OPTICAL BISTABILITY IN GAUSSIAN INHOMOGENEOUSLY BROADENED RING LASERS WITH SATURABLE ABSORBER

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Abstract

The optical bistability (OB) in Gaussian inhomogeneously broadened ring lasers with saturable absorber (LSA) in both resonance and out-of-resonance is theoretically analyzed in the rate-equation approximation based on the dual two-level model. The OB effect may appear for appropriate sets of LSA control parameter values which can be displayed in phase diagrams. The characteristics of the OB curves as well as their stability behavior are analytically and numerically studied in detail. The influence of the control parameters, including detuning, are investigated and displayed in the figures. A brief comparison with the Lorentzian case is given as well.

1. Introduction

In the cw operation regime, a laser with saturable absorber (LSA) can exhibit bistable action under certain conditions. The optical bistability (OB) is then due to the nonlinear response of the intracavity saturable absorber to laser light, which results in reversible hysteresis of the laser output as a function of the pumping power. A considerable number of theoretical works has been devoted to this phenomenon (see, for example, [1–4]).

The OB effect in a dominant inhomogeneously broadened ring LSA has been recently discussed [5–8], but only for the Lorentzian case because of the analytic convenience. Yet in a gaseous laser media, the atomic transitions are Doppler broadened by the assumedly Gaussian velocity distribution. It is also noted that if the difference between the Lorentzian and Gaussian models in a resonant LSA is only by a magnitude factor, it may be more significant in an off-resonance region. The OB study in the ring LSA with Gaussian inhomogenous broadening is therefore required for a correct and complete description. Such is the purpose of this paper. Based on the dual two-level model, the rate equations describing the action of the ring LSA under consideration and their steady-state analysis are presented in Sec. 2. Section 3 gives the OB occurrence conditions displayed on phase diagrams. Section 4 is used to investigate the OB stability behavior. The results obtained are summarized in Sec. 5.
2. Rate Equations. Steady-State Analysis

Our theoretical model is a ring cavity into which the absorption and amplification cells are inserted. The technical details of the LSA, e.g., the cavity losses and the pumping of the cells, are incorporated into the relevant phenomenological parameters of the model. We are concerned with the case where the cavity can sustain only one running mode. The atoms of the absorber and amplifier are considered as two-level systems. The homogeneously broadened atomic linewidths of both media are assumed to be of Lorentzian shape with the same half-width $\Gamma$. The inhomogeneous gain profile of halfwidth $\varepsilon$ centered at $\Omega_0$ is composed of a continuous distribution of homogeneous packets at frequencies $\omega_{\mu}$ which can be represented by the following function:

$$ g(\omega_{\mu} - \omega) = \frac{\Gamma^2}{\Gamma^2 + 4(\omega_{\mu} - \omega)^2} . $$

(1)

In general, the rate equations for such a ring LSA with Gaussian inhomogeneous broadening can be written as

$$ \frac{dn_j}{dt} = -X_j n_j + \sum_{\mu=-\infty}^{\infty} B g(\omega_{\mu} - \Omega_j) (n_j + 1) [N_{\mu a} - N_{\mu b}] ; $$

(2)

$$ \frac{dN_{\mu a}}{dt} = R_{\mu a} - [B g(\omega_{\mu} - \Omega_j) n_j + \gamma] N_{\mu a} ; $$

(3)

$$ \frac{dN_{\mu b}}{dt} = R_{\mu b} - [B g(\omega_{\mu} - \Omega_j) n_j + \gamma_b] N_{\mu b} . $$

(4)

In the system of equations (2)-(4), we use the following notations:

- $B$ is the Einstein coefficient;
- $n_j$ is the photon number of the jth mode with circular frequency $\Omega_j$;
- $X_j$ is the cavity loss rate in this mode, assumed to be constant;
- $N_{\mu a}$ and $N_{\mu b}$ are the population differences between the atomic upper and lower levels in both media, respectively;

The Gaussian inhomogeneous broadening is taken into account by the sum over the $\mu$-index of the homogeneous packets;

The laser pumping rate $R_{\mu a}$ has the following form:

$$ R_{\mu a} = GR_0 \exp \left[ -\frac{4(\omega_{\mu} - \Omega_0)^2}{\varepsilon^2} \ln 2 \right] \quad \text{with} \quad G = \sqrt{\pi \ln 2} ; $$

(5)

$R_{\mu b}$ is the pumping rate in the absorber, assumed to be constant;

Finally, $\gamma_a$ and $\gamma_b$ denote the relaxation rates of the upper levels in the amplifying and the absorbing atoms, respectively.

Setting the time derivatives in Eqs. (2)-(4) equal to zero and evaluating the sum over $\mu$ by the transformation [7]

$$ \sum_{\mu=-\infty}^{\infty} f(\omega_{\mu}) \Rightarrow \frac{1}{\pi \varepsilon} \int_{-\infty}^{\infty} f(\omega) \, d\omega , $$

(6)

we obtain the steady-state equation:

$$ Q_j - \frac{\alpha}{2} \left( Q_j + \frac{B}{\gamma} \right) \left[ G\sigma_0 \Re W \left( \frac{2\delta_j \sqrt{\ln 2} + i\alpha \sqrt{(1 + Q_j) \ln 2}}{\sqrt{1 + Q_j}} \right) \frac{\sigma_b}{\xi \sqrt{(1 + Q_j/\xi)}} \right] = 0 , $$

(7)

308