built-in drive circuit	5.5	840	45
Fundus OCT	AM8P8006SL45G	Built-in drive circuit	7	880	50

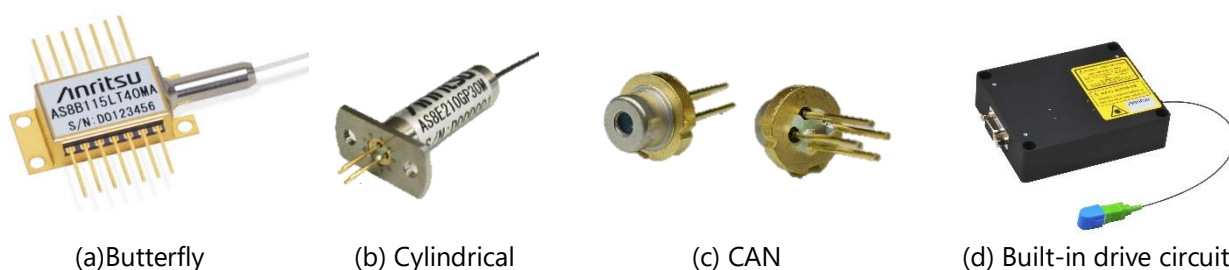


Fig. 5.1 SLD Package Types

Anritsu is continuing with development of various light sources for ophthalmology and other fields.

6 Reference

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