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Passive harmonic mode-locking of soliton fibre lasers

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ABSTRACT

We show that low time jitter of a harmonic passively mode-locked laser can be obtained at repetition rates close to acoustic eigen-frequencies of the optical fibre.

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Passively mode-locked fibre soliton lasers (FSL) are attractive optical short pulse source for laboratory and telecommunications applications. The energy quantization effect caused by the soliton regime of operation of FSLs results in excellent stability of the duration and energy of the individual pulses, but also leads to pulse repetition rate instabilities which for many applications is unacceptable. Recently, we have experimentally demonstrated that, under certain conditions, stable passive harmonic mode-locking occurs in a ring laser configuration [1], and time jitter as low as 600 fs can be obtained at a repetition rate as high as 463 MHz in a fully passive ring configuration [2].

In this paper we present the further investigation of this effect and show that a passive self-stabilization effect driven by transverse acoustic waves due to electrostriction becomes much stronger when the laser repetition rate is close to an acoustic eigen-frequency or its k-th harmonic.

The physical idea lying behind this phenomenon is quite simple: each pulse excites a weak acoustic wave which causes a change of the refractive index ($\sim 10^{-12}$ for 1 ps pulses). When several pulses exist inside the laser cavity (each generating an acoustic wave) after several round-trips all of them are trapped by the acoustic field of their predecessors which results in passive phase modulation. If σ_T is the time jitter of the harmonically mode-locked laser then it can be shown [2] that $\sigma_T \sim (\delta n)^{-1/2}$, where δn is the refractive index change induced by the soliton stream.

To find the value of the refractive index change induced by N (>> 1) pulses travelling inside a FSL we have applied the theory developed in [3]. The solution of the wave equation can be treated as a solution for a damped harmonic oscillator with an external force. Thus one can expect strong enhancement of the refractive index perturbation (and consequently low jitter) at the repetition rates coinciding with acoustic eigen-frequencies. Our computer simulations have revealed that for stable operation the repetition rate should be slightly detuned from the corresponding resonant frequency.

Fig.1 shows the calculated temporal dependencies of refractive index change for 467 MHz repetition rate and damping time of 10 μsec. One can see that the refractive index perturbation increases $\sim 10^3$ times and its temporal variation looks like that produced by a conventional phase modulator. Note also, that refractive index enhancement occurs not only at resonant frequencies but also at its harmonics which makes its spectral dependence rather complicated.

Knowing the acousto-induced refractive index change and using the expression for the time jitter, derived in [2], we can obtain the dependence of σ_T on repetition frequency. The solid curve in Fig.2 represents the calculated time jitter and circles are experimental data from [2] which fit reasonably well with theoretical results.

In conclusion we have shown that substantial enhancement of the refractive index perturbation and consequently lower jitter occur when the repetition rate of a harmonic passively mode-locked laser is near an acoustic eigen-frequency of the FSL fibre.

REFERENCES

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FIGURE CAPTIONS

Fig.1 Temporal dependence of the refractive index change when the laser repetition rate is equal to the 10-th acoustic eigen-frequency of the laser fibre. Refractive index change due to action of a single soliton is about 10^{-12}.

Fig.2 Time jitter as a function of repetition frequency. Solid curve - theory, circles - experiment.

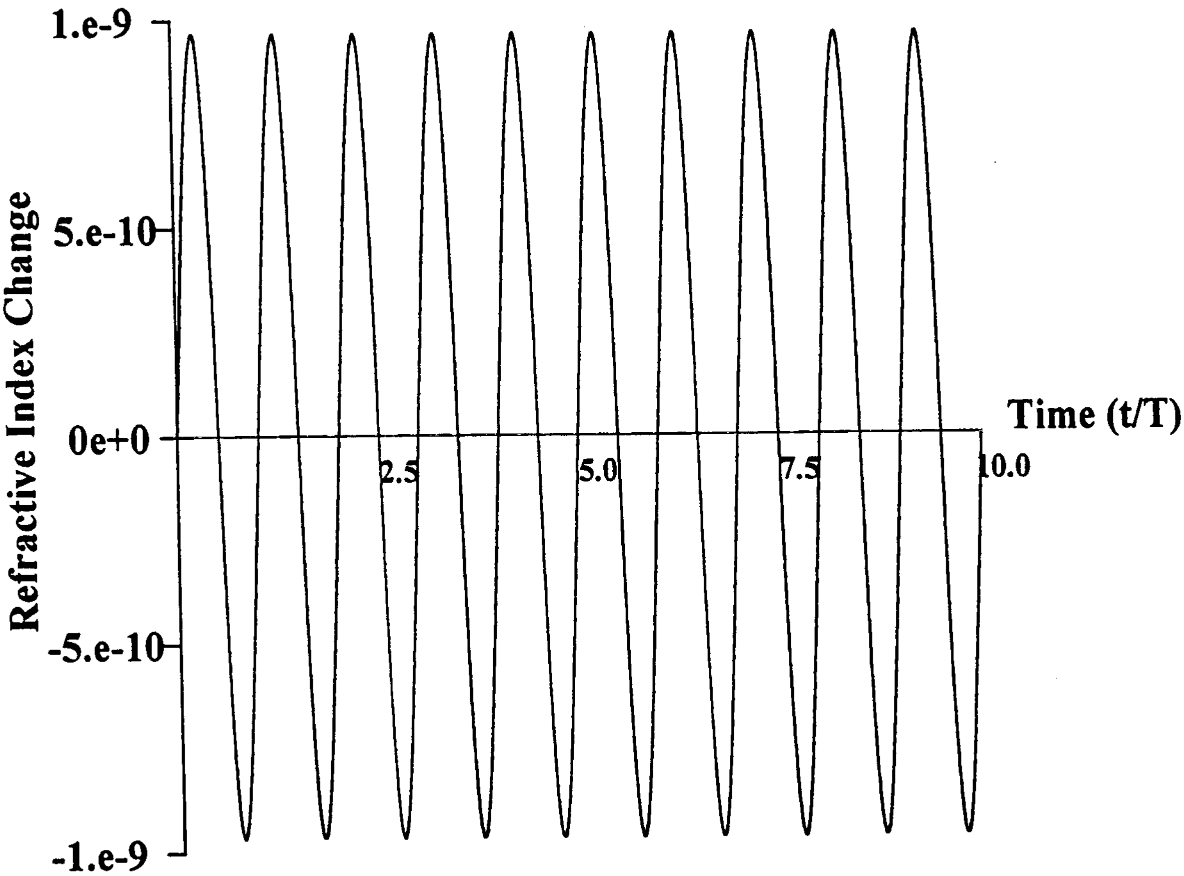
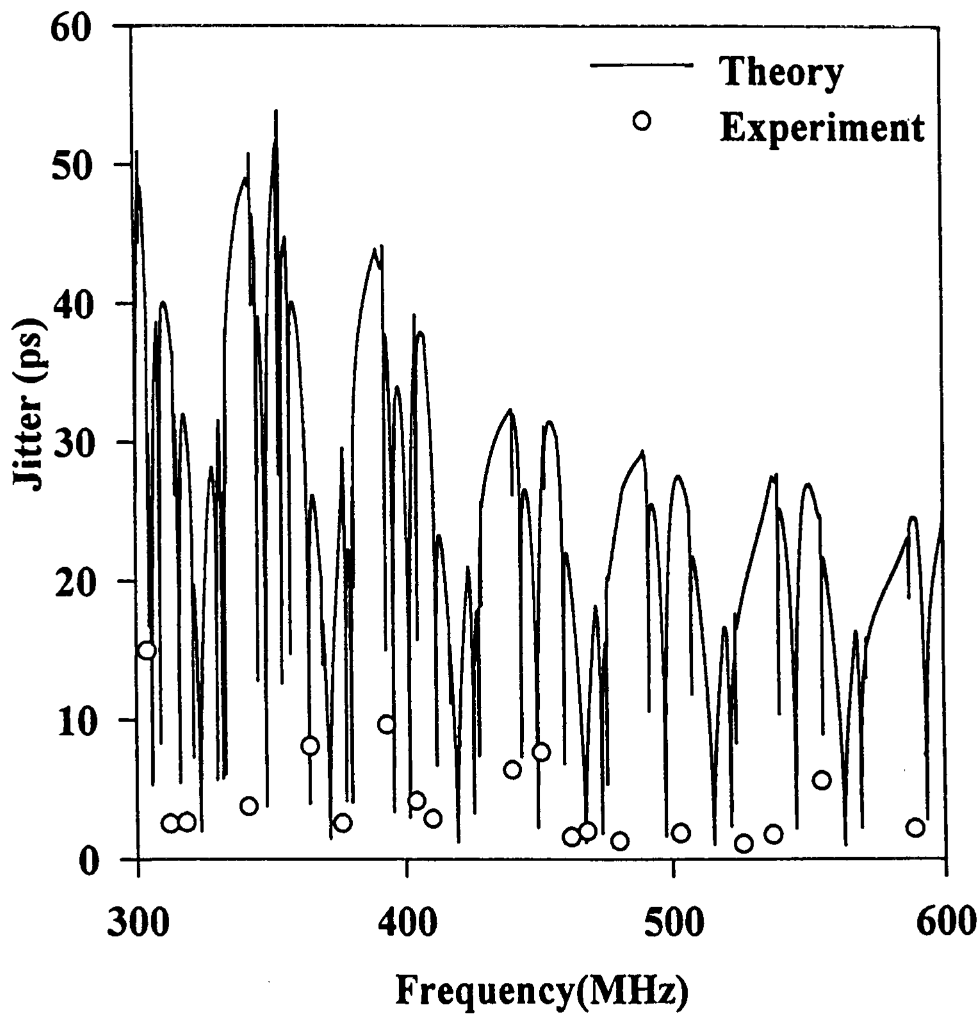

1.e-9
5.e-10
0e+0
-5.e-10
-1.e-9
Refractive Index Change
Time (t/T)
2.5
5.0
7.5
10.0

Fig 1



60
50
40
30
20
10
0
Jitter (ps)
Theory
Experiment
300
400
500
600
Frequency(MHz)

Fig2