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A NONLINEAR FABRY-PEROT FILLED WITH CS₂
AND NITROBENZENE

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ABSTRACT

We have studied the characteristics of a nonlinear Fabry-Perot filled with Kerr liquids CS₂ and nitrobenzene, and found excellent agreement between theory and experiment. The transient behavior due to cavity field buildup is discussed.

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Felber and Marburger¹ have proposed the use of a nonlinear Fabry-Perot (FP) with a nonabsorbing medium as a broadband nonlinear optical device. Most experimental observations have, however, been made on FP with an absorbing medium, although in those cases it is shown that the dispersive contribution to the field-induced refractive index usually dominates.² Recently, we have studied the characteristics of a nonlinear FP filled with a nonabsorbing liquid crystalline material which has a large optical Kerr constant.³ However, since the response time of the medium is long compared with the input laser pulsewidth, only the transient characteristics were observed. In this paper, we report some recent results of our study on a nonlinear FP filled with CS₂ and nitrobenzene, both of which are strong nonabsorbing Kerr liquids with a short response time. From our results, we can see how the FP behaves towards the quasi-steady-state limit in its three modes of operation. We find that the experimental results are in excellent agreement with the dynamic theory of the nonlinear FP.³

Our experimental setup has already been described earlier.³ In the present case, we used two single-mode Q-switched ruby lasers with different pulsewidths, $\tau_p = 14$ and 62 nsec FWHM respectively. Both lasers had a Gaussian beam profile with a maximum peak intensity of about 25 MW/cm². The FP cavity was constructed with plane mirrors separated by 1 cm corresponding to a cavity round-trip time t_R of about 0.1 nsec. The finesse of the cavity was ~ 13 so that the cavity buildup time is $\tau_c \cong 0.45$ nsec at zero detuning. The response of the Kerr medium is governed by the Debye relaxation. The Debye relaxation time τ_D is 2 psec for CS₂ and 45 psec for nitrobenzene. The nonlinear refractive index n_2 is 2.2×10^{-11} esu for CS₂ and 1.1×10^{-11} esu for nitrobenzene.

Our results are shown in Figs. 1 and 2. In each figure, the three different modes of operation of the nonlinear FP are shown, with the phase detuning $\Delta\phi_0 = 0$ for power limiter, $\Delta\phi_0 = -0.1 \pi$ rad. for differential gain, and $\Delta\phi_0 = -0.2 \pi$ for optical bistability. The dots in the figures are obtained from measurements while the curves are theoretical curves. Figure 1 shows the results of the response of the FP with nitrobenzene to a $\tau_p = 14$ nsec input pulse. The different modes of operation are clearly seen in the I_{out} versus I_{in} plots. Here, we have $\tau_p/t_R = 140$ and $\tau_p/\tau_D = 310$, yet the curves still exhibit some remenant transient characteristics: the I_{out} versus I_{in} curve appears as a loop instead of a line in the power limiter and differential gain cases and shows a rather smooth switching in the bistable case. If we used CS_2 instead of nitrobenzene in the FP cavity so that τ_p/τ_D becomes 7000, the results were almost identical to those given in Fig. 1 when the input intensity was reduced by half because of the larger n_2 of CS_2 . However, little transient behavior remained when a $\tau_p = 62$ nsec input pulse was used on a FP with CS_2 , as shown in Fig. 2. In this case, we still have $\tau_p \gg \tau_D$, but $\tau_p/t_R = 620$. These results indicate that the observed transient response in the present case is mainly due to the finite buildup time of the cavity field. The quasi-steady-state limit of operation can only be reached when $\tau_p/t_R \gtrsim 300$.

The theoretical curves in Figs. 1 and 2 were calculated from the time-dependent theory of the nonlinear FP we had developed earlier.³ It takes into account the cavity field buildup and the transient medium response. We first fit the input laser pulse by $I_{in}(t)$. We then calculated numerically the round-trip phase increment $\Delta\phi_0$ due to the field-induced refractive

index in the cavity, and the output pulse $I_{\text{out}}(t)$ with the response function of the detector system included in the calculation. Finally, $I_{\text{out}}(t)$ versus $I_{\text{in}}(t)$ using t as a varying parameter was plotted. In each figure, one normalization constant was used to fit the peak of $I_{\text{out}}(t)$ in case (a), and then the same normalization constant was used in cases (b) and (c). As shown in Figs. 1 and 2, the theoretical curves describe the experimental results very well.

In the bistable mode of operation, if the detector response is infinitely fast, $I_{\text{out}}(t)$ would actually show an overshoot and damped oscillation after the optical switching. This results from the transient buildup of the cavity field from its initial value to the final value at switching. In our experimental observation, the effect was largely damped out by the slow detector response except for a small overshoot. If we consider overshoot and oscillation as part of the switching, then switching can be considered as over only after 2 or 3 times the cavity buildup time τ_c . Therefore, the switching speed of a nonlinear FP is eventually limited by τ_c .

In conclusion, we have shown that even when the medium response is very fast, the operation of a nonlinear FP still shows transient characteristics if the input pulsewidth τ_p (or equivalently, the characteristic time of the input intensity variation) is not sufficiently large in comparison with the cavity round-trip time t_R or the cavity buildup time τ_c . The quasi-steady-state limit is only approached when $\tau_p/t_R \geq 300$. Then even in the quasi-steady-state limit, optical switching in the bistable mode of operation may exhibit overshoot and ringing and the switching speed is limited by the cavity buildup time.

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ences, Office of Basic Energy Sciences, U. S. Department of Energy.

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Figure Captions

Fig. 1 I_{in} , I_{out} , and $\Delta\phi$ as a function of time t and $I_{out}(t)$ versus $I_{in}(t)$ of a nonlinear Fabry-Perot filled with nitrobenzene. $\tau_p = 14$ nsec, $\tau_D = 45$ psec, $t_R = 0.1$ nsec, and $\tau_c = 0.55$ nsec. Cases (a), (b), and (c) correspond to the three modes of operation of the Fabry-Perot: power limiter, differential gain, and optical bistability respectively.

Fig. 2 I_{in} , I_{out} , and $\Delta\phi$ as a function of time t and $I_{out}(t)$ versus $I_{in}(t)$ of a nonlinear Fabry-Perot filled with CS_2 . $\tau_p = 62$ nsec and $\tau_D = 2$ psec. The rest are the same as in Fig. 1.

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