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SIMULTANEOUS PHASE-LOCKING AND MODE SELECTION THROUGH THE USE OF ELECTROOPTIC CRYSTALS*

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ABSTRACT

An electrooptic crystal is used simultaneously as a phase-locking and mode-selecting device in conjunction with a CW argon laser. Details of design and performance are discussed. The desirable characteristics of both controlling phenomena are found to be present when employing this new technique.

1. INTRODUCTION

The device to be described is an effective control element in utilizing the output of a free running gas laser.

Insertion of an intracavity band pass filter inside the cavity in the form of a parallel plate etalon limits the number of possible oscillating axial modes and reduces the beam divergence. However this is not free of disadvantage since the power output may be reduced.

On the other hand, by phase-locking a gas laser its time output is made to consist of a series of pulses separated by the double pass transit time, each with a power exceeding the free-running value by a factor equal to the number of locked modes.[1]

In order to achieve simultaneous phase-locking and mode selection a KDDP crystal was used as a modulator-etalon combination. The effects of such a device on the spectral and time characteristics of the output of an argon laser were studied and it was seen that both phenomena can be integrated in a single crystal, thereby compensating for the decrease in power due to mode selection by the presence of increased peak powers resulting from phase-locking.

2. DESIGN OF THE MODULATOR

A KDDP crystal (1/4" x 1/4" x 1-7/8") with a 45° Z cut was used. Its end surfaces were optically finished with partially reflective coatings ($R \approx 11\%$ at 5000A°). These reflection coatings were a compromise for a resonable etalon Q and insertion loss. Gold electrodes were evaporated on the surfaces perpendicular to the z axis. The crystal was mounted in a boron nitride holder for low rf losses and placed inside an aluminum cylinder.

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[1] A.J.DeMaria, W.H.Glenn, Jr., M.J.Brienza and M.E.Mack, Proc. IEEE, 57, 1(1969).

3. PHASE-LOCKING OBSERVATIONS

The axial mode spectrum of a model 140 Spectra Physics argon laser with a 180 cm mirror spacing is shown in Fig. 1. The effective cavity length with the crystal inside corresponds to a phase-locking frequency of 80.15 MHz. Dc and rf voltages up to 500V peak to peak at the phase-locking frequency and multiples thereof were applied to the crystal. The etalon action of the KDDP crystal at various angles is shown in Fig. 2. The number of locked modes may be varied by tilting the modulator up to an angle of 3°; this angle was sufficiently small so as not to appreciably deteriorate the optical properties of the crystal.

Without the modulating rf field the amplitude of each mode varies considerably in time. Such a laser output exhibits little coherence and its frequency domain behavior is highly erratic (Fig. 3a). When the etalon-modulator is placed inside the cavity at an angle less than 1° the mode spectrum consists of three modes spaced by 1.92 GHz (Fig. 3b). When the modulator is driven at one or two times the axial mode interval (i.e. 80.15 or 160.30 MHz) a bunching of fairly stable modes appears around each of the three etalon mode frequencies (Figs. 4a and 4b); the number and intensity of these side modes increases as the voltage on the crystal is increased and the detuning is decreased (Figs. 5 and 6).

The time output consists of two pulses per period of the driving voltage as shown in Fig. 7. This phenomenon is known as "double-pulsing"[2] and results from the fact that there are two trains of locked modes.

In the case of every third free running axial mode being coupled together by operating the modulator at or near to three times the axial mode spacing (i.e. 240.45 MHz) the effect on the spectral output is similar to the one observed at the other two frequencies. It should be noted that phase-locking can be achieved with lower driving power with etalon action present than without it because of the smaller number of modes to be locked.

The time output for the phase-locked region of operation consists of one pulse per modulation period. When the output of the argon laser is quenched, it consists of one locked oscillation with modes 240.45 MHz apart. In the nonquenched mode of oper-

[2] L.M.Osterink, M.L.Report #1536, Stanford University (1967).

ation the output consists of three simultaneously oscillating locked signals, the modes of one adding to the modes of the others, and the same time output is obtained.

Application of a dc voltage up to 250 V on the crystal results in fine tuning of the oscillating modes up to ± 50 MHz. This is easily understood in terms of the standing wave pattern in the cavity and the way it is influenced by a dc voltage on the crystal. A voltage V will change the index of refraction by Δn, thus changing the effective length of the cavity by $\Delta L = L\Delta n$ where L is the length of the crystal. The most dramatic change in the wavelength of the standing wave pattern occurs when $\Delta L = \pm\lambda/4$. For $\lambda \cong 5000A$, $n_o = 1.63$, $r_{63} = 13 \times 10^{-12}$ m/V, the required dc voltage is approximately 250 V. This phenomenon was observed experimentally.

4. CONCLUSION

In effect, phase-locking, reduction in the number of the oscillating modes through etalon action, and fine tuning can all be accomplished using a single electrooptic device with all the subsequent technical and economic advantages.

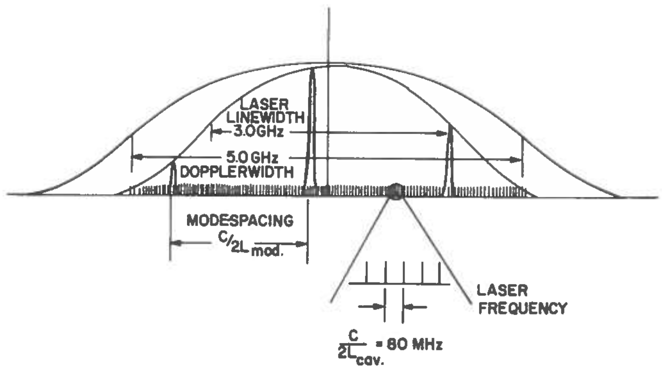


Fig. 1: Gain profile of a typical argon transition and the associated axial mode spectrum of the cavity and etalon.

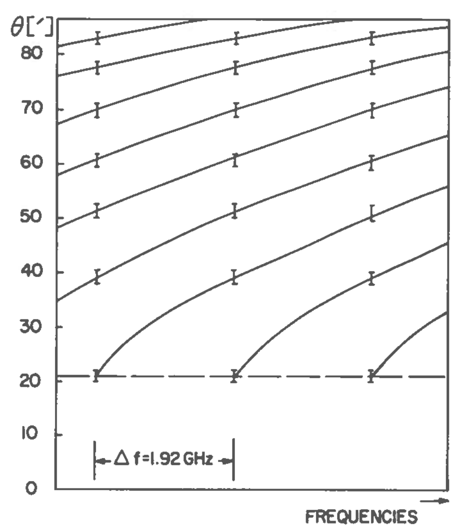
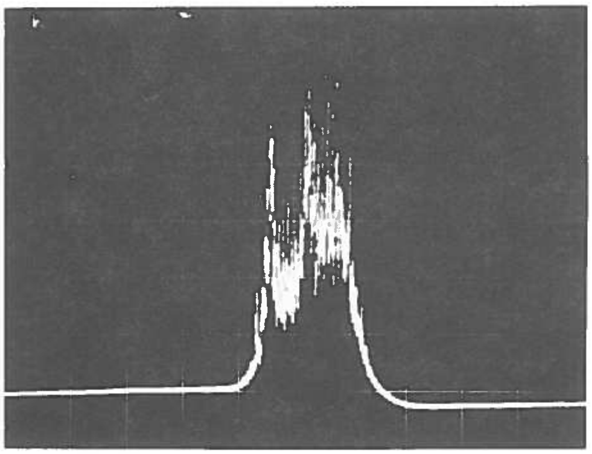
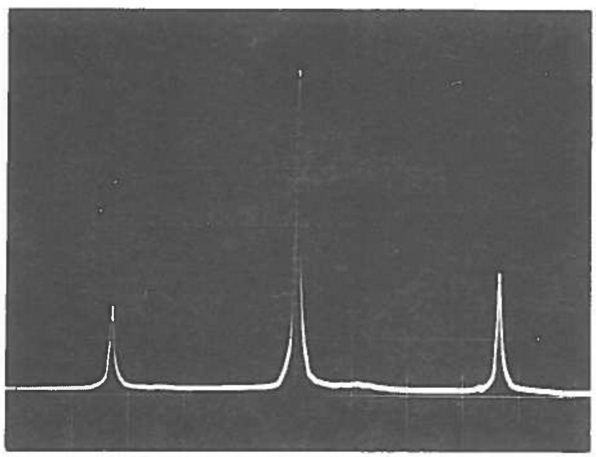


Fig. 2: Etalon angle versus frequency with the number of nodes as a parameter.

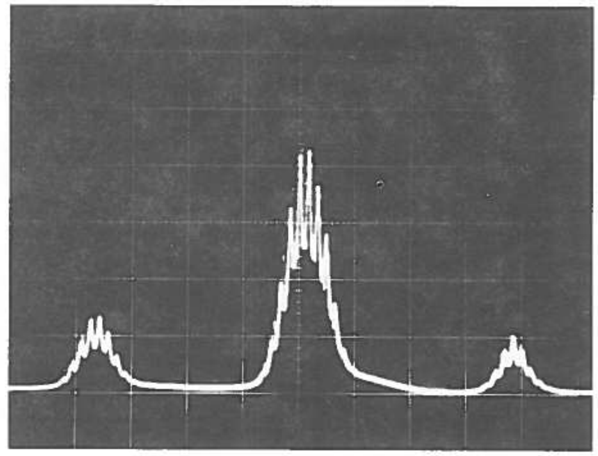


(a)

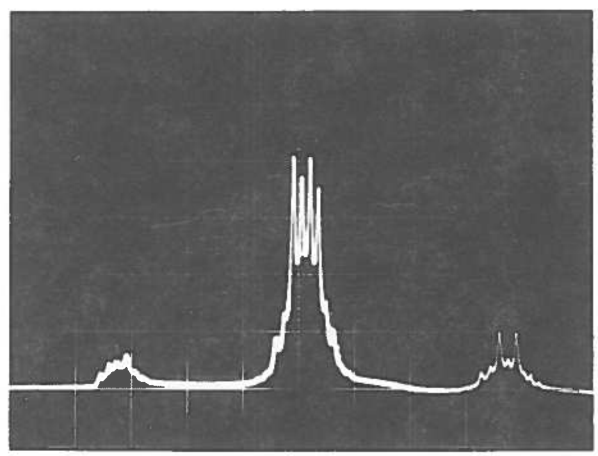


(b)

Fig. 3: Optical mode spectrum of phase-locked argon laser.
(a) Free running (dispersion ~2000 MHz/div)
(b) Free running with etalon action (dispersion ~500 MHz/div)

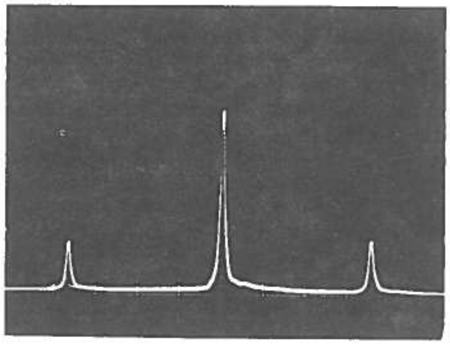


(a)

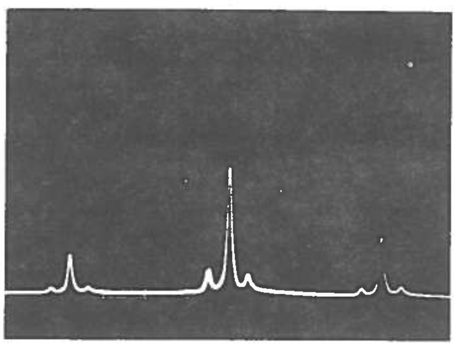


(b)

Fig. 4: Optical mode spectrum of argon laser phase-locked with etalon action (dispersion 500 MHz/div)
(a) At c/2L (80.15 MHz)
(b) At 2c/2L (160.30 MHz)



(a)



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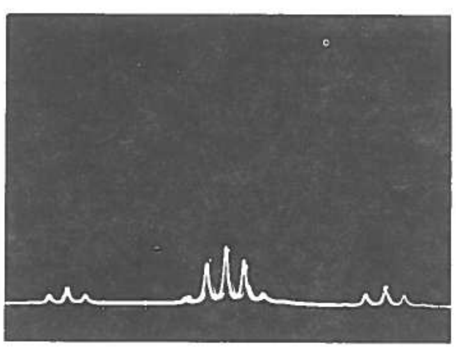
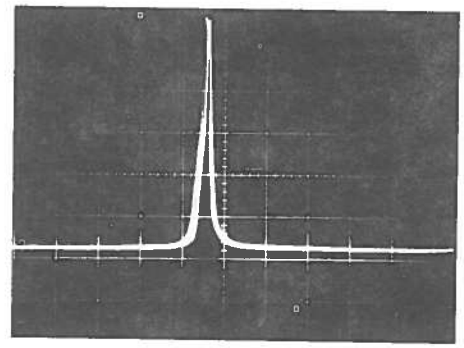
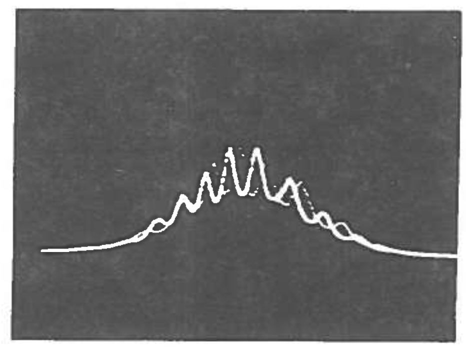


(c)

Fig. 5: Optical mode spectrum of argon laser phase-locked with etalon action (dispersion 500 MHz/div)
(a) Free running
(b) Phase-locked at 3c/2L and low rf power (.1% detuning)
(c) Phase-locked at 3c/2L and maximum rf power (.1% detuning)



(a)



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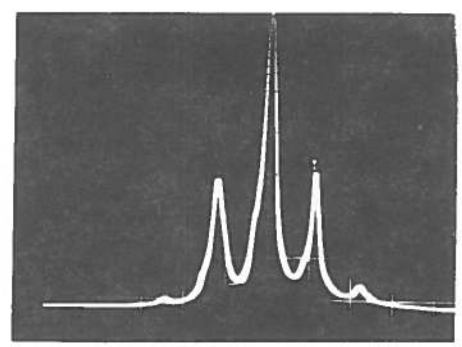
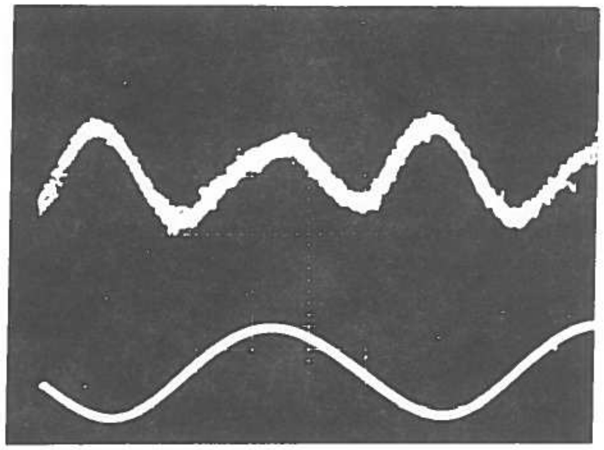


(c)

Fig. 6: Expanded portion of the optical mode spectrum with etalon action
(a) Free running
(b) Phase-locked at 3c/2L at zero detuning
(c) Phase-locked at 3c/2L at .4% detuning.



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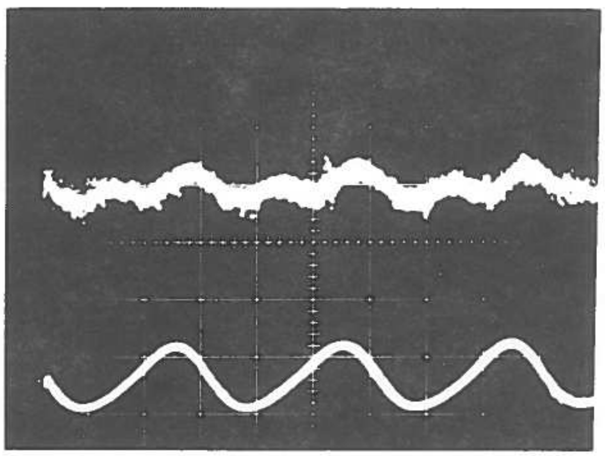

(b)

Fig. 7: Time output of phase-locked argon laser (2 ns/div).
(a) Phase-locked at 80 MHz(c/2L)
(b) Phase-locked at 160 MHz(c/L)
The bottom trace in both (a) and (b) is the modulator drive voltage; the upper trace is the laser output.