Studies of nonlinear dynamics in an end-pumped solid-state laser near degenerate resonator configurations

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Abstract

We used Collin's integral together with rate equations to study the nonlinear dynamics of an axially pumped solid-state laser operated near degenerate cavity configurations with a plano-concave cavity. When the pump size is larger than the fundamental mode size, we found propagation-dominant instabilities and chaos under the so-called good-cavity conditions near the 1/3-degenerate cavity configuration that had not previously been studied numerically. We call the propagation dominant because the laser behaves as a conservative system governed by beam propagation. We also obtained a V-shaped quasi-periodic threshold and a bifurcation diagram for classifying various instabilities that depends on cavity configuration. Although it had previously been predicted that chaos would be impossible under nearly degenerate conditions, we have recognized that the laser is transformed into chaos as a result of the interplay of beam propagation and gain dynamics as the cavity is tuned close to degeneracy.

When the pump size is less than the fundamental mode size, we found that there are stationary modes called the multibeam-waist modes that show an additional beam waist besides the well-known waist on the flat mirror end near g_1g_2 = 1/4 and 3/4. The multibeam-waist mode possesses a small waist size without a ring structure in the near field on the flat mirror end; nevertheless, it has a far-field pattern with many concentric rings. When the specific modes propagate through a lens, they are

capable of exhibiting multiple beam waists. The numerical results show good agreement with the experimental observations. Furthermore, by simultaneously considering the wavelike and raylike character of the multibeam-waist mode, we found that it can be represented as a superposition of N consecutive round-trip electric fields of period-N solution in the degenerate empty cavity, where N = 2 for $g_1g_2 = 1/2$ and N = 3 for $g_1g_2 = 1/4, 3/4$.

Also due to small-size pumping, we found new instabilities and determined the unstable regions on each side of the degeneracy near $g_1g_2 = 1/4$. We illustrated the temporal behaviors including periodic self-pulsing, period-2 self-pulsing, and chaotic output. As the cavity is tuned, we observed various far-field mode patterns including an asymmetrical mode pattern, the asymmetric output power with respect to the point of degeneration, and the asymmetric beating frequencies beside the degeneracy. Our numerical results reveal that the thermal lens effect leads to these asymmetric phenomena. We ascribed the short-cavity instabilities to the interaction among the degenerate transverse modes that constitute a supermode by the gain dynamics. However, the spatiotemporal instabilities in the long-cavity side are ascribed to the interaction between the supermode and the other empty-cavity modes.