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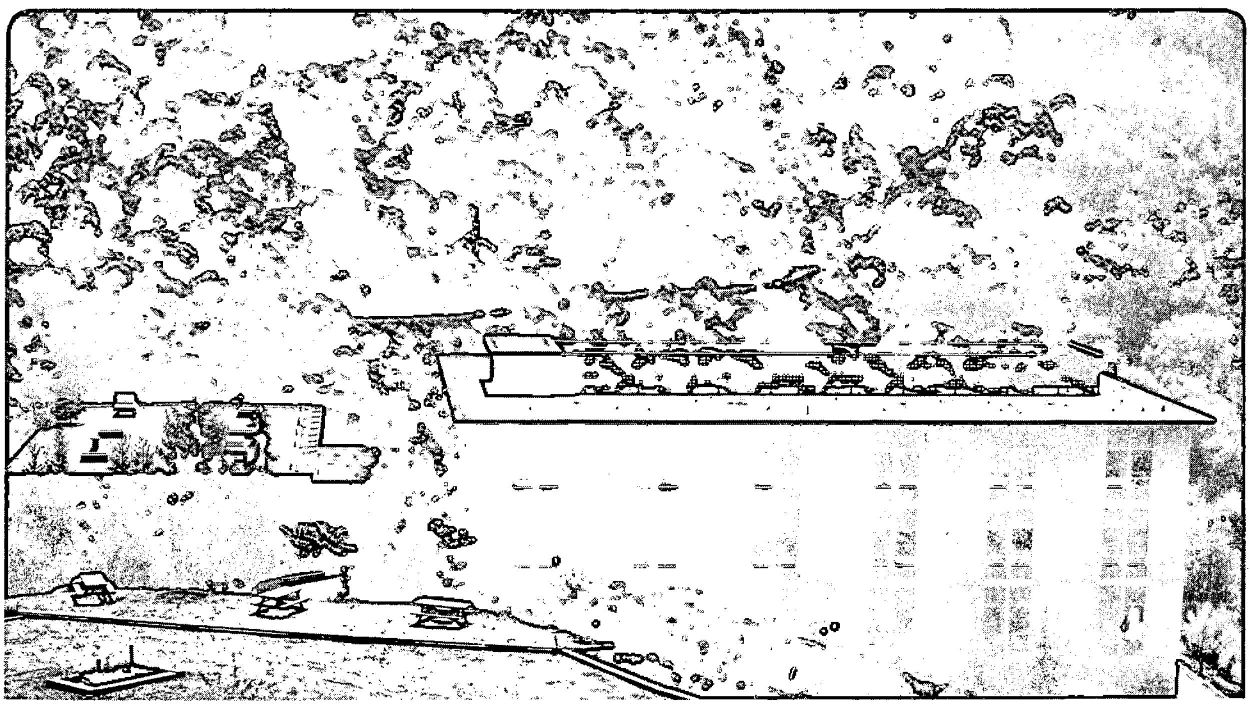

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Nonlinear dynamics have been studied in a number of modelocked laser systems, primarily in actively modelocked systems. However, less attention has been paid to the dynamics of passively modelocked laser systems. With the recent revolutionary advances in femtosecond modelocked laser technology, the understanding of instabilities and dynamics in passively modelocked lasers is an important issue. Here, we present experimental and numerical studies of the dynamics of an additive-pulse modelocked (APM) color-center laser. However, it is important to note that our discussions are more general, and apply to other types of passively modelocked lasers, because we have also observed these dynamics in a self-modelocked Ti:sapphire laser, and in a modelocked Er:fiber laser as well. The APM laser and the other above mentioned lasers are all examples of lasers using a fast saturable absorber (FSA).

We have studied two types of APM lasers; the Fabry-Perot APM[1,2] and the Michelson APM.[3] Both were based on a color-center laser which used NaCl as the gain medium. The Fabry-Perot APM laser consists of a main cavity (containing the NaCl gain crystal) and a control cavity which contains a single-mode fiber to provide the Kerr nonlinearity. These two cavities are coupled end-to-end in the Fabry-Perot configuration. When passively modelocked at a power of P=200 mW, the laser produces pulses of less than 150 fsec duration, at a repetition rate of 76 Mhz, corresponding to a pulse spacing of 13 nsec. At a slightly higher power, (P=240 mW), a period-doubled pulse train is produced (Figure 1[a]), and at even higher power (P>280 mW), a quasiperiodic pulse train is generated (Figure 1[b]). Yet the measured pulse intensity autocorrelations still indicate relatively short pulses ($\tau \sim 150$ fsec).

Numerical simulations of the Fabry-Perot APM laser show that this period-doubling is expected as the nonlinearity is increased. The bifurcation diagram in Figure 2 shows how the laser pulse energy varies as the control cavity nonlinearity is increased. First, the laser goes from CW to modelocking (the "second-threshold"). As the nonlinearity is increased, the pulses get shorter and shorter until the laser goes to period-doubled modelocking. With further increases in n_2 the

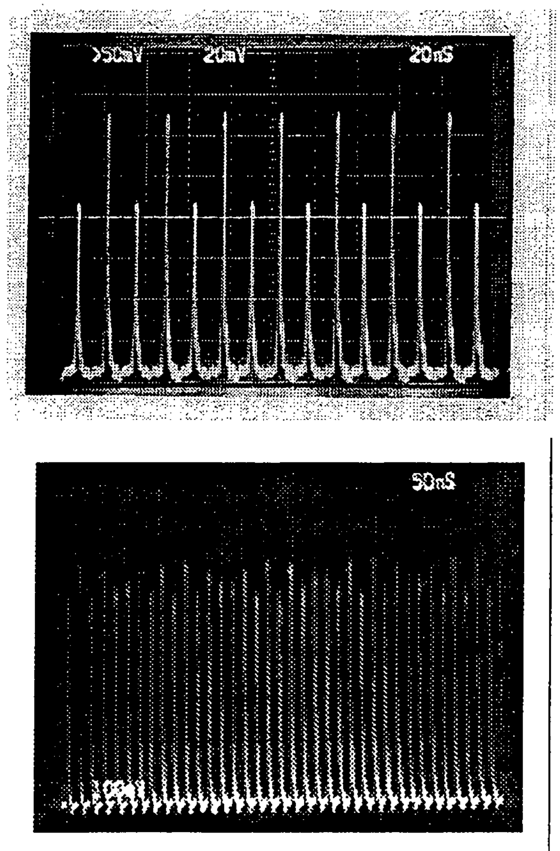

Figure 1. Period-doubled pulse train (a) and quasiperiodic pulse train (b) from APM laser. Note that pulse spacing is 13 nsec in both traces.

laser makes a switching transition to another period-doubled mode, and then a sudden transition to apparent chaos, indicating a crisis.

The figure also shows the pulse solutions at two values of nonlinearity. Note that the pulse solutions for the upper and lower branches have very different intensity profiles.

We have also studied and numerically simulated the Michelson APM laser and have found that it exhibits none of these effects, no matter how large the nonlinearity is made, or how hard the laser is driven. The only instabilities encountered in reality were relaxation oscillations. This agrees with previous observations by Grant[4] who did an experimental comparision between the F-P and Michelson configurations. In the simulations of the Michelson APM, as the nonlinearity is increased beyond the normal bounds, the modelocked pulse becomes distorted, broadened, and develops multi-peaked structure, but no pulse train instabilities were generated. This also agrees with the predictions of Cormier & Piché.[5]

Another type of APM laser cavity is the "figure-8" configuration, which has been used for modelocked Er:fiber lasers. We might expect this to be similar to the Michelson cavity in terms of behavior; however, we have not considered this case yet.

In conclusion, we have studied the nonlinear dynamics of pulse train instabilites and pulse reshaping in APM lasers using two different cavity configurations. These results are important for understanding the general behavior of various types of self-modelocked lasers which use fast-saturable absorber effects.

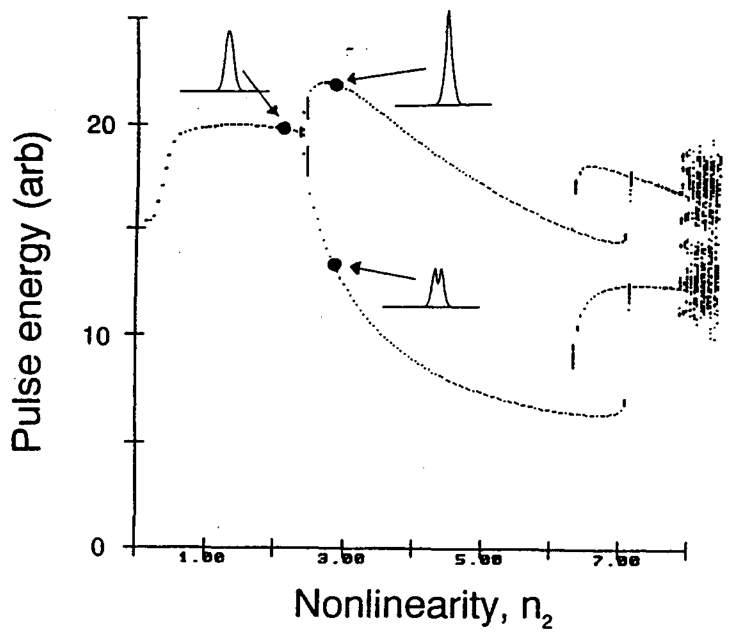

Figure 2. Bifurcation diagram of (simulated) laser pulse energy versus nonlinearity for a Fabry-Perot APM laser. Pulse solutions are shown for two values of nonlinearity: one for normal modelocking ($n_2 = 2.3$) and two for period-doubled modelocking ($n_2 = 2.8$).

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