GAIN MODULATION IN ERBIUM DOPED OPTICAL FIBRE BY PULSE PUMPING.

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ABSTRACT.

An erbium doped fibre laser, which is optically pumped at a wavelength of 532nm from a frequency doubled Q-switched Nd-YAG laser, is described. Gain modulation due to the short (100ns) high rep rate (2KHz) pump pulses produces intense, short laser pulses at 1.538μm. The properties of this laser are examined theoretically and experimentally.

INTRODUCTION

Sources to pump erbium lasers are limited by the excited state absorptions in erbium and the poor absorption cross-sections at diode laser wavelengths [1]. A frequency doubled Q-switched Nd-YAG laser is a possible source but this tends to produce less gain than would be expected. It is shown here that the reduction in average gain in pulse pumped erbium fibre is due to strong gain modulation by the pump pulses. In a laser configuration the gain modulation results in an intense short pulse of emission at 1.538 μm. Short pulses at this wavelength have many applications including OTDR for telecommunications fibre testing and optical range finders.

THEORY

In most laser systems the pump energy is continuous or from a pulsed source of which the pulse length is long compared with the lifetime of the absorbing level. In this case the pump pulses of wavelength 532nm have a pulse width of 100ns and a repetition rate of 2kHz. The simplified energy level diagram of figure 1 is referred to in this theoretical model. The pump band is the $^2H_{11/2}$ level {3} which has a lifetime of 1.6μs. Most of the ions in the pump band will decay by multi-phonon action to the meta-stable $^4I_{13/2}$ level{2}. The fluorescence life time of level {2} is 15ms. Erbium is effectively a 3 level laser emitting at 1.55μm.

To analyse the problem the basic rate equations for a three level laser [2] have been solved numerically. In this analysis N1,N2,N3 are the populations of ions in each of the energy levels and dN1,dN2 and dN3 are the changes in these populations. Initially the meta-stable level {2} is unpopulated. After the first short pump pulse level {3} has a population N3 equal to the reduction in population of the ground level dN1. The population of this level decays mainly nonradiatively to the meta-stable level {2}. We can ignore the weak visible transition to ground from level {3}. The population of level {2} will approach dn1 in a few micro-seconds. After the first pump pulse N2 is less than N1.
There is negligible decay of the population of level 2 between pump pulses. As the fibre is pumped by subsequent pulses the population of level {2} increases by dn1 after each pulse. In this analysis we are able to ignore the effects of nonuniform pumping to a first approximation.
After a number of pulses the inversion of level {2} will produce sufficient gain to overcome the resonator losses to produce a pulse

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of stimulated emission. Figure 2 shows the population of all the levels before and after pumping. There is a time delay between the pump pulse and the laser emission which shortens as the pump power or the pump repetition rate increases. Figure 3 shows the calculated laser pulse for various pump powers. After laser emission occurs the population of level {2} is clamped so that N2=N1 which is below the laser threshold. However if the pump power is large enough then there will be sufficient number of ions in level {3} to reinvert level {2} above threshold and produce further laser pulses as shown in figure 3. As the pump pulse power is increased the laser threshold will be attained due to depopulation of the ground level {1} by the pump pulse and not by an increase in N2 via level {3}. The delay between the pump pulse and the laser emission will only be due to the pump pulse duration and the laser cavity build up time which in this case is less than 100ns as seen in figure 3.

EXPERIMENT

The experimental laser is shown in figure 4. The pump is an intra-cavity frequency doubled Q-switched Nd-YAG laser. The pulse power absorbed in the fibre is up to 50W. This is sufficient to cause damage to a dielectric mirror when focused. For this reason the input end of the fibre also serves as the output coupler with 4% Fresnel reflection providing optical feedback. A dichroic beam splitter is used to separate the pump and output beams. Three metres of fibre doped with 150 molar ppm Er^{3+} was used as the gain medium. The far end of the fibre was butted up to a silvered mirror with a reflectivity of over 99%. The pump pulse and output laser pulses are shown in figure 5 for various pump powers. For an absorbed pump energy of approximately 3μJ a single laser pulse of 0.9 W is emitted. The delay between the pump and laser emission is 4us during which 91% of the excited ions have decayed from level {3} to level {2}. The pulse width was 280ns and the wavelength was 1.538μm. An increase in the pump energy produces 3 laser pulses, the first one 1.2μs after the pump pulse.

CONCLUSIONS.

We have shown that short intense pulses can be obtained from a fibre laser by pulse pumping a 3 level laser which is partially inverted. Nd-YAG lasers operating at 1.064 μm or 1.319 μm are frequently used in optical fibre analysis. However a suitable intense pulsed source at 1.55μm is previously only obtained by Raman shifting the Nd-YAG output or from a colour centre laser. The laser described here provides a convenient method for obtaining intense pulses at 1.538μm.

It is also noted that the depopulation of the ground state leads to a very high instantaneous gain. In an amplifier configuration, in which a frequency doubled Q-switched Nd-YAG laser is the pump, considerable energy will be lost due to amplified spontaneous emission during the high gain period. The average gain is therefore much less than for the equivalent cw pump source.

REFERENCES.

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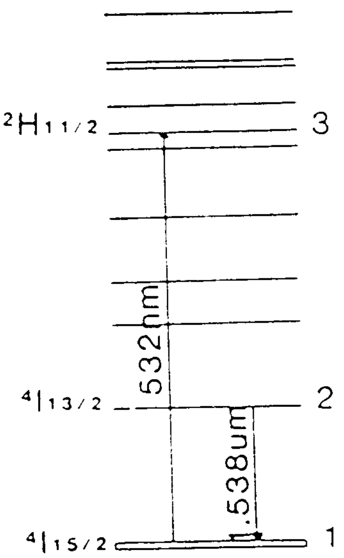

Figure 1.
Er^{3+} energy levels

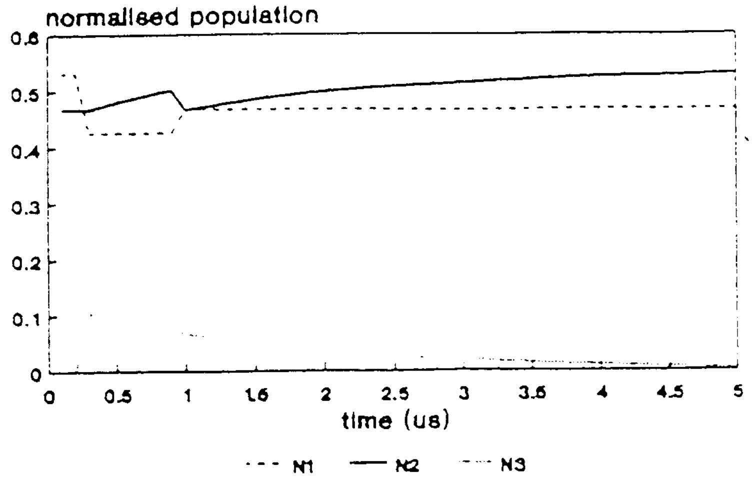

Figure 2. Population of energy levels during pulse pumping and laser emission.

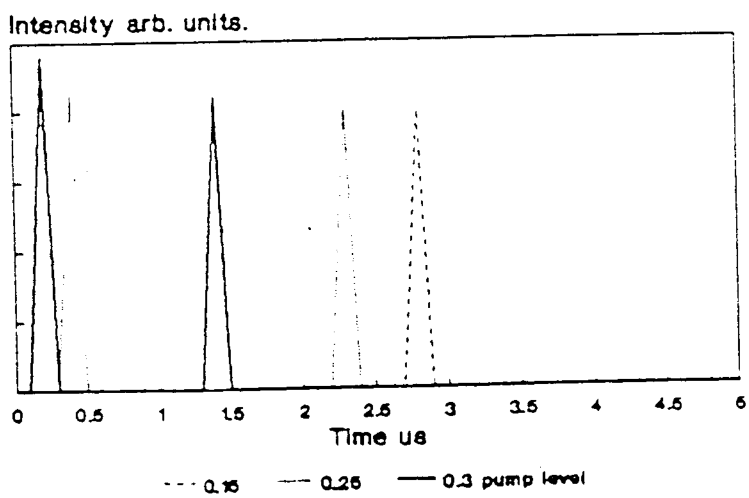

Figure 3. Computed output pulses for pumped excitations N3/N1 = 0.15,0.25,0.3.

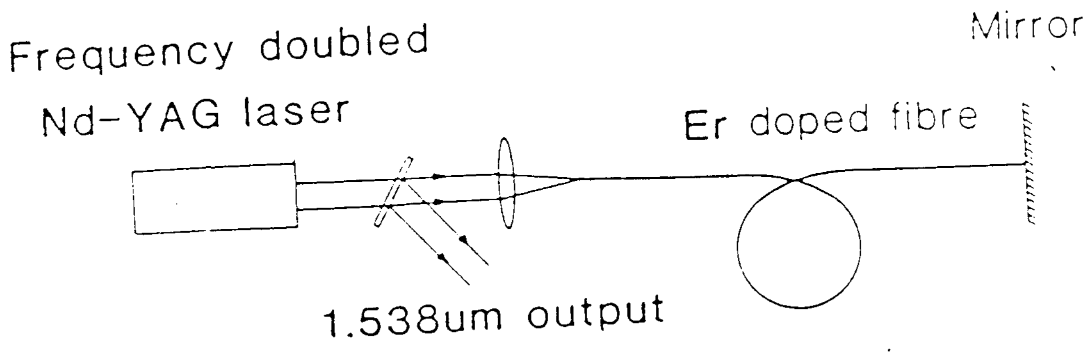

Figure 4. Schematic of pulsed erbium laser.

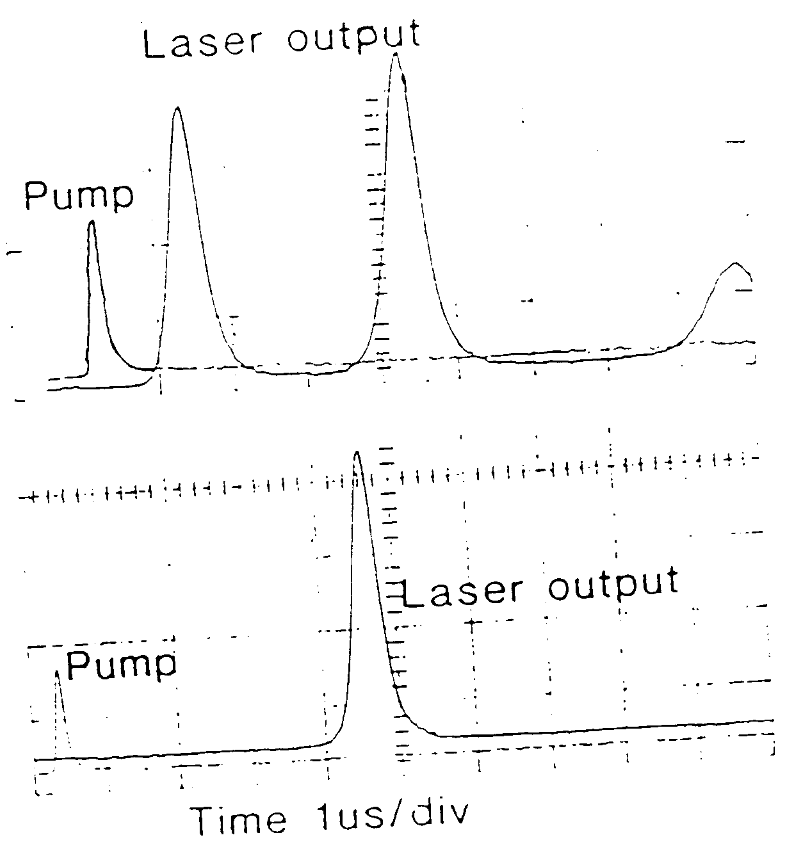

Figure 5. Output laser pulses at 1.538um for two different pump powers.