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Measurement on pulsed light

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To generate pulses from a diode laser, it is driven with a pulsed electrical current. During the pulse, the electric current heats up the diode laser, causing a shift in the output wavelength. Consequently, the wavelength at the beginning and end of the laser pulse are different.
This property of diode lasers is currently studied at a university in Germany, using a Yokogawa Optical Spectrum Analyzer (OSA). The diode laser under examination is driven with a 1 to 10 Hz pulse repetition frequency and produces a 1 msec pulse width. The OSA records the optical spectrum by measuring optical power during a wavelength sweep.
During a sweep, it is assumed that the optical input signal is present, i.e. an assumption that is not valid when analyzing a pulsed input signal. Under normal circumstances, the absence of light between laser pulses will cause a distortion of the recorded spectrum, making it unsuitable for analysis. However, with the special recording methods offered by Yokogawa OSAs, the pulsed nature of the light is taken into account, and the true spectrum will be displayed, allowing a valid analysis.

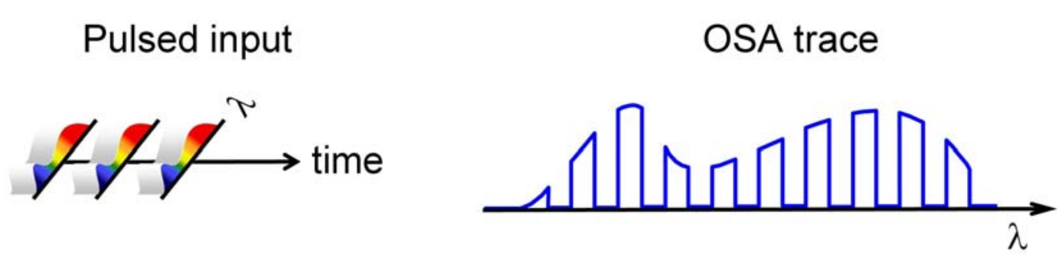


Figure 1 – Due to the wavelength sweeping nature of the OSA, the absence of light between pulses can produce a distinct on/off distortion on the recorded spectrum.

Note that other pulsed light sources exist, e.g. pulsed lasers, flash lamps, pulsed LED’s. The following discussion is valid for all pulsed light sources.

1. Measurement on Pulsed Lasers

Lasers are designed for specific applications, each with a specific requirement of the output spectrum of the laser. A common application for OSAs is the analysis of laser output, e.g. testing on output wavelength, bandwidth (line width), spectral stability, power distribution.
From the point of view of an Optical Spectrum Analyzer, three groups of pulsed lasers can be distinguished, i.e. lasers with low, high and ultra-high pulse repetition frequencies.

> **i** In many laser applications, a high power laser beam is required. To produce a high-power laser beam, typically the laser accumulates power for a period of time, which is subsequently released in a short pulse. A pulsed laser repeats this process at a specific pulse repetition frequency.

1.1. Ultra-high Pulse Repetition Frequencies (MHz)

For extremely high pulse repetition frequencies, the OSA will produce a spectrum as if the light source was a continuous wave, i.e. not pulsed, as the detection electronics inside the OSA is slow enough to react to the extremely fast changes of the input signal independent of the instrument’s settings.

1.2. High Pulse Repetition Frequencies (kHz)

When testing lasers with pulse repetition frequencies in the kHz range, the disturbing effect of the laser pulses may be noticeable. The effect can be eliminated by reducing the reaction speed of the detection circuit, essentially creating the same situation as described in the previous paragraph.
This is achieved by selecting a slow responding amplifier circuit out of the set of circuits that is available in the OSA (Fig. 2) by selecting an appropriate sensitivity setting.
Each circuit corresponds to a specific sensitivity setting, and offers a specific gain and response time. A high sensitivity setting corresponds to a high-gain circuit with relatively slow response and vice versa.

> **i** The sweep speed of the OSA accommodates for the response-time of the detection circuit, i.e. in a high sensitivity setting the wavelength sweep will be slower compared to the sweep in a low sensitivity setting.

By choosing a high sensitivity setting, the OSA spends more time on signal integration at each wavelength, ideally capturing many laser pulses per sample.

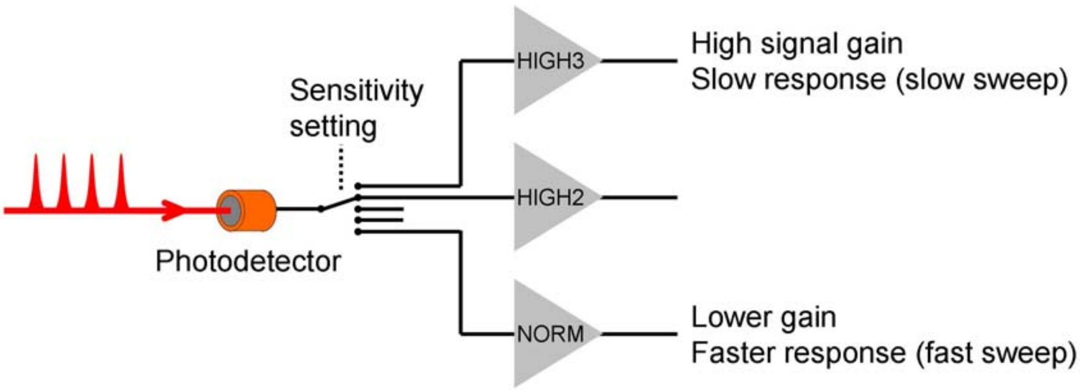


Figure 2 – Each sensitivity setting on the OSA corresponds to a specific signal amplifier circuit, each offering a specific gain, time-response and sweep speed of the OSA.

1.3. Low Pulse Repetition Frequencies (Hz)

For low pulse repetition frequencies, even the highest sensitivity setting of the OSA may not be able to remove the distortion of the recorded spectrum. The repetition frequency is simply too low and a different method should be used to eliminate the distortion from the spectrum.

<u>Measurement with trigger input</u>

If the pulsed laser provides a trigger signal, it is advisable to make use of it by feeding it to the OSA trigger input. In trigger mode, the OSA will derive each sample from a single laser pulse. On each trigger, the OSA moves to the next wavelength and records the integrated detector signal $P(\lambda)$.

It is important to avoid a high sensitivity setting (something that may not be intuitive to an OSA user). The reason is that a slow detector circuit cannot react quickly enough to the short presence of the light pulse (Fig. 3.b.). In a low sensitivity setting, the fast detection circuit will produce a much stronger integrated signal (Fig. 3.c.), i.e. better signal-to-noise ratio of the OSA trace.

Figure 3.a.
Assuming a laser producing square shaped pulses.

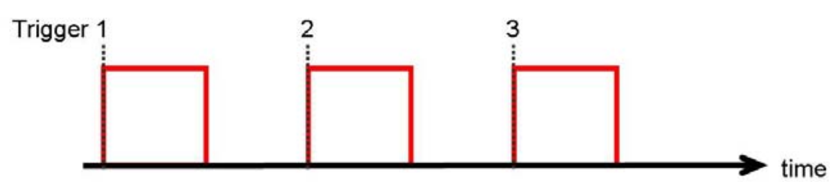


Figure 3.b.
The integrated detector signal $P(\lambda)$ is weak due to the slow response of the detector circuit.

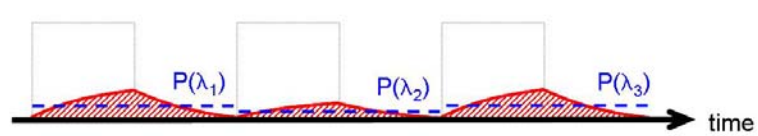
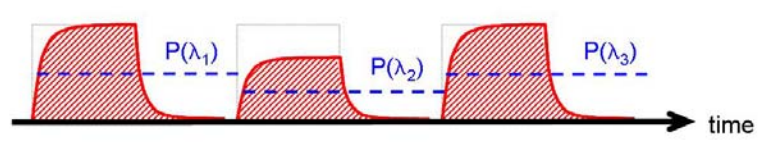


Figure 3.c.
The fast response of a low-sensitivity setting produces a strong detector signal.



For example, at a university in Sweden, the spectrum is recorded of a pulse with a wavelength of 1624 nm and a pulse width of 3-4 ns (Fig. 4). The pulses were generated by a 10Hz Nd:YAG laser pumping an OPO[1]. The AQ6375 OSA, model AQ6375, was synchronized to the laser trigger signal, meaning that the recorded signal at each wavelengths originates from a single laser pulse. Notice that, without sample averaging for noise cancellation, the OSA is able to record individual 3-4 ns short pulses.

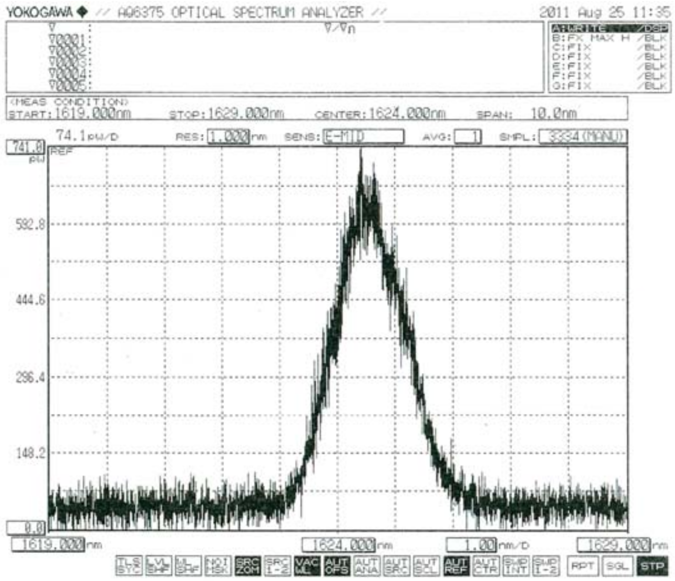


Figure 4 – AQ6375 recorded spectrum of an Nd:YAG laser OPO system, producing 3-4 ns pulses, repeating at 10Hz.

<u>Measurement without a trigger input</u>

For lasers that do not provide a trigger signal, the “Peak Hold” function of the OSA should be used. By doing this, at each wavelength the pulsed detector signal is recorded over a certain time interval. The maximum signal obtained over the time interval is taken as the power value at the given wavelength. (Fig. 5.)

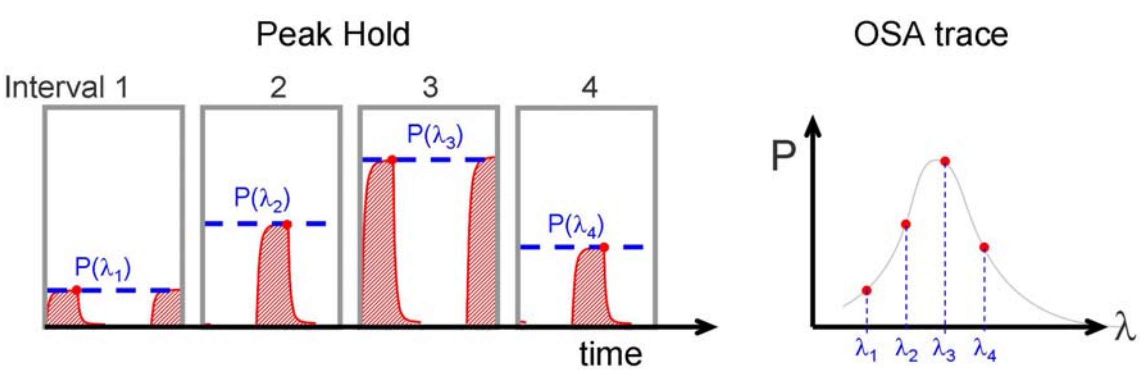


Figure 5 – At each wavelength, the pulsed detector signal is recorded over a certain time interval. The maximum signal obtained over the time interval is taken as the power value at the given wavelength.

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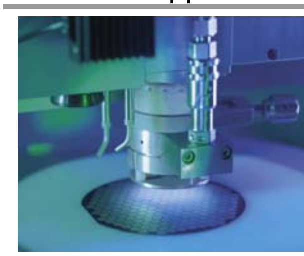
[1] OPO stands for Optical Parametric Oscillator, i.e. an instrument that generates new wavelengths of light when pumped by an intense laser beam.

The time interval is user selectable (0 – 9999 msec), so that it can handle pulse frequencies of 0.1Hz and higher. The time interval should be set to a larger value than the time between two pulses (i.e. 1 / rep. frequency), so that at least one pulse is captured during each time interval. Because of this, Peak Hold measurement will always be slower than measurement synchronized to a trigger signal.

2. Measurement on Pulsed Lasers

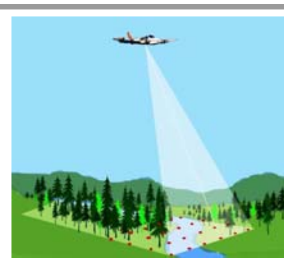
Many types of pulsed lasers exist. Pulsing with a repetition frequency in the kHz range, the Q-switched DPSS[2] laser is the most common type, offering a pulse repetition frequency in the 1–250 kHz range (Fig. 6). Lasers that fall in the low-repetition frequency category are typically pumped by flash lamps or electric discharge, e.g. Nd:YAG lasers, excimer lasers and Nitrogen lasers. Other light sources that fall into this category are, for example, pulsed driven LEDs, gas discharge lamps, or the chopped output of a continuous source. Yokogawa Optical Spectrum Analyzers can be used in combination with any of these sources.

kHz laser applications

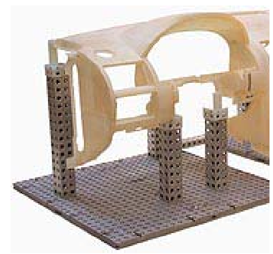


Laser dicing, i.e. cutting of silicon wafers, separating individual LED, IC,RFID

Super-continuum generation, and other types of non-linear optics



Distance measurement (LIDAR[3]) as used, for example, in geographic mapping

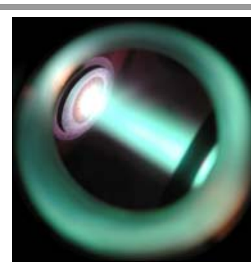


3D printing (rapid prototyping) of, for example, a car dashboard

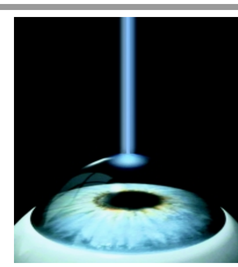
Sub-kHz laser applications

Pulsed high-power lasers are used in environmental monitoring

Pulse driven LEDs are driven to achieve a higher brightness



Laser research such as cavity ringdown spectroscopy[4] or Laser Induced Fluorescence (LIF)



For laser assisted eye surgery (LASIK), typically a pulsed excimer laser is used

Figure 6 – Example applications of different pulsed light sources.

[2] Q-switching is a technique for generating high power laser pulses. “DPSS laser” stands for diode pumped solid state laser, typically using a crystal (e.g. Nd:YAG) as the laser gain medium.
[3] LIDAR stands for Light Detection and Ranging
[4] Ref. M.D. Wheeler et al. J. Chem. Soc. Faraday Trans. 94, 337 (1998)