Conclusion: These experiments show that a sapphire resonator can be excited by the thermal effect. The vibration of a bar in a flexural mode, described here, was generated by heating a thin layer vapour-deposited on one side of the bar. The mechanical displacement was detected by an optical method. A Q-factor of 800 000 has been measured for the bar vibrating at a resonance frequency of 20 262 Hz in an environmental pressure of about 0·2 torr. This figure shows that sapphire crystals can, as expected, compete with quartz crystals with regard to the Q-factor. Further experiments are necessary to examine the operation of different modes of vibration, the practical range of frequencies and the influence of the temperature. It should also be interesting to study other possible techniques of excitation[2] and detection.[3,4]

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E. DIEULESAINT
D. ROYER
X. SERVAJAN

Laboratoire d'Acoustoélectricité
de l'Université Pierre et Marie Curie
10 rue Vauquelin, 75231 Paris Cedex 05, France

13th January 1986

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MODE-LOCKING OF A NEODYMIUM-DOPED MONOMODE FIBRE LASER

Indexing terms: Lasers and laser applications, Doping

A neodymium-doped monomode fibre laser operating at 1·08 μm has been actively mode-locked using intracavity acousto-optic loss modulation. The mode-locked laser output consisted of a train of pulses of less than 1 ns FWHM with an energy of ~17 pJ at a repetition rate of 41·45 MHz. When the laser was simultaneously Q-switched the peak power of the mode-locked pulses inside the 690 ns-wide envelope was enhanced by more than three orders of magnitude.

Introduction: Rare-earth-doped monomode fibre lasers have previously been demonstrated to operate continuously.[1] It has also been demonstrated that these lasers can be Q-switched by acousto-optic switching or mechanical chopping and produce peak powers of several watts.[2] In this letter we report the first demonstration of mode-locking in a fibre laser.

Experiment: The laser cavity (Fig. 1) is similar to that described by Alcock *et al.*[2] The active medium was a 2 m length of Nd^{3+}-doped low-loss fibre (which was monomode at about 1 μm).[3] The pump laser was a continuous-wave rhodamine 6 G dye laser operating at 590 nm which was launched through a butted high reflector ($R \simeq 98.5\%$ at 1·08 μm). An acousto-optic rhomb mode-locker (Crystal Technology) with Brewster-angled surfaces was inserted between the intracavity × 10 microscope objective and output coupler ($R \simeq 70\%$). Since the fibre was not polarisation-preserving, two λ/4 plates were used to convert the elliptically polarised output from the fibre into vertically polarised radiation and so reduce the reflection loss off the Brewster surfaces.

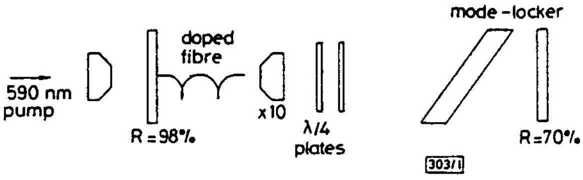

Fig. 1 *Cavity arrangement*

When radio-frequency power was applied to the transducer on the mode-locker, an acoustic standing wave was set up in the rhomb. This produced a time-varying refractive index grating and caused Bragg diffraction of the incident 1·08 μm laser beam, thereby effecting cavity loss modulation. Since the resonances of the high-Q transducer were highly temperature-dependent, it was found necessary to mount the mode-locker in a temperature-stabilised enclosure.

The output coupler was mounted on a translation stage so that the frequency difference between longitudinal cavity mode beats could be matched to the loss modulation frequency. Simultaneous Q-switching and mode-locking was achieved by also inserting a mechanical chopper wheel between the modulator and intracavity microscope objective.

The laser output was detected by a Ge photodiode and the amplified photocurrent fed into a Tektronix 7L14 RF spectrum analyser. With no RF power applied to the mode-locker the laser output cintained weak longitudinal cavity mode beats. When RF at 20·723 MHz was applied to the mode-locker and the cavity length was adjusted to match the loss modulation frequency, the beats became stronger and narrower. Eventually higher harmonics appeared and dramatically increased in intensity as the RF power was increased. The RF spectrum (Fig. 2) shows the comb of modes obtained with 250 mW of RF power applied to the mode-locker. The high-frequency roll-off is due to the bandwidth of the amplifier and detector.

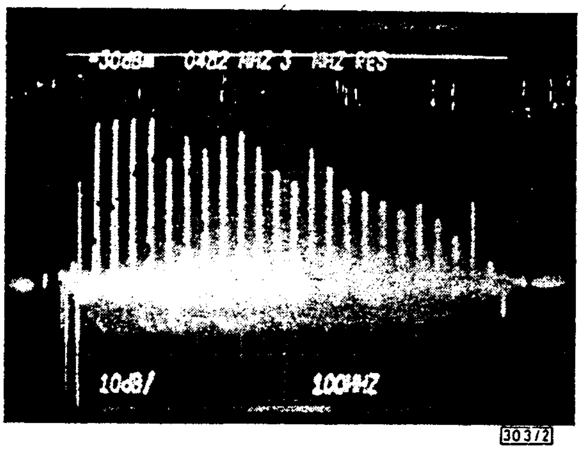

Fig. 2 *Comb of modes*

The laser output was then studied in the time domain using a fast detector (RCA CA309709E, FWHM resolution of ~60 ps) and oscilloscope (Tektronix 7A19 amplifier in a 7904 mainframe). The laser output consisted of a train of short pulses with a repetition rate corresponding to the cavity round-trip time. The pulse shown in Fig. 3 has an FWHM of less than 1 ns, limited by the 400 MHz bandwidth of the oscilloscope, and an energy of ~17 pJ. The structure around the pulse is believed to be due to etalon effects in the cavity.

With the laser mechanically Q-switched the output consisted of a train of pulses whose FWHM was less than 3 ns, inside a 690 ns envelope (Fig. 4). The energy of the largest pulse in the envelope was ~20 nJ. Structure was seen on the mode-locked pulses and is again believed to be due to etalon effects in the cavity. In addition, the build-up time for the Q-switching was not long enough for a steady state to be reached, and so the pulses would be longer than the CW case.

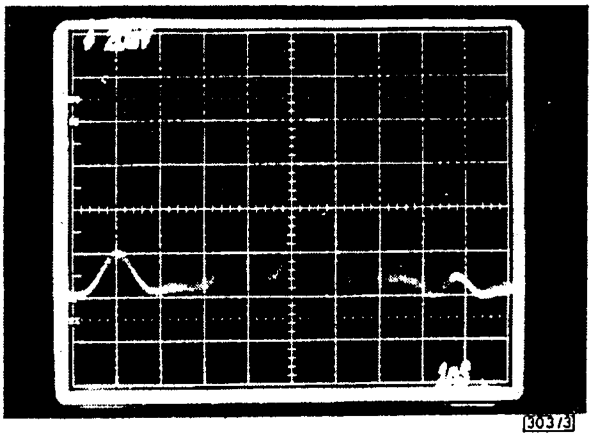

Fig. 3 *Mode-locked pulse*

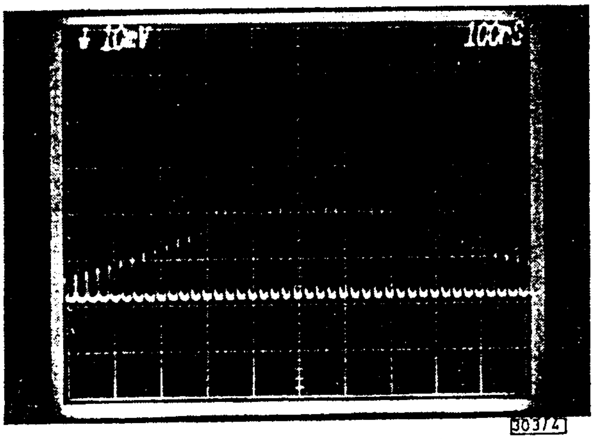

Fig. 4 *Q-switched and mode-locked train of pulses*

Discussion: Although the laser gain bandwidth of the broad rare-earth transition in glass fibres offers the potential of the generation of very short mode-locked pulses, there are a number of possible limitations which need to be eliminated before the shortest pulse duration can be achieved.

We have observed that the lasing bandwidth is influenced by etalon effects in the cavity, and have therefore attempted to eliminate these effects where possible, for example by using a long focal length intracavity microscope objective and Brewster-angled surfaces on the mode-locker. However, some etalon effects still remain. Since the output endface of the fibre was neither wedged nor antireflection-coated, immersion in index-matching liquid may provide a solution to this problem.

Since the length of the active medium is significantly greater than in conventional laser systems, and the small mode size (a few micrometres) leads to high intensities, the frequency chirp produced by second-order dispersion and self-phase modulation could have an important influence on pulse duration when these systems are mode-locked. The higher peak power available when the system is Q-switched greatly increases the degree of self-phase modulation and is approaching the level at which other nonlinear effects such as stimulated Raman scattering can be expected to occur.

However, the presence of self-phase modulation also provides scope for obtaining pulse compression in fibre lasers operating in the negative group-velocity dispersion region, such as 1·5 μm operation in Er^{3+}-doped fibres,* with soliton propagation in the laser medium itself as an interesting possibility.

In conclusion, we have demonstrated mode-locking and simultaneous mode-locking and Q-switching of a fibre laser. Further analysis of the etalon effects and nonlinear effects is in progress, aimed at achieving shorter pulse durations. A prelase scheme is also being examined which would allow the pulse duration to approach the steady-state value under conditions of simultaneous Q-switching and mode-locking.

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I. P. ALCOCK
A. I. FERGUSON
D. C. HANNA
A. C. TROPPER

Physics Department
University of Southampton
Southampton SO9 5NH, United Kingdom

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ERROR-CORRECTING CODING FOR BANKING DOCUMENT BAR CODES

Indexing terms: Codes, Reed–Solomon codes, Bar codes, Error-correction codes

Bar codes, used for the automatic processing of financial payment records, may be protected by extended Reed–Solomon codes over prime field alphabets. New decoding methods which handle both random and erasure errors are presented.

Introduction: Bar codes are currently being used as a means of enhancing the processing of financial documents sucn as bank cheques. In one implementation, cheques are routed automatically through the banking system's return paths by means of bar codes printed on the back of each item. As each document passes through a high-speed sorter, a bar code reader senses the records printed by previous processing institutions and optionally applies additional records for further processing by other institutions.

Several formats have been proposed[1] for the bar code symbols and for the record structures, and the most popular and technically promising ones are likely to be based on decimal or hexadecimal alphabets, i.e. 10 or 16 information symbols. However, most formats are designed to accommodate relatively short records which can be printed at various decision points in the documents' processing paths. An additional synchronisation symbol is usually included in the alphabet, giving either 11 or 17 symbols. However, these values correspond with prime finite fields for which powerful extended Reed–Solomon codes exist. The emphasis in the following discussions is on the decimal format because the hexadecimal scheme is a straightforward extension of these techniques.

Extended Reed–Solomon code over prime finite field, GF(p): A standard Reed–Solomon code can be extended by adding two more check digits, increasing the minimum distance by two.[2,3]