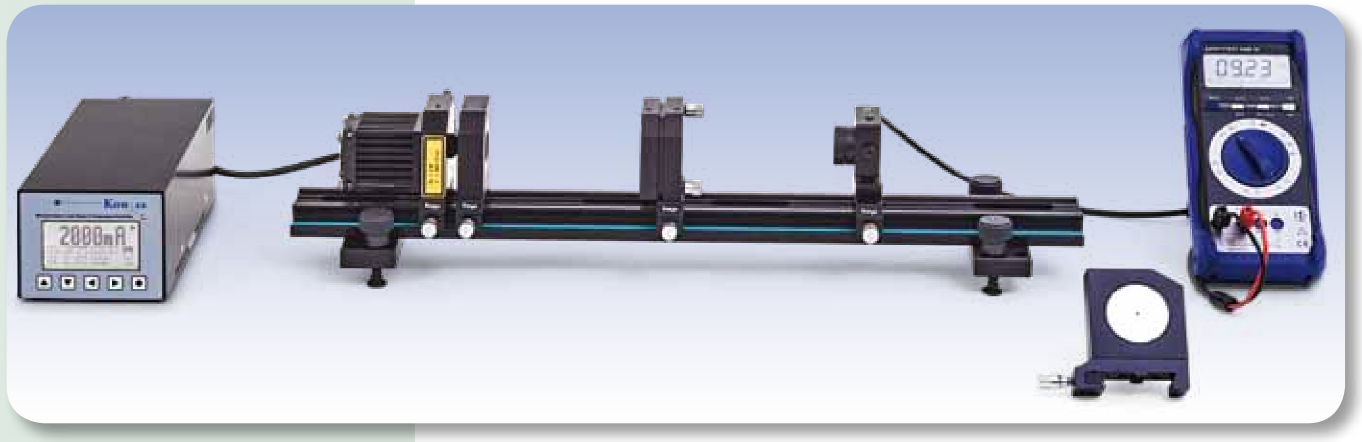

EXPERIMENT PROCEDURE

- **Calibrate the diode laser for stable optical pumping of the Nd:YAG laser.**
- **Determine the lifetime of the top laser energy level $^4F_{3/2}$ in the Nd:YAG crystal**
- **Adjust the resonator and observe the resonator modes.**
- **Measure the output power of the Nd:YAG laser as a function of the pumping power and determine the lasing threshold.**
- **Observing spiking when the laser diode is being operated in pulsed mode.**

WARNING

This experiment uses a class 4 laser set-up emitting in the non-visible (infra-red) spectrum. For this reason, goggles for protection against laser light must be worn at all times. Do not look directly into the laser beam even while wearing protective goggles.

OBJECTIVE

Set up and optimise an Nd:YAG laser

SUMMARY

In this experiment an Nd:YAG laser with a diode laser pump is to be set up and optimised. Once the diode laser is calibrated for stable optical pumping and the resonator has been optimised, the system can then be used as an Nd:YAG laser. An investigation is to be made of both steady-state and non-steady-state operation and the lifetime of the top laser energy level $^4F_{3/2}$ in the Nd:YAG crystal will then be determined.

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	Collimator lens f = +75 mm	1008646
1	Laser Mirror I	1008638
1	PIN Photodiode	1008640
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

BASIC PRINCIPLES

An Nd:YAG laser is a solid-state laser which emits an infra-red beam. The laser medium is a neodymium-doped yttrium-aluminium garnet crystal. Pumping is handled by a semiconductor laser. Usually the light emitted has a wavelength of 1064 nm.

Fig. 1 shows the energy levels for an Nd:YAG crystals with the most important transitions for optical pumping and laser operation. By means of optical pumping using light with an approximate wavelength of 808 nm, transitions can be excited between the ground state (1) and the top pumping level (4). Its lifetime is very short and rapid, non-radiating transitions take place into the upper metastable excited laser level (3). This prevents transitions occurring back into the ground state. The lasing transition of wavelength λ = 1064 nm takes place into the lower excited laser level (2). This has a very short lifetime and decays without emission into the ground state. This means that each of the levels is occupied to a certain extent. States 4 and 2, however, decay so quickly that the number of atoms in each of these states can be assumed to be close to zero. This means that the dynamic response of the laser can be described using the following rate equations for inversion density n (the difference in the number density of atoms in Nd energy levels 2 and 3) and photon density p of the laser field:

(1a) $$\frac{dn}{dt} = W \cdot (N_{Nd} - n) - \sigma \cdot c \cdot p \cdot n - \frac{n}{\tau_3}$$

(1b) $$\frac{dp}{dt} = \frac{L_{Nd}}{L} \cdot \sigma \cdot c \cdot p \cdot n - \frac{p}{\tau_{res}}$$

W: pumping rate
N_{Nd}: number density of Nd atoms
σ: effective cross section for emission or absorption of a photon
c: speed of light
τ_3: lifetime of excited laser level 3
L: length of resonator
L_{Nd}: length of Nd:YAG crystal
τ_{res}: time constant for resonator losses

In (1a) the first term relates to the optical pumping, the second refers to the induced emission and the third covers the decay from the top laser level via spontaneous emission. The first term in (1b) concerns creation of a photon by induced emission, while the second describes the fall in the photon density due to losses in the resonator. For greater accuracy, it is also necessary to take into account that photons are already present at the start of the process due to spontaneous emission.
For steady-state operation and disregarding spontaneous emission, the following solution is obtained:

(2) $$p = \frac{1}{\sigma \cdot c \cdot \tau_3} \cdot \frac{W - W_s}{W_s}$$

where $$W_s = \frac{1}{\tau_3} \cdot \frac{n_i}{n_i - N_{Nd}} \qquad n_i = \frac{L}{L_{Nd} \cdot \sigma \cdot c \cdot \tau_{res}}$$

The pumping rate therefore needs to exceed a certain threshold, after which the photon density rises linearly in proportion to the pumping rate. It is not possible to measure the photon density and pumping rate directly. Therefore the experiment will demonstrate that the output power of the laser PL is linearly dependent on the pumping power above a certain threshold.
Fig. 2 shows solutions of the rate equations for non-steady-state operation. In this case there is an initial rise in the photon population inversion. Once the threshold inversion ni has been reached, the inversion density increases linearly. There is a rapid rise in photon density and the inversion density falls to a value slightly below the threshold. As this process is repeated, the overshoot of the inversion density gradually decreases until the system settles into the steady state. The experiment will also demonstrate this so-called spiking.
First, though, the wavelength of the diode laser used for the pumping is calibrated to the transition where λ = 808 nm and then the change in the spontaneous emission over time is measured with the diode laser operating in pulsed mode (Fig. 3). From these measurements it is possible to determine the lifetime of the upper laser level. Once the resonator is set up and calibrated, spiking may be observed (Fig. 4). Finally the output power is measured as a function of the pumping power.

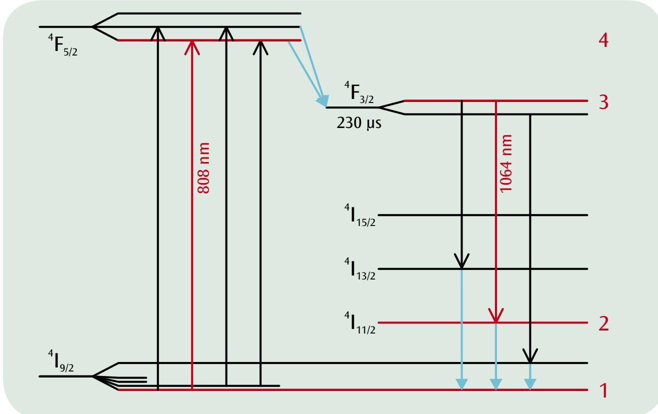

Fig. 1: Energy level diagram for Nd:YAG crystal. The transitions which are relevant to this experiment are indicated in red

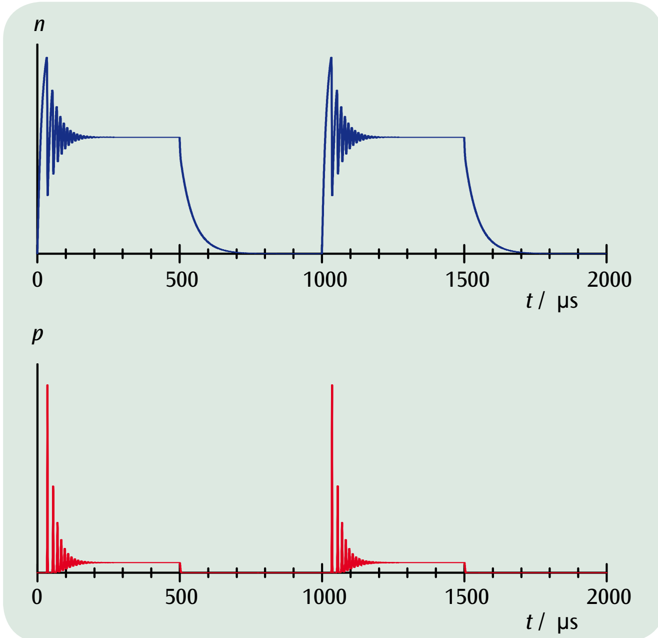

Fig. 2: Non-static solutions of the rate equations (spiking)

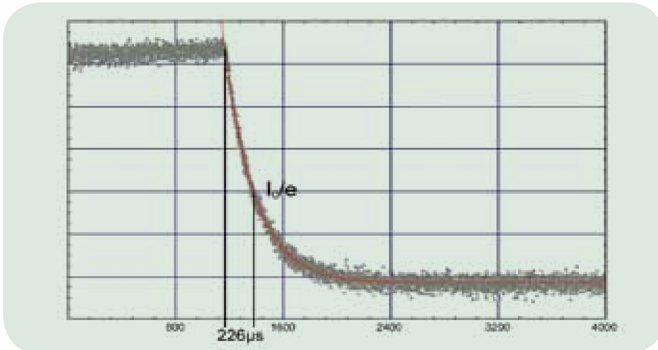

Fig. 3: Measurement of spontaneous emission in order to determine the lifetime of the upper laser level