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Acousto-Optically Q-Switched Fibre Laser Source of High Peak Power and Short Duration Pulses for Fibre Sensor Applications

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We report on a fibre laser source which emits high peak power (>0.7 kW) and short (2.8 ns) Q-switched pulses at 1.06 μm suitable for distributed fibre sensor applications using an absorbed pump power of 13 mW and miniature acousto-optic modulator.

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Introduction

The generation of short optical pulses having high peak powers has a variety of applications within the fields of distributed temperature sensing[1], fibre diagnostics based on optical time domain reflectometry (OTDR)[2], and nonlinear fibre optics. Q-switching of rare-earth doped fibre lasers has been recently shown to be promising in this respect and in particular the use of highly doped phosphate glass fibre allows the use of short laser cavity while providing high gain.[3] A robust and low-cost method for Q-switching of fibre lasers is the use of acousto-optic modulator (AOM). So far, the use of AOMs for Q-switching have been limited by their speed, their modulation depth and the cavity length. The speed of the AOM and the attainable modulation depth are generally difficult to optimise simultaneously unless the device is designed carefully.[4] Maximum peak powers of 110 W at the wavelength 1.06 μm with 15 ns duration have previously been reported[5] for Q-switched fibre lasers based on the use of Nd^{3+} doped alumino-silicate fibre as the gain medium. In this work we used a specially designed fast AOM having high diffraction efficiency at moderate RF power levels in combination with a special high gain neodymium-doped glass fibre. Advantages of the AOM for Q-switching applications include low cost, small electrical power requirements (low voltage), small size facilitating the construction of robust, short cavity lasers and weaker polarisation and wavelength dependence. Furthermore, the frequency-dependent deflection angle in the AOM gives the possibility of wavelength tuning in addition to Q-switching.

Experimental:

A Neodymium-doped phosphate compound-glass fibre was used as the amplifying medium. The core material of the fibre was Schott LG750 (1% wt. Nd^{3+}) which was fabricated into a single-mode fibre with a compatible phosphate cladding glass using a rod-in-tube manufacturing technique described elsewhere.[6] The fibres with LG750 as the core material exhibit a gain of 0.95 dB per mW of pump for pumping at 812 nm, which is the highest gain coefficient reported so far for Nd^{3+} doped fibre amplifiers. In addition, the relatively high neodymium concentration of the fibre means that only a short fibre length is required to absorb the pump. The AOM Q-switch which was fabricated by Gooch & Housego[7], uses a TeO_2 crystal as the acousto-optic material, anti-reflection coated to give 0.1% reflectivity at 1.064 μm with 99.6% transmittance. This material was selected because of its high acousto-optic figure of merit (M_2 = 525), and high compressional wave acoustic velocity which allows simultaneously fast switching and high diffraction efficiency. The $LiNbO_3$ piezo-electric thickness mode transducer was designed to resonate at 125 MHz RF frequency with 4.25 mm interaction length. In order to obtain fast switching speed, a small optical beam waist must be used. A special design of top electrode was used, therefore, in order to apodise the acoustic beam and match its divergence to that of the optical beam, to maintain diffraction efficiency.[4] Under CW operation, the AOM exhibits >80% diffraction loss (in the 0^{th} order) and >65% diffraction efficiency in the 1^{st} order with 1.5 W RF power using a gaussian beam with 105 μm radius. Under pulsed operation with equivalent average RF power the diffraction loss is >70% (0^{th} order) and the diffraction efficiency is >50% (1^{st} order) for repetition rates as high as 10 kHz and RF pulse widths down to 10 μsec and 100 ns respectively. The measured rise time of the AOM under these conditions is 34 ns.

Figure 1 shows the Q-switching fibre laser setup. A 27 mm length of Nd^{3+} doped phosphate fibre was inserted into a silica capillary using conventional UV-cure adhesive and the ends of the capillary were polished perpendicular to the tube axis. A dichroic dielectric mirror having >99% reflection at 1.053 μm and >95% transmission at 810 nm was bonded with the UV-cure adhesive to one end. An inter-cavity quarter pitch GRIN lens was used to collimate the fibre output through the AOM and onto the 50% reflection mirror which acts as the output coupler. The beam radius of the collimated laser output was measured using the knife edge technique and estimated to be 105 μm. The total cavity length is 85 mm with the AOM occupying only 28 mm of it. A 50 mW laser diode operating at 810 nm was used as the pump source and was coupled into the fibre using conventional launch optics. Using an undoped fibre with similar waveguide characteristics the optimum coupling efficiency estimated to be 40-45%. With the ratio of the absorbed to coupled pump power being ~58% we determined that a maximum of 13 ± 1 mW of the incident 50 mW pump could be absorbed in the doped fibre.

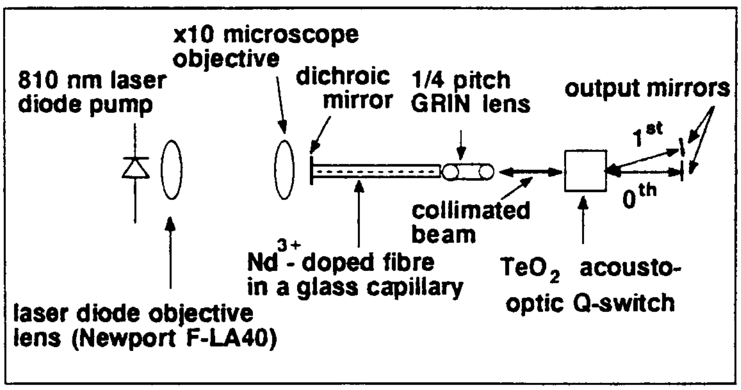

Fig.1 Schematic of the fibre laser Q-switching setup.

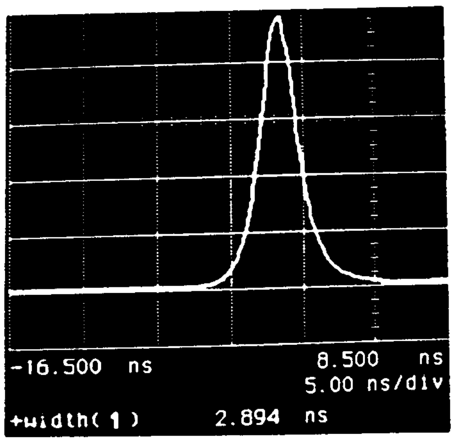

Fig.2 Typical oscilloscope trace of the Q-switched pulses.

Results and Discussion:

The maximum CW output level from this laser configuration was measured to be 7 mW with a slope efficiency of 55±3% and a threshold of 4.0±0.3 mW when the AOM is OFF under 0^{th} order operation. Although we performed experiments both under the 0^{th} order and the 1^{st} order configurations, the data presented in the figures correspond to 0^{th} order operation only. With the AOM being ON, the 16% transmission in the 0^{th} order is enough to prevent CW lasing with the highest available pump level. This property is one of the major reasons which allows for high population inversion to be achieved between the Q-switched pulses and consequently high peak power and short pulses to be emitted.[8] Under 1st order operation the maximum CW laser output was 1.5 mW with a slope efficiency of 30±3% when the AOM is ON and orientated so that a maximum diffraction is achieved. The 0th order beam was blocked inside the cavity to achieve the alignment easily and to avoid any feedback from this beam. The CW threshold with this configuration is higher (8.7 mW) because of the lower output of the AOM (52%) and the fact that the beam is distorted after being diffracted, thus reducing the launch efficiency back into the gain medium. It is worth noting here that this distortion has no effect in the 0th order configuration because the Q-switched pulses emitted in this case when the AOM is OFF.

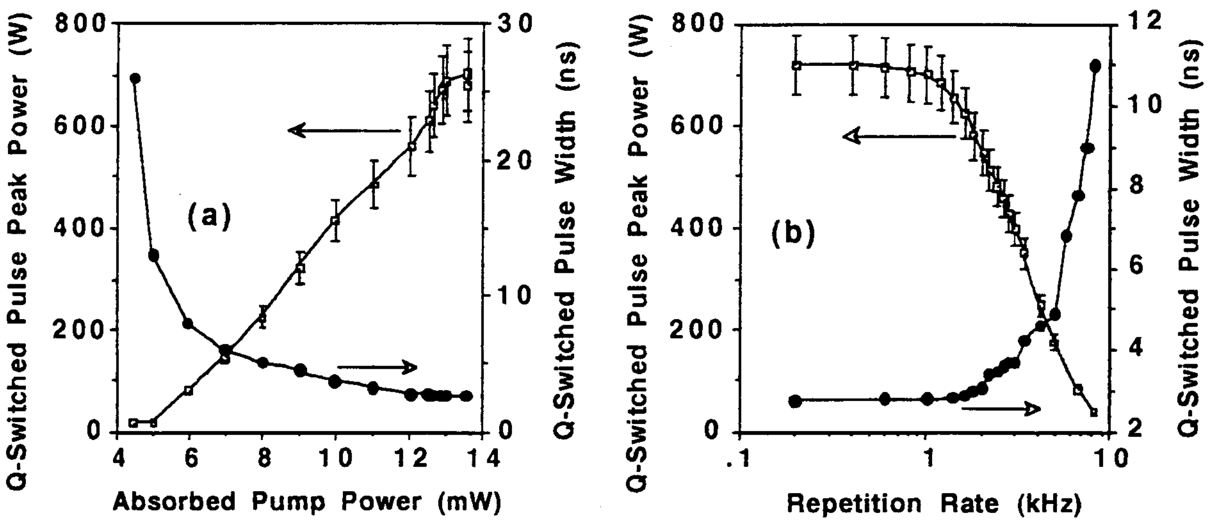

Fig.3 The Q-switched pulse peak power and duration versus the pump power (a) and the repetition rate (b) under 0th order operation.

Figure 2 shows oscilloscope trace of the output pulse shape at maximum pump power. The height of the pulse corresponds to 702 W and the width is 2.8 ns using 1 kHz repetition rate. Figure 3a shows the variation of the peak power and pulse duration with the absorbed pump power. For 0th order operation, a further increase of the pump power above 13.6 mW will cause the peak power to drop because the AOM is not able then to prevent CW lasing between the pulses. By overdriving the laser diode for short times we observed such decrease in the peak power as shown in the few measured values around 13.5 mW. With the 1st order operation on the other-hand the AOM is able to prevent CW lasing between the pulses for any pump level up to the bleaching level of the neodymium ions in such a fibre length. After solving the kinetic laser equations[6] we predict[9] that one should be able to get peak powers of the order of a kW and pulse durations of 1.4 ns using 26 mW absorbed pump power which is easily achievable from a 100 mW laser diode. In the 1st order operation the RF pulse width (100 ns) and average RF power (0.5 mW) are smaller by a factor of 100 than those used in the 0th order operation. This is an advantage of the 1st order operation, not only because of energy consumption considerations, but also to avoid the heating of the AOM usually associated with larger RF pulse widths and higher RF powers. The dependence of the pulse peak power and duration on the repetition rate are shown in Figure 3b. Above 1.5 kHz the peak power starts to decrease significantly and the pulse duration to increase as expected for a medium with an upper-level lifetime of 305 μsec. This is because there is not enough time for the population inversion to reach its maximum value during the time between the pulses.

Conclusions:

In conclusion, we have obtained >0.7 kW peak power Q-switched pulses with 2.8 ns duration from a laser-diode pumped Nd-doped fibre laser for only 13 mW of absorbed pump power using 0^{th} order operation of a specially designed fast acousto-optic modulator having high diffraction efficiency. Under 1^{st} order operation we obtained pulses of >150 W peak power and 4 ns duration but with the average RF driving power smaller by a factor of 100 (0.5 mW) than the 0^{th} order operation. These are the largest peak powers and shortest pulse durations obtained to date from a diode-pumped, acousto-optically Q-switched fibre laser source. The improved performance over previous acousto-optically Q-switched fibre lasers has been achieved by the use of a short, high-gain phosphate glass fibre and a fast acousto-optic modulator with high diffraction efficiency. It is anticipated that this fibre-laser source of short, high peak-power pulses will be of considerable use in distributed fibre sensor systems and for fibre diagnostics such as OTDR.

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