

Wide-band Measurement Technology for the AQ6373B Optical Spectrum Analyzer

Manabu Kojima ^{*1}
Atsushi Horiguchi ^{*1}

Tsutomu Kaneko ^{*1}
Gentaro Ishihara ^{*1}

Toshikazu Yamamoto ^{*1}
Tohru Mori ^{*1}

In line with the advancement of optical communications technology, Yokogawa's technology for optical spectrum measurement has also evolved, centering on spectroscopy using a monochromator. Its wavelength coverage has expanded beyond optical communication bands, ranging from 350 to 2,400 nm. Among Yokogawa's solutions, the AQ6373B covers from 350 to 1,200 nm and accurately measures the characteristics of short-wavelength lasers, LEDs and optical filters. This paper describes the wide-band measurement technology implemented in the AQ6373B.

INTRODUCTION

To date, gas lasers and solid-state lasers have been used in the biomedical and industrial processing equipment fields. These lasers are typically large and consume large amounts of electric power. However, in recent years, these lasers are gradually being replaced with smaller semiconductor lasers that consume less power. In line with the expansion of the semiconductor laser market, research and development of related products is becoming increasingly active. Therefore, there is a growing need for high-performance optical spectrum analyzers to evaluate and analyze optical spectra.

However, many existing compact optical spectrum analyzers, which cover a wide wavelength range including a visible light range required for research and development related to semiconductor lasers, do not have sufficient performance in terms of light sensitivity, dynamic range, or other factors, and this has necessitated construction of a large system using a monochromator. In contrast, the AQ6373B shown in Figure 1 covers an entire visible light range and satisfies users' requirements for measuring a wide wavelength range efficiently using a single instrument. This paper introduces the items of the development, performance, and functions of the AQ6373B.



Figure 1 External view of AQ6373B

MONOCHROMATOR FOR A WIDER WAVELENGTH BAND

The measurable wavelength range of the AQ6373B ranges from 350 nm to 1,200 nm, a wide wavelength range to be covered by a single instrument. This section describes how this wide range has been created.

Lenses for a Wider Wavelength Band

Key components of a monochromator include a collimator mirror and a focusing mirror. Conventionally, these optical components are composed of reflecting optical systems using parabolic mirrors. An alternative to a reflecting optical system is a refracting optical system using lenses. Because requirements for machining accuracy for a refracting type are not particularly strict compared with those for a reflecting type, many component vendors are providing a stable supply of components for refracting optical systems, and their supply is expected to continue to be stable. Refracting optical systems are widely used in consumer products such as cameras and projectors because of this reason. Meanwhile, the most

^{*1} Development & engineering Dept.2,
Yokogawa Meters & Instruments Corporation

important issue that needs to be considered when using lenses is the chromatic aberration that creates differences in focal lengths depending on a particular wavelength. Yokogawa has resolved this problem and developed high-precision triplet lens covering a wide wavelength range. Figure 2 shows the configuration of the newly developed lens set. It is composed of three lenses with different glass materials. Chromatic aberration is eliminated by combining high dispersion glass and low dispersion glass, where the dispersion means variation in refractive indexes depending on a particular wavelength. Figure 3 shows the chromatic aberration characteristics of the developed lens set indicating the ratio of chromatic aberration per a focal length. The peak aberrations in the wavelength range from 350 nm to 1200 nm are +0.08% at 350 nm and -0.02% around 450 nm and at 1200 nm, proving that the chromatic aberration is well compensated for in a wide wavelength range.

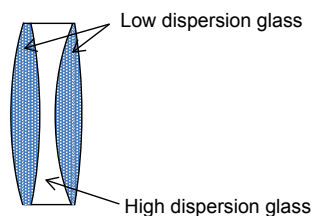


Figure 2 Configuration of the lens set for wider wavelength range

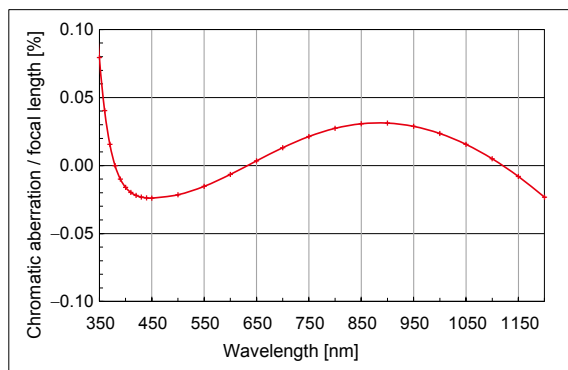


Figure 3 Chromatic aberration characteristics

The radius curvature of the lens is optimally designed to reduce not only chromatic aberration but also aberrations such as spherical and coma aberrations and astigmatism. This makes the spot size at the light emission slit of a monochromator sufficiently small.

Switching Diffraction Order

In a monochromator using a diffraction grating as a wavelength dispersing element, the wavelength characteristic of the diffraction efficiency is the key factor for wider wavelength range measuring. Although the diffraction efficiency can be optimized mainly by the groove shape of a diffraction grating, it is difficult to achieve high diffraction efficiency throughout the wide measurement range of the

AQ6373B by only using diffracted light of a single diffraction order. Accordingly, the AQ6373B switches the diffraction orders between first- and second-order depending on a particular wavelength to be measured, and this ensures highly efficient measuring over the wide wavelength range. Figure 4 shows the ranges to which each diffraction order is applied.

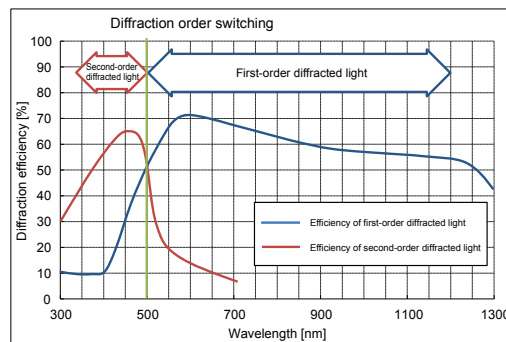


Figure 4 Diffraction efficiency and the ranges to which diffraction orders are applied

Figure 5 shows the incident and reflection angles at a diffraction grating. A diffraction grating reflects the incident light at a different angle depending on the wavelength of the incident light. The relationship between the angle and the wavelength is expressed by the following equation.

$$m\lambda = d (\sin \alpha + \sin \beta) \quad m = 1, 2, \dots$$

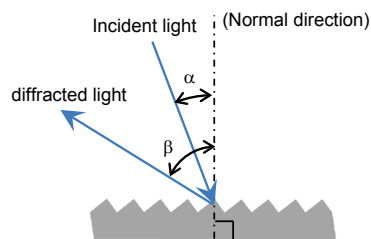


Figure 5 Incident angle and reflection angle at a diffraction grating

In this equation, λ is a wavelength of a light, α is an incident angle, β is a reflection angle, d is a groove spacing, and m is a diffraction order. The reflection direction of light of wavelength λ is not unique but the light is reflected in multiple directions corresponding to a diffraction order m . For example, in the case of the AQ6373B, when measuring second-order diffracted light of wavelength 350 nm to 500 nm, the first-order diffracted light of wavelength 700 nm to 1000 nm, double that of the former light wavelength, overlaps onto it. Therefore, the AQ6373B measures the diffracted light of the desired diffraction order while suppressing the diffracted light of other orders by using optical filters. Three optical filters for that purpose are integrated into the monochromator, and they are switched automatically according to the wavelength range.

ACHIEVING HIGH WAVELENGTH RESOLUTION

The wavelength resolution (WR) of a monochromator is given by the following equation.

$$WR = \varepsilon \cdot \frac{d}{m \cdot f} \cos(\beta)$$

To achieve high wavelength resolution, i.e. to reduce WR , making the focal length f of the focusing mirror longer and the slit width ε narrower is effective as seen in the equation. The AQ6373B achieves high wavelength resolution by optimizing these parameters. Particularly, in the wavelength range using the second-order diffracted light, shown in Figure 4, it achieves wavelength resolution as small as 0.01 nm. This is because the diffraction order m of 2 in the equation has the same effect as doubling the focal length. With this high wavelength resolution of 0.01 nm, the optical spectrum of a blue semiconductor laser oscillating at narrow intervals of longitudinal modes can be clearly observed. Figure 6 shows a measurement example of the optical spectrum of a blue semiconductor laser carried out by the AQ6373B.

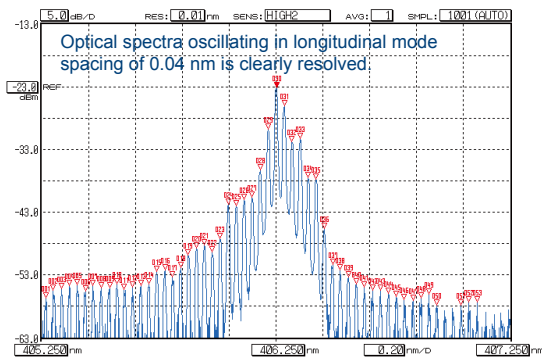


Figure 6 Measurement example of blue semiconductor laser spectrum by the AQ6373B

INPUT THROUGH LARGE CORE DIAMETER FIBER

One of the major features common to all series of Yokogawa's optical spectrum analyzers is a free-space structured input section⁽¹⁾, which enables measuring through either a multimode or singlemode fiber. The free-space structure has been achieved for the monochromator of the AQ6373B by optimizing the layout of optical and other components. This suppresses the lowering of level repeatability caused by an optical connector and also enables connection with a multimode fiber with low insertion loss. Because the AQ6373B covers a visible light range, many of its applications include measuring of optical spectra of light in space. In such cases, the light propagating in space is first input into an optical fiber in order to introduce it into the instrument. Although not easy, to input the light into an optical fiber efficiently, an optical fiber with a relatively large core diameter is used. In the AQ6373B, assuming such cases, the light exit slit width can be adjusted by users in

two stages according to the core diameter of the optical fiber connected to the optical input section. The small diameter fiber mode is selected when the fiber core diameter is 50 μm or smaller, and the large diameter fiber mode is selected when the fiber core diameter is between 50 μm and 800 μm . Figure 7 shows a measurement system for measuring spectral characteristics of an optical filter. Two lenses are placed facing each other and the optical filter to be measured is placed between the two lenses where the light from the source is collimated. A broadband light source such as a halogen lamp is used as the light source, and large diameter optical fibers are used to emit a light to space and input a light in space efficiently. Figure 8 shows a measurement example of spectral characteristics of an optical filter by the AQ6373B, where the large diameter fiber mode is selected. In this way, the AQ6373B can minimize the light power loss through the monochromator by using large core diameter fibers, and this enables measuring with a high dynamic range.

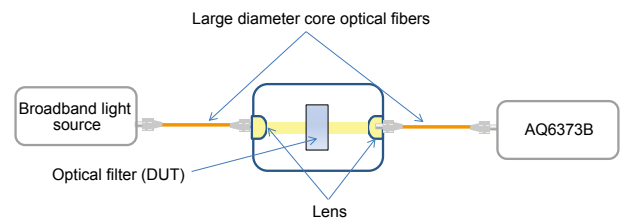


Figure 7 Measurement system for measuring spectral characteristics of an optical filter

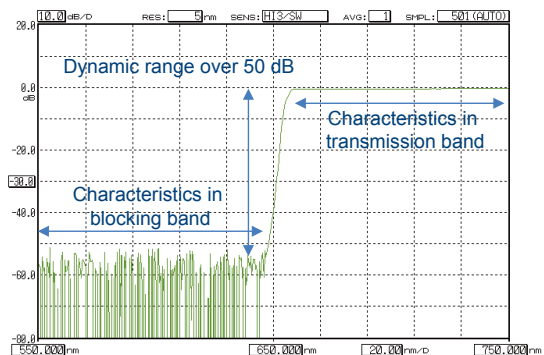


Figure 8 Measurement example of spectral characteristics of an optical filter by the AQ6373B

TEMPERATURE COMPENSATION TECHNOLOGY

A monochromator focuses a beam on the light emission slit by using a collimator mirror or lenses and a focusing mirror or lenses. The slit width is usually below several 10 μm in order to achieve high wavelength resolution. The optical components of a monochromator are arranged on a chassis typically made of aluminum. When the ambient temperature changes, this configuration causes the beam spot at the emission slit to go out of focus due to the linear expansion or contraction of aluminum, the material the chassis is made of. This degrades the wavelength resolution and lowers measurement sensitivity. The lens for the AQ6373B has been designed so that the change in its focal length caused by

temperature fluctuation matches that in the aluminum chassis. Generally, the focal length of a lens is determined by its radius of curvature and the refractive index of the glass material. For the AQ6373B, more than 100 glass materials were investigated in order to select the optimum material that created appropriate temperature compensation. This technology has been patented under Japan patent No. 5453730.

IMPROVED WAVELENGTH MEASUREMENT ACCURACY

A monochromator performs wavelength sweeping by rotating its diffraction grating, and highly accurate wavelength measurement can be achieved by precisely controlling the rotation angle of the diffraction grating. The AQ6373B uses the rotary driving technology for a diffraction grating, which was cultivated during the development of the AQ6370 series optical spectrum analyzers for optical communication, and enables highly accurate wavelength measurement within the wide range from 350 nm to 1200 nm. Figure 9 shows an evaluation example of the AQ6373B wavelength accuracy. The vertical axis represents the error in wavelength measurement, and the horizontal axis is the measured wavelength. This evaluation was carried out by using a He-Ne gas laser as a light source and line spectra of mercury and argon lamps.

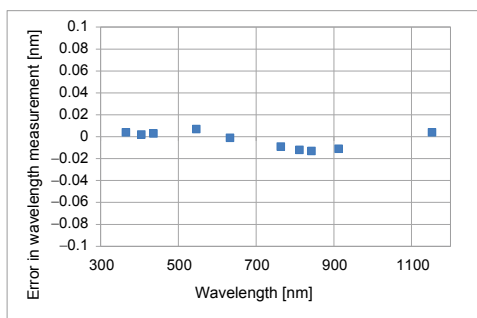


Figure 9 Evaluation example of the AQ6373B wavelength accuracy

FUNCTIONS AND THEIR APPLICATIONS

This section introduces some functions of the AQ6373B and their applications.

Data Logging Function

The AQ6373B has a data logging function that measures and analyzes optical spectra automatically at predetermined time intervals, and can save the results and display them in graph format. It can log analysis results such as a peak wavelength, peak power, and an optical signal-to-noise ratio (OSNR), and users can verify changes in these parameters graphically. This function can also log optical spectral data itself, and users can retrieve the spectral data at any time and observe temporal changes in the optical spectrum after a device heat run test has been completed. Figure 10 shows a measurement example of temporal change in a laser wavelength by the data logging function.

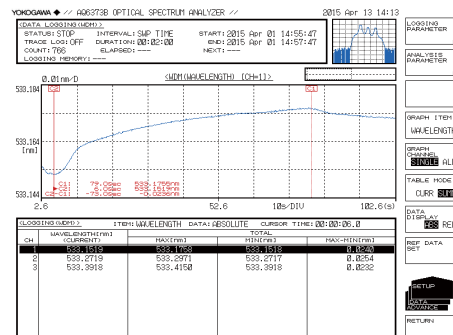


Figure 10 Measurement example of temporal change in a wavelength

Chromaticity Analysis Function

The AQ6373B has a chromaticity analysis function that analyzes emission spectra of visible light LEDs that are used in many areas including those involving lighting, display and measuring, and can calculate the dominant wavelength and chromaticity coordinates (x, y, z). Figure 11 shows an example of chromaticity analysis results of a white LED spectrum.

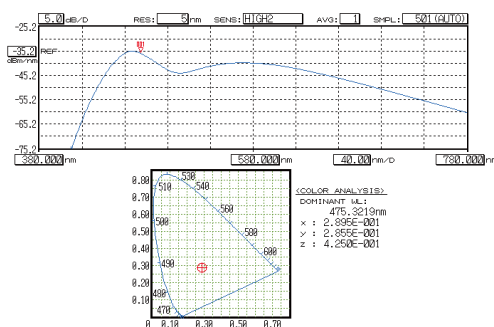


Figure 11 Example of chromaticity analysis results of a white LED spectrum

CONCLUSION

This paper described the wide wavelength band technology, performance, and functions of the AQ6373B optical spectrum analyzer. The high-precision, high-resolution and high-dynamic-range wavelength measurement technologies that were cultivated during the development of the AQ6370 series for optical communication, and optical component design technology for a wide wavelength band including a visible light range, are integrated into the AQ6373B. Yokogawa expects that its optical spectrum measurement technology will contribute to research, development and productivity improvements of semiconductor lasers, optical filters and other devices used in the biomedical, environmental measurement, optical fiber communication and other fields, and looks forward to the continued evolution of these fields as a result.

REFERENCES

- (1) Manabu Kojima, Tohru Mori, et al., "High-speed Measurement Technologies of AQ6370C Optical Spectrum Analyzer," Yokogawa Technical Report English Edition, Vol. 55, No. 1, 2012, pp. 23-26