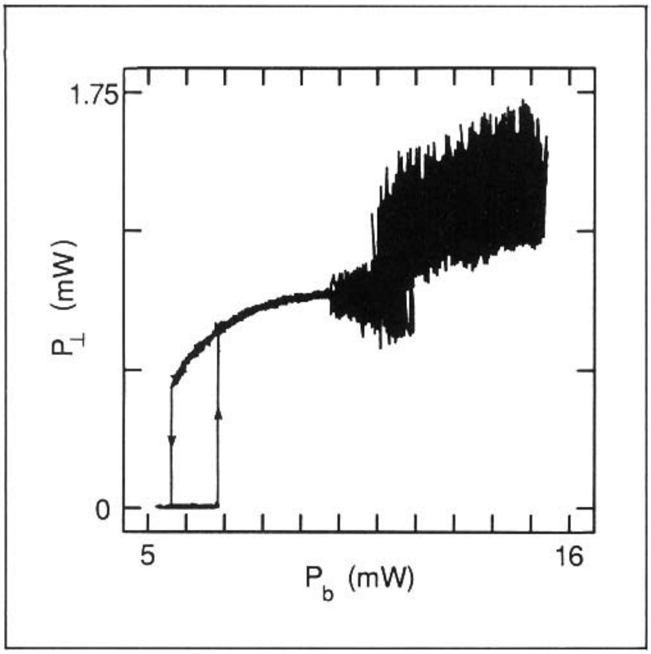

Output power of the forward wave emitted in the polarization component orthogonal to that of the input waves, plotted versus the input power of the backward wave. For low input powers (less than 8 mW), the system shows a hysteresis loop, whereas for higher input powers, the system shows periodic and chaotic fluctuations.

por. We find that this system displays highly complex dynamical features, including bistability and chaotic instabilities involving the polarizations of the transmitted waves. These observations are intriguing because bistability and chaos usually require that feedback be imposed externally; in our experiment, feedback was present only due to the nonlinear coupling of the two counterpropagating beams.

The observation of dynamical instabilities due solely to the mutual coupling of two interacting beams is of practical importance because counterpropagating beams are present in many nonlinear optical devices. Furthermore, the observation of intrinsic bistability in this system suggests potential applications of this phenomenon in optical switching.

There has been considerable theoretical interest in studies of the dynamical behavior of counterpropagating laser beams in various nonlinear media. Silberberg and Bar-Joseph[1] have studied the propagation of counterpropagating waves through a scalar Kerr medium. They found that for a medium with noninstantaneous response, the intensities of the transmitted waves could fluctuate periodically or chaotically in time. Such effects have been observed experimentally by Khitrova et al.[2] Several authors[3] have studied theoretically the propagation of counterpropagating vector waves through a tensor Kerr medium and have found that the steady state polarizations of the transmitted fields could be multivalued. Gaeta et al[4] have studied theoretically the dynamical behavior of propagation through a nonlinear medium with tensor properties and have found that the states of polarization of the transmitted waves could become temporally unstable. In most cases, the threshold for this polarization instability is lower than that of the intensity instability of Silberberg and Bar-Joseph.[1]

In our experiment, the output of a single mode dye laser tuned near the D_1 sodium resonance line was split into two beams with linear and parallel polarizations sent counterpropagating through a sodium vapor cell. The experiment entailed measuring the power of one polarization component of the transmitted forward beam, whose input power was held fixed at 74 mW, while the input power in the backward beam was slowly ramped up to 16 mW and back to zero. Typical results showing bistability, hysteresis, and temporal instabilities are presented in the figure. At a power of 9 mW, the polarization abruptly switches from the original state to a state with $\sim$0.55 mW in the orthogonal component. As the power P_b is increased further, the power in the orthogonal component continues to increase until P_b is $\sim$13 mW, where the system becomes temporally unstable. As the power P_b is slowly decreased, the system returns to a dynamically stable state and the output power in the orthogonal component remains on the upper branch until P_b reaches 2 mW, where the polarization switches abruptly back to the initial state.

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Lorenz-like dynamics in coherently pumped lasers

R. Corbalan, Universitat Autonoma de Barcelona, Spain and R. Vilasecz, Universitat de Valencia, Spain

A very active and profound revolution in science ignited some 25 years ago with the realization, after the pioneering work of Lorenz,[1] that, just as quantum systems and systems with a large number of particles are unpredictable, low-dimensional, deterministic nonlinear systems also are able to display transitions not only from disorder to order (synergetic behavior) but also from order to complexity (temporal and spatio-temporal instabilities and chaos).

This revolution entered the field of optics[2] around 1975 with Haken's discovery[3] of the isomorphism between the three Lorenz equations[1,4] and the single mode homogeneously broadened laser equations. Unfortunately, the experimental realization of a chaotic Lorenz-Haken laser has proven a challenging problem, in spite of the fact that, since the beginning of experimental studies in lasers, they have shown irregular dynamical pulsations. Only recently, a coherently pumped far-infrared ammonia laser has allowed the first observation of a behavior remarkably similar with the predictions of the paradigmatic Lorenz-Haken model.[5,6]

However, the theoretical understanding of the dynamics of this ammonia laser on the basis of the Lorenz-Haken theory, has raised considerable controversy [5,7,8] for the inability of this model to describe important physical aspects of the real system. Thus, while two-level (i.e., incoherently pumped) lasers are considered in the Lorenz-Haken model, coherently pumped lasers operate on a three-level scheme. In such conditions, the coherent pump laser field not only affects the populations of various energy levels, but can also induce a strong interaction with the generated field through nonlinear coherent effects such as the Ramon process and the AC Stark effect. This can result in new dynamic features of the coherently pumped lasers.[2b,7,9]

Indeed, the numerical study[10] of a homogeneously-broadened three-level laser model—for a parameter range appropriate for the ammonia laser—revealed striking differences between the theoretical predictions and the experimental observations[5] of Lorenz-like behavior in this laser.

By our incorporating the Doppler-broadening in the three-level laser model, considering operation in the backward emission direction, as in the experiments[5], and analyzing the dynamics of the laser phase in addition to that of intensity, we have been able to reproduce[8,11] qualitatively the main experimental features of the heteroclynic or Lorenz-type behavior observed in the experiments[5], including instability pump threshold, detuning-pump bifurcation diagram, and symmetric spiral attractor. The incorporation of the Doppler broadening complicates considerably the laser model, which in our case was composed by 217 coupled ordinary differential equations. It is remarkable that such a complex model predicts a behavior so similar to that of the simple three (or five for the detuned laser) equations model for the Lorenz-Haken laser.

Coherently pumped lasers have thus become most interesting systems for nonlinear dynamics with the first demonstration of Lorenz-like dynamics in the real world. Moreover, these lasers are very versatile systems that include as limit simple cases the two-level laser (when coherent pumping effects are eliminated) and the Raman laser (when the detunings of the pump and generated fields are equal and much larger than the molecular transitions linewidths). We believe they have also produced evidence of two rather general aspects: (1) that highly-dimensional dynamical systems can approach asymptotically in time-low dimensional attractors, and (2) that the dynamical behavior of lasers usually proves resistant to a qualitative understanding on the basis of simple models that, instead, yield a satisfactory explanation of the stable output emission.

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Second harmonic generation in periodically-poled $LiNbO_3$

G.A. Magel, E.J. Lim, M.M. Fejer, and R.L. Byer, Stanford University

Compact, solid-state sources of coherent blue light have applications in biomedicine, displays, printing, and optical storage. Because blue semiconductor diode lasers are not currently available, techniques for the efficient nonlinear optical frequency conversion of infrared diode