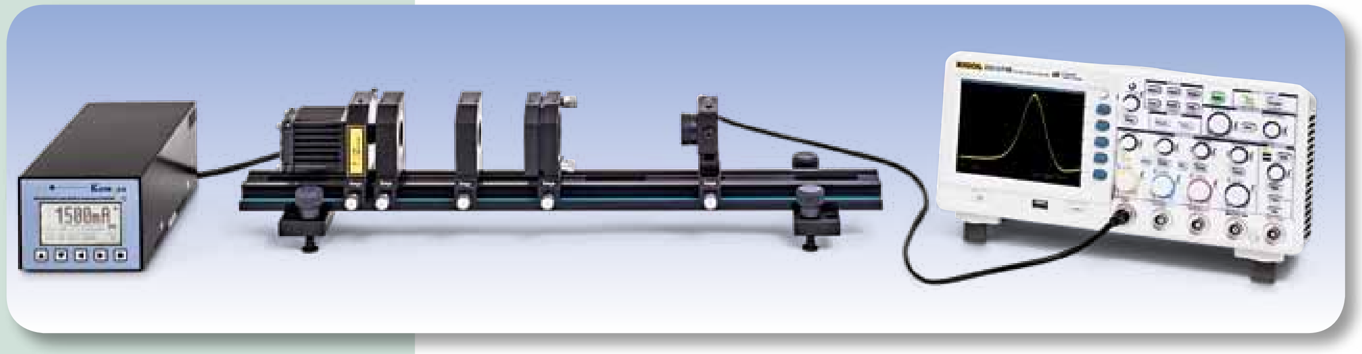
Q-SWITCHING FOR ND:YAG LASER



OBJECTIVE

Q-switching circuit for Nd:YAG laser with Cr:YAG module

EXPERIMENT PROCEDURE

- **Set up and optimise a Q-switching circuit for an Nd:YAG lasers using a Cr:YAG module.**

- **Record the pulses and determine their duration.**

SUMMARY

Q-switching of a laser makes it possible to generate short, high-energy pulses. It works by controlling the laser threshold by increasing or decreasing resonator losses. You are to implement a passive Q-switching circuit with the help of a Cr:YAG module and then record the laser pulsing over time. The energy of the pulses can be calculated from the average power and the frequency with which they are repeated

REQUIRED APPARATUS

Quantity	Description	Number
1	Laser Diode Driver and Two-Way Temperature Controller Dsc01-2.5	1008632
1	Optical Bench KL	1008642
1	Diode Laser 1000 mW	1009497
1	Nd:YAG Cristal	1008635
1	Passive Q-Switch	1008637
1	Laser Mirror I	1008638
1	PIN Photodiode, Fast	1008641
1	Filter RG850	1008648
1	Alignment Laser Diode	1008634
1	Transport Case KL	1008651
1	Laser Safety Goggles for Nd:YAG Laser	1002866
1	Digital Multimeter P3340	1002785
1	Digital Oscilloscope 4x60 MHz	1008676
1	HF Patch Cord, BNC/4 mm Plug	1002748
1	HF Patch Cord	1002746
1	IR Detector Card	1017879

WARNING

This experiment involves operation of class-4 laser equipment which emits light in the (invisible) infra-red part of the spectrum. Goggles which protect against laser light should always be worn. Even when wearing such goggles, never look at the laser beam directly.

BASIC PRINCIPLES

Q-switching (also called giant pulse formation) makes it possible to generate short, high-energy laser pulses, as required in the processing of materials, for example. It works by controlling the laser threshold by increasing or decreasing resonator losses. When losses are high, it prevents the build-up of oscillation in the resonator and causes pumping energy to be stored in the laser crystal. Once the resonator is enabled by reducing the losses, a laser pulse of intensity orders of magnitude greater than the intensity in continuous mode is generated. The difference between this and spiking is that the inversion density with Q-switching far exceeds the threshold value. A distinction is made between active and passive Q-switching. Passive Q-switches are absorbers in which the capacity to absorb can be modified by means of the light in the resonator. Active switches are typically acousto-optic, electro-optic or mechanical switches, which control the transmission externally.

Use of an absorbing crystal as a passive Q-switch requires that the absorption can be saturated. That means that its effective absorption cross section must be larger than that for the light from atoms in an excited state, also that the lifetime of the excited level is both longer than the duration of the laser pulse and shorter than the frequency of repetition. A Cr:YAG crystal fulfils all these criteria.

In order to fully describe the dynamic response of the passively Q-switched laser, the rate equation for the inversion density n achievable by means of optical pumping in an Nd:YAG crystal for a photon density p in the field of the laser light (see experiment UE4070310) also needs to take into account the population density in the ground state of the Cr:YAG crystal. Due to the extremely rapid increase of the photon density, both the pumping rate and the rate of spontaneous emission can be disregarded. The threshold for the inversion density is defined as follows:

$$n_S = \frac{1}{\sigma \cdot c \cdot \tau_{\text{res}}} \tag{1}$$

τ_{res}: time constant for reduction in photon density due to resonator losses

σ: effective cross section for emission or absorption of a photon

c: speed of light

This implies that the change in inversion density n and in the photon density p over time is given by:

$$\frac{dn}{dt} = -\frac{n}{n_S} \cdot \frac{p}{\tau_{\text{res}}} \tag{2a}$$

and

$$\frac{dp}{dt} = -\left(\frac{n}{n_S} - 1\right) \cdot \frac{p}{\tau_{\text{res}}} \tag{2b}$$

In a giant pulse, the inversion density is approximately constant and remains almost equal to the initial inversion density:

$$n(t) = n_i \tag{3}$$

Equation (2b) can then be used to determine the photon density:

$$p(t) = \exp\left[\left(\frac{n_i}{n_S} - 1\right) \cdot \frac{t}{\tau_{\text{res}}}\right] \tag{4}$$

The inversion density n_i for a giant pulse is very much greater than the threshold inversion density n_S. That means that the time it takes for the photon density to increase is much shorter than the time constant τ_{res} for resonator losses.

Another key point in time is reached when the inversion density falls back to the threshold level. Then the photon density ceases to change as described in equation (2b), i.e. no more laser photons are generated. Equation (2a) then gives us:

$$\frac{dn}{dt} = -\frac{p_{\max}}{\tau_{\text{res}}} \quad \text{where } p(t) = p_{\max} \tag{5}$$

The photon density therefore falls after reaching its maximum with a time constant equal to that for the resonator losses.

The maximum value for the photon density is given by the following:

$$p_{\max} = n_S \cdot \ln\left(\frac{n_S}{n_i}\right) - \left(n_S - n_i\right) \tag{6}$$

This means that lasers with an upper laser level that has a very short lifetime, i.e. which only have a very small excess inversion density, do not exhibit any significant increase in output power when used in pulsed mode.

In this experiment the Cr:YAG module is added to the resonator and fine adjustment of the laser is carried out anew. The laser signal is measured using a PIN diode and traced on an oscilloscope.

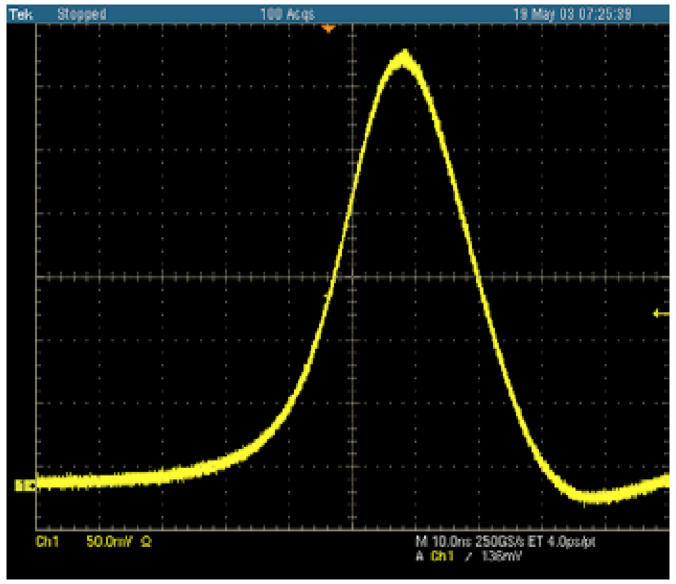


Fig. 1: Pulse over a period of time for an Nd:YAG laser with passive Q-switching