AQ6375 OPTICAL SPECTRUM ANALYZER FOR LONG WAVELENGTH BAND

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We have developed the AQ6375 grating-based desktop optical spectrum analyzer, which can measure an optical spectrum over a wide wavelength range from 1.2 to 2.4 µm with high wavelength resolution at high speed. Despite the popularity of desktop optical spectrum analyzers in the telecommunication wavelength region, a large-scale optical spectrum measurement system with a monochromator has commonly been used for measuring the long wavelength region, and so there was a need for a desktop optical spectrum analyzer for long wavelengths. Deep optical absorptions appearing in the long wavelength region around 2 µm caused by CO_2, NO_X and H_2O are attracting attention in the environmental and medical fields, and thus sensitive measuring equipment by laser absorption spectroscopy using a near infrared semiconductor laser is becoming more popular. With excellent optical spectrum measurement capabilities (high resolution and high speed), operability and maintenance performance, the AQ6375 optical spectrum analyzer will contribute to the performance improvement and spread of near-infrared semiconductor lasers used in laser absorption spectroscopy.

INTRODUCTION

In recent years, global environmental issues have received increasing attention, promoting effective initiatives to reduce greenhouse gases. In addition to CO_2, a well known greenhouse gas, there are other gases that can damage the environment, including SO_2 (sulfur dioxide) and NO_X (nitrogen dioxide). In order to small concentrations of these gas molecules with high sensitivity, laser absorption spectroscopy technology is gaining attention and is under active development [1,2].

A laser absorption spectroscopy method requires a high performance near-infrared laser that supports a single vertical mode oscillation in an infrared wavelength band of 2 µm. For this reason, until now it is common to use or develop a large measurement system with a single high performance spectrometer for measuring the laser oscillation spectrum. However, such large measurement systems can have problems in terms of measurement resolution, measurement speed, operability and maintainability. Therefore, the development of a high performance desktop optical spectrum analyzer that measures the 2 µm band, instead of the optical transmission wavelength range, has been expected.

Yokogawa has developed various optical spectrum analyzers that cover the communication wavelength range, including high-performance desktop and small transportable types. By utilizing our accumulated technology on optical spectrum measurements,

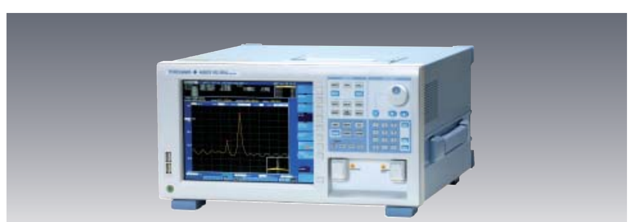

Figure 1 AQ6375 Optical Spectrum Analyzer

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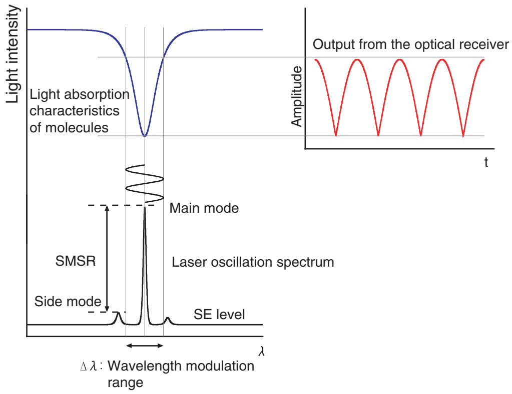

Figure 2 Laser Absorption Spectroscopy

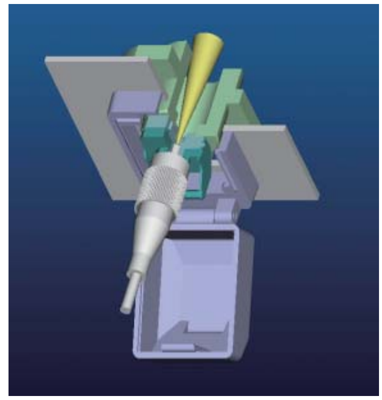

Figure 3 Free Space Optical Input Interface

we have developed the AQ6375 optical spectrum analyzer that supports long wavelength (2 μm) measurement (Figure 1).

This article describes the features and performance of the AQ6375.

GAS CONCENTRATION MEASUREMENT BY LASER ABSORPTION SPECTROSCOPY

Laser absorption spectroscopy offers the following advantages that have recently gained increased attention:

① Measurement of a wide variety of gases
② Capability of detecting molecules in the air
③ High-speed measurement

In addition, the following features are added by using a near-infrared semiconductor laser as a laser light source.

④ Compact, light-weighted unit
⑤ Low cost
⑥ Easy maintenance
⑦ High reliability

In recent years, these practical measuring devices have been developed and are rapidly becoming popular.

Laser absorption spectroscopy uses a laser that oscillates in the single vertical mode. As shown in Figure 2, this technology can measure concentrations by slightly modulating the oscillation wavelength of the laser around the absorption wavelength specific to a gas molecule to be detected, and by detecting a change in light intensity due to molecule absorption.

The laser used in laser absorption spectroscopy requires excellent single mode operation performance, which directly determines the limits of detection. Furthermore, since gas molecules have relatively strong absorption lines in the near-infrared region of about 2 μm, it is required to develop a laser that produces a stable oscillation in this region in order to achieve sensitive detection.

AQ6375 OPTICAL SPECTRUM ANALYZER

Existing lasers that oscillate in the near-infrared region of about 2 μm with the single vertical mode include DFB-LD (Distributed Feedback Laser Diode) and VCSEL (Vertical Cavity Surface Emitting Laser Diode) [3,4].

Important parameters for evaluating the performance of lasers are SMSR (Side Mode Suppression Ratio) which represents the amplitude difference between the main mode and the side mode, and SE (Spontaneous Emission) level which is the magnitude of background noise light. Both parameters can be obtained based on the results of laser oscillation spectrum measurement.

The AQ6375 optical spectrum analyzer we have developed is capable of achieving high optical performance for measurement in the near-infrared region. It can measure optical spectra of the near-infrared semiconductor lasers described above at high resolution, and at the same time provide high-speed measurement and excellent operability just like our AQ6370 optical spectrum analyzer. For these reasons, we believe that the AQ6375 can contribute to the improvement and wider use of semiconductor lasers.

The features of the AQ6375 are described below.

Features of AQ6375

(1) Wide near-infrared measurement range

The AQ6375 can measure wavelengths in the 1.2 to 2.4 μm measurement range, covering only the wavelength range for laser absorption spectroscopy, but also the wavelength range used in communications. The AQ6375 is suitable not only for measuring the optical spectrum from semiconductor lasers, but also the ultra-wide band spectrum of a supercontinuum (SC) source.

(2) High wavelength resolution

Equipped with a high-precision Czerny-Turner double path monochromator with additive dispersion, the AQ6375 has achieved higher resolution than a single spectroscope despite its very compact size. When used with single mode fiber, it provides a wavelength resolution of 0.05 nm in the 2 μm wavelength region (2000 nm). With an adjustable slit system installed in the monochromator, the AQ6375 allows the wavelength resolution to be set between 0.05 nm and 2.0 nm depending on measurement conditions.

(3) High sensitivity and high speed measurement

The AQ6375 uses an InGaAs photodiode, with its

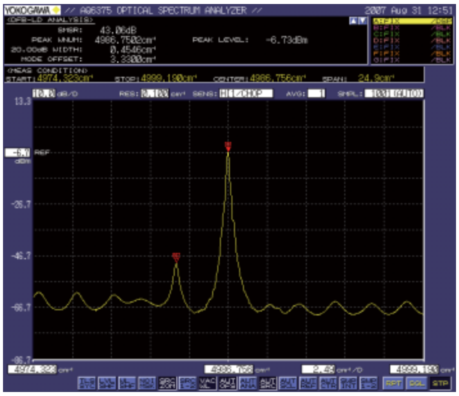

Figure 4 Screen of Spectrum Displayed in the Wave Number Mode

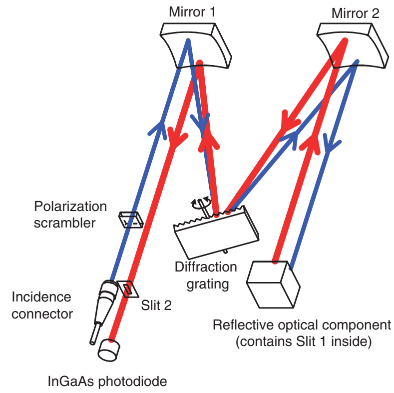

Figure 5 Optical Configuration of Double Path Monochromator with Additive Dispersion

monochromator configured as a reflective optical system and all optical components coated with gold. This design allows for the prevention of the intensity loss in the monochromator and the implementation of high sensitivity and high speed measurement.

(4) Free space optical input interface

The monochromator uses, as its interface, the free space (space incidence) optical input interface that is a unique feature of our monochromator (Figure 3).

This optical input interface supports the direct input not only from a single mode fiber but also a multiple mode fiber. In order to facilitate accurate measurement in the near-infrared range, AR (antireflective) coating has been applied on the end face of optical fiber to reduce the intensity of reflection light. This is also a way to address the problem of the limited availability of low-cost optical isolators in the market. The free space optical input interface is also advantageous in that it does not damage this coating.

(5) Quick response and high speed remote interface

The AQ6375 features the key command response system, which has already received good response from users of our previous models, and the remote interface. These aspects help achieve significantly high throughput especially when the AQ6375 is used as an integrated part of an automatic measuring system.

(6) Easy-to-use interface

The AQ6375 provides a user-friendly interface much like the AQ6370's. It offers various analysis functions such as tracing, waveform zooming, center wavelength analysis and SMSR analysis, as well as the mode for setting and displaying spectrum using a wave number (cm^{-1}) which is a reference commonly used for measurement in the near-infrared range. Figure 4 shows an example of spectrum displayed in the wave number mode.

Architecture of High Resolution Monochromator

The AQ6375 is a diffraction-grating based optical spectrum analyzer that uses dispersive spectroscopy. It offers high optical performance by optimizing a variety of parameters of the monochromator, which has been developed through our long experience and research, for use in measurement over the near-infrared range. In order to achieve high levels of wavelength resolution and measurement sensitivity in a wide wavelength range, the AQ6375 uses a Czerny-Turner double path monochromator with additive dispersion, which itself has been configured as a reflective optical system. In addition, all optical components have been coated with gold to minimize the intensity loss that may occur in the monochromator.

In many spectroscopes with high wavelength resolution, generally, a double monochromator that consists of two single monochromators placed in cascade is used, and such a system tends to be large and require substantial floor space. In addition, this type of system has many problems including difficulty in use, such as that it must be placed on a shock absorbing desk or other equipment for use because of its sensitivity to vibration, and difficulty and inconvenience in maintaining the optical performance.

Yokogawa's additive-dispersion double path monochromator is a compact device that uses only one diffraction grating to diffract the light twice, resulting in both the wide optical dynamic range and the high wavelength resolution similar to those of the double monochromator mentioned above. Figure 5 illustrates the configuration of the additive dispersion double path monochromator used in the AQ6375.

The light beam from the incidence connector (optical input interface) goes through Mirror 1, the diffraction grating and Mirror 2 to Slit 1 in the reflective optical component (first diffraction, the light path is shown as a blue line in Figure 5), which in turn reflects the light. Then, the light reflected from the reflective optical component goes back through the optical path including Mirror 2, the diffraction grating and Mirror 1 to Slit 2 (second diffraction, a red line in Figure 5). In the reflective optical component, the incident image is flipped both horizontally and vertically, the dispersion of the light is increased to two times that of the light after the first diffraction (incident light), and the dispersion direction is reversed before emission from the component. The reflective optical component is designed so that it offsets the position of the light in the direction of non-dispersion (Figure 5: i.e. the direction parallel to the rotation axis

Table 1 Main Specifications of the AQ6375 Optical Spectrum Analyzer

Applicable fiber	SMF (9.5/125 μm), MMF (50/125 μm, 62.5/125 μm)
Measurement wavelength range	1200 to 2400 nm
Wavelength accuracy	±0.05 nm (1520 to 1580 nm) , ±0.1 nm (1580 to 1620 nm), ±0.5 nm (Full range)
Wavelength resolution setting	0.05, 0.1, 0.2, 0.5, 1.0, 2.0 nm
Measurement sensitivity setting	NORM_HOLD, NORM_AUTO, NORMAL, MID, HIGH1, HIGH2, HIGH3
Level sensitivity (Sensitivity: HIGH3)	-62 dBm (1300 to 1500 nm) -67 dBm (1500 to 1800 nm, 2200 to 2400 nm) -70 dBm (1800 to 2200 nm)
Level accuracy	±1.0 dB (1550 nm, input level: -20 dBm, sensitivity: MID, HIGH1, HIGH2 or HIGH3)
Maximum input power	+20 dBm (Total input power)
Close-in dynamic range	45 dB or more (1523 nm, ±0.4 nm of peak wavelength, resolution: 0.05 nm) 55 dB or more (1523 nm, ±0.8 nm of peak, wavelength, resolution: 0.05 nm)
Polarization dependency	±0.1 dB (1550 nm)
Sweep time	NORM AUTO: 0.5 sec NORMAL: 1 sec MID: 10 sec HIGH1: 20 sec HIGH2: 60 sec HIGH3: 600 sec (any 100 nm, SMPL: 1001)

of the diffraction grating), and the light is emitted from it with the angle of the output light being identical to that of the incident light. These features have made it possible to obtain the same spectrum wavelength in both the first and second paths (onward and return) over a wide wavelength range. This reflective optical component eliminates the need for an optical alignment adjustment mechanism that is synchronized with a rotation angle of the diffraction grating, and helps implement a compact, high performance monochromator with a structurally simple configuration.

OPTICAL PERFORMANCE OF AQ6375

Table 1 lists the main specifications of the AQ6375 optical spectrum analyzer.

Figure 6 shows the results of measurement of the spectrum of the light from a DFB-LD that oscillates in the near-infrared region of 2 μm with the single vertical mode. The measurement was performed with the wavelength resolution of 0.05 nm, the sensitivity of HIGH1, and the span of 100 nm, and the resulting spectrum waveform was enlarged for observation using the waveform zooming feature. As the displayed waveform shows, the high wavelength resolution and wide optical dynamic range provided by the AQ6375 allow the light from the near-infrared semiconductor laser to be accurately measured by clearly separating the main oscillation mode and the side mode. In addition, its high sensitivity enables highly precise measurement of the spontaneous emission light (SEL) of the laser, which helps to accurately obtain the primary laser parameters such as SMSR and SE.

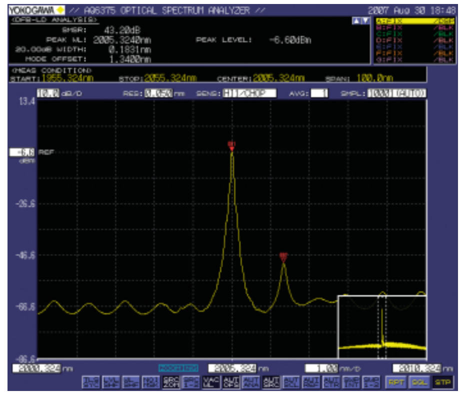

Figure 6 Results of Measurement of the Spectrum of Light Emitted from the Near-Infrared Semiconductor Laser

CONCLUSION

We have developed the easy-to-use desktop optical spectrum analyzer AQ6375 that provides high optical performance and is suitable for performing optical measurements at the near infrared band of 2 μm. We believe that the high measurement performance of the AQ6375 will contribute to the acceleration of the development of new devises and measurement instruments such as near-infrared semiconductor lasers and other related devices, and the improvement of productivity in the device development. It is also our hope and expectation that the AQ6375 will contribute to the promotion and development of environmental measurement. ◆

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