FACILITY FORM 602

N65-19863	1
(ACCESSION NUMBER)	(THRU)
13	1
(PAGES)	(CODE)
Cr-57464	26
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

LASER MODULATION AT THE ATOMIC LEVEL

Monthly Report No. 6

Date of this report: 10 January 1965
Period Covered: 1 December 1964 to 31 December 1964

Submitted to
National Aeronautics and Space Administration
Contract No. NASw 1008

GPO PRICE $
OTS PRICE(S) $

Hard copy (HC) $1.00
Microfiche (MF) $0.50

GENERAL DYNAMICS | ELECTRONICS

LASER MODULATION AT THE ATOMIC LEVEL

Monthly Report No. 6

Date of this report: 10 January 1965
Period Covered: 1 December 1964 to 31 December 1964

Submitted to
National Aeronautics and Space Administration
Contract No. NASw 1008

Prepared by:
E. G. Brock, Manager
F. C. Unterleitner, Sr. Staff Member
Y. C. Kiang, Staff Member
J. F. Stephany, Staff Member

Approved by:
E.G. Brock
E. G. Brock
Manager
Quantum Physics Laboratory

General Dynamics Corporation
General Dynamics/Electronics
Research Department
Rochester, New York

LASER MODULATION AT THE ATOMIC LEVEL

Purpose

Research on methods of influencing internally the radiating centers of active laser materials in order to achieve laser modulation is the principal objective of the work carried out under this contract.

Summary

19863 ABST

The frequency shift of ruby laser emission under inhomogeneous magnetic fields was measured by time resolved spectroscopy. The 0° ruby shows a frequency shift of 0.32 cm^{-1} with 5 kgauss peak field, while 90° ruby emission shifts $+0.25$ cm^{-1} for the same field strength.

The influence of crystal field splitting on the YAG:Nd^{3+} laser transition Zeeman splitting is discussed. The possibility of confirming nearby tetragonal site symmetry is also discussed. No experimental work on YAG:Nd^{3+} was performed this month.

AuTHOR 7

Man-Hours Worked

The total number of man-hours worked during the reporting period is 418.

I. STUDY OF RUBY

A. Inhomogeneous Field Frequency Shifts for 0° and 90° Ruby Rods.

In previous months the experimental program centered about the determination of variation in gain as a function of inhomogeneous magnetic field intensity. In communications terminology this would be considered the amplitude modulation characteristic of the laser oscillator with inhomogeneous field modulation. Amplitude modulation is the desired mode of modulation when the field is inhomogeneous, but there is nevertheless some incidental frequency modulation, since the Zeeman splitting of the R_1 line is asymmetric. The experiments described here were performed to determine this frequency modulation characteristic.

1. Experimental. The experimental arrangement involves the well-known technique of imaging a Fabry-Perot ring pattern on a radial slit perpendicular to the direction of scan of a streak camera.[1] In the present case a CW gas laser (He-Ne, 6328 Å wavelength) was used in order to simplify the alignment of the optical system; see Fig. 1. The two lasers were aligned by setting the CW laser beam so that the reflections from the ruby surfaces coincided with the incident beam. Alignment was checked by observing angular coincidence of the ruby laser burst with the CW laser beam. Resolution of the system was found to be critically dependent on the 370-mm focal length objective lens of the telescope which focuses the Fabry-Perot rings on the slit. The lens was set to minimize aberrations for the central fringe on the streak camera photographs.

The STL streak camera is used to obtain time resolution of the spectra. A few high-speed streak photographs were made which show that typical "spike" durations were of the order of 0.2 - 0.3 μsec. Most of the photographs were taken with the microsecond streak unit which has exposure times from 20 to 200 μsec, permitting the laser frequency to be measured during the entire first half cycle of the magnetic field. Spectra were recorded on Polaroid type 57, 4- by 5-inch sheet film and were measured using the precision x, y stage on a Nikon shadowgraph.

2. Data analysis. The half cone angle θ of the interference maxima due to the mth order of interference of light of wavelength λ passing through an etalon of plate separation d is given by

$$\cos\theta = m\lambda/2d. \tag{1}$$

For the small angles that we deal with, Eq. (1) becomes

---

[1] For example, T. P. Hughes, Nature, 195, 325 (1962).

$$1 - \frac{\theta^2}{2} \simeq m\lambda/2d. \tag{2}$$

The experiment was arranged so that segments of the three innermost rings could be observed. If the distances of three successive interference maxima from an arbitrary reference line parallel to the streak direction are designated y_1, y_2, and y_3 respectively, the position of the center of the pattern y_o is found from the relation

$$y_o = \frac{1}{2} (2y_2^2 - y_1^2 - y_3^2)/(2y_2 - y_1 - y_3). \tag{3}$$

The wavenumber difference between two wavelengths of the same order of interference is then given by

$$\nu_i - \nu_j = \gamma [(y_i - y_o)^2 - (y_j - y_o)^2]$$

where (4)

$$1/\gamma = 2d [(y_2 - y_o)^2 - (y_1 - y_o)^2] .$$

The interferometer spacing used was 0.310 cm, and the positions of the interference maxima could be read with an average deviation of $\pm 4 \times 10^{-4}$ inch out of a pattern width of about 1.0 inch. The resulting error in $(\nu_i - \nu_j) = \Delta\nu$ was analyzed and found to be approximately ± 0.006 cm^{-1} or ±7%, whichever is greater. The ± 0.006 cm^{-1} is fixed by the $\pm 4 \times 10^{-4}$ inch deviation in the coordinate measurements, and the ±7% deviation is due to error in fixing y_o, which is a systematic error in all $\Delta\nu$ since the same y_o is used for all measurements from a given picture.

3. Results for 0° ruby. The plot of frequency shift from an arbitrary reference frequency versus time, as derived from a streak photograph by the above described procedure, is shown in Fig. 2(a). This time dependent spectrum was converted to a frequency dependent spectrum by using the time dependence of the magnetic field at the center of the loop;

$$H(t) = H_p \, a \, e^{-\delta t} \sin \omega t \tag{5}$$

where $a = 1.105$, $\delta = 2.59 \times 10^3$ sec^{-1} $\omega = 4.02 \times 10^4$ sec^{-1}, and H_p is the peak magnetic field. A plot of emission frequency versus peak magnetic field is shown in Fig. 2(b). The result is both qualitatively and quantitatively in good agreement with predictions. In the 0° orientation the maximum gain should shift from a frequency that corresponds to transitions to the lowest levels of the ground state to ones going to the upper levels of the ground state. This shift is $-0.38\ \text{cm}^{-1}$, which is reduced to $-0.32\ \text{cm}^{-1}$ by overlap of the components. Results of more accurate computations of predicted line shape and position should be ready for the next monthly report.

4. Results for 90° ruby. The frequency shift of the 90° ruby (see Fig. 3(b)) could not be observed over as large a magnetic field range as the 0° ruby because of the rapid reduction in gain with fields above 4-kgauss peak. Over the observable range the positive frequency shift is of the sign and order of magnitude predicted by the rough calculations. Again we must await the results of more detailed calculations before comparison of experimental and theoretical results can be made.

B. Future Work

With the conclusion of refined calculations of predicted gain curves, the determination of inhomogeneous magnetic field effects on the amplitude and frequency of ruby laser emission will be terminated. In the interests of testing the homogeneous field coils, measurement of the frequency shift of ruby laser output in a homogeneous field will be carried out in order to test the procedure with a material of known Zeeman splitting before proceeding with work on materials where it is not known.

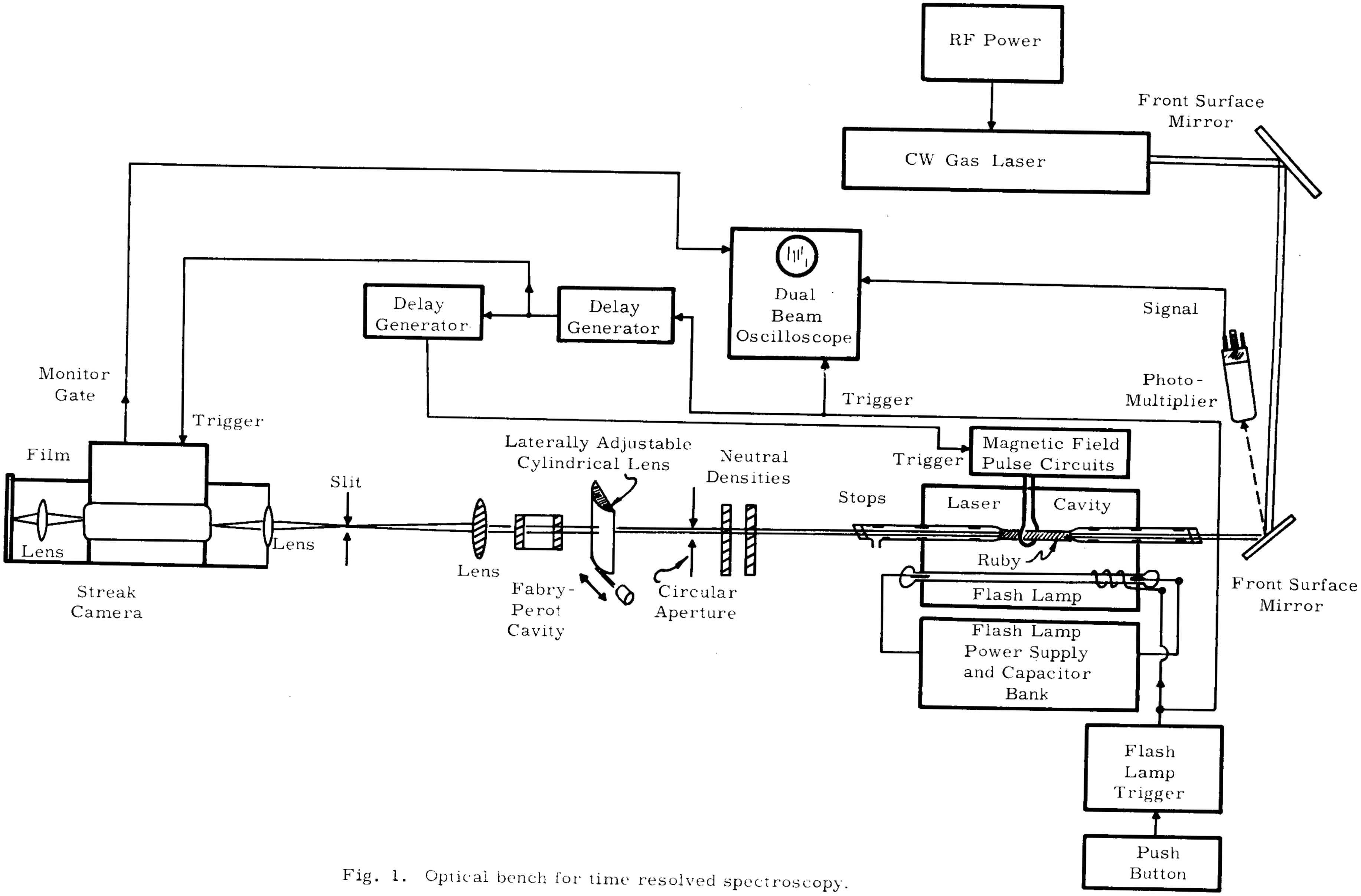

Fig. 1. Optical bench for time resolved spectroscopy.

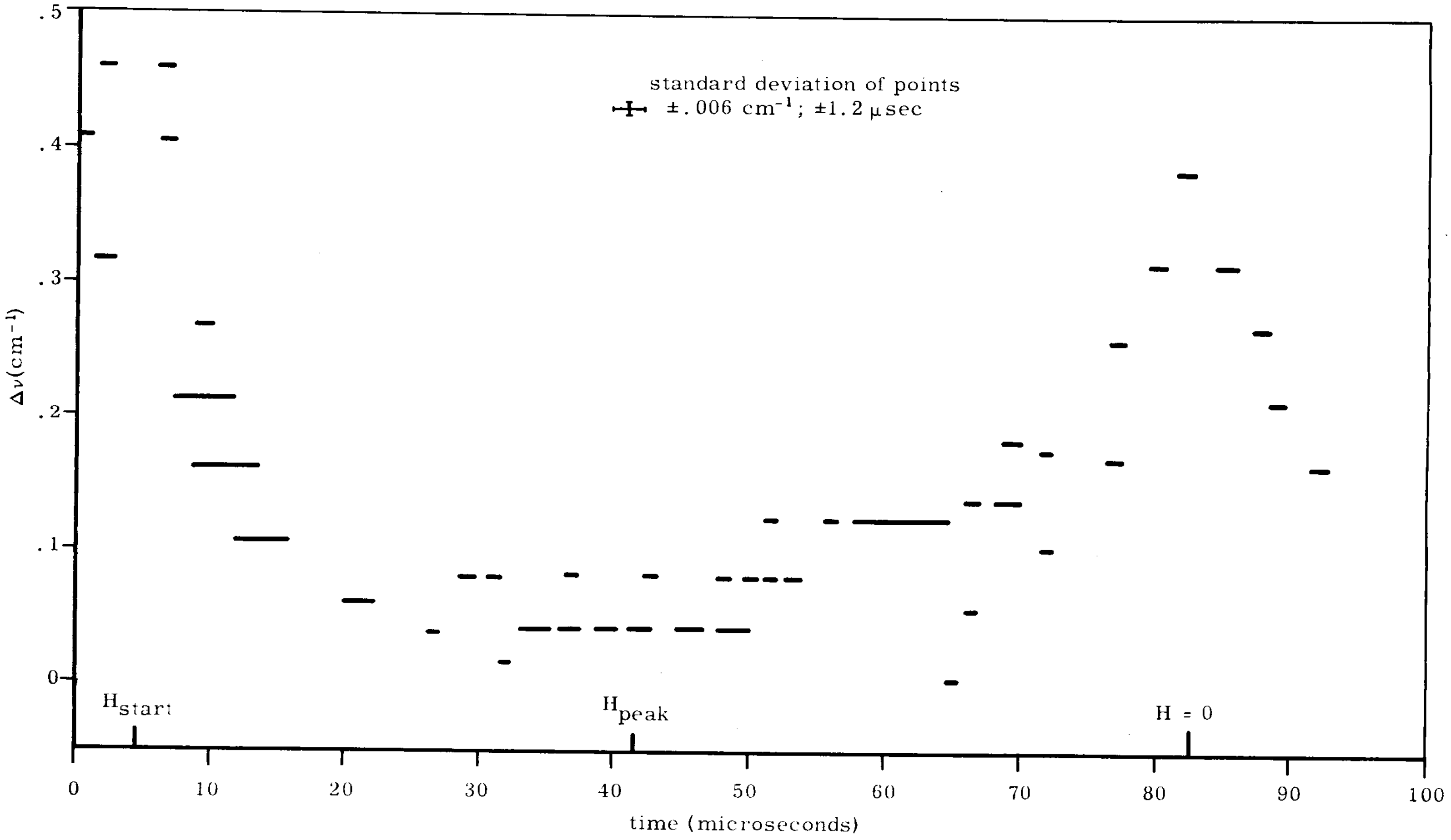

Fig. 2(a). Time resolved spectrum of 0° ruby in inhomogeneous pulsed magnetic field of 9.3 kgauss peak intensity.

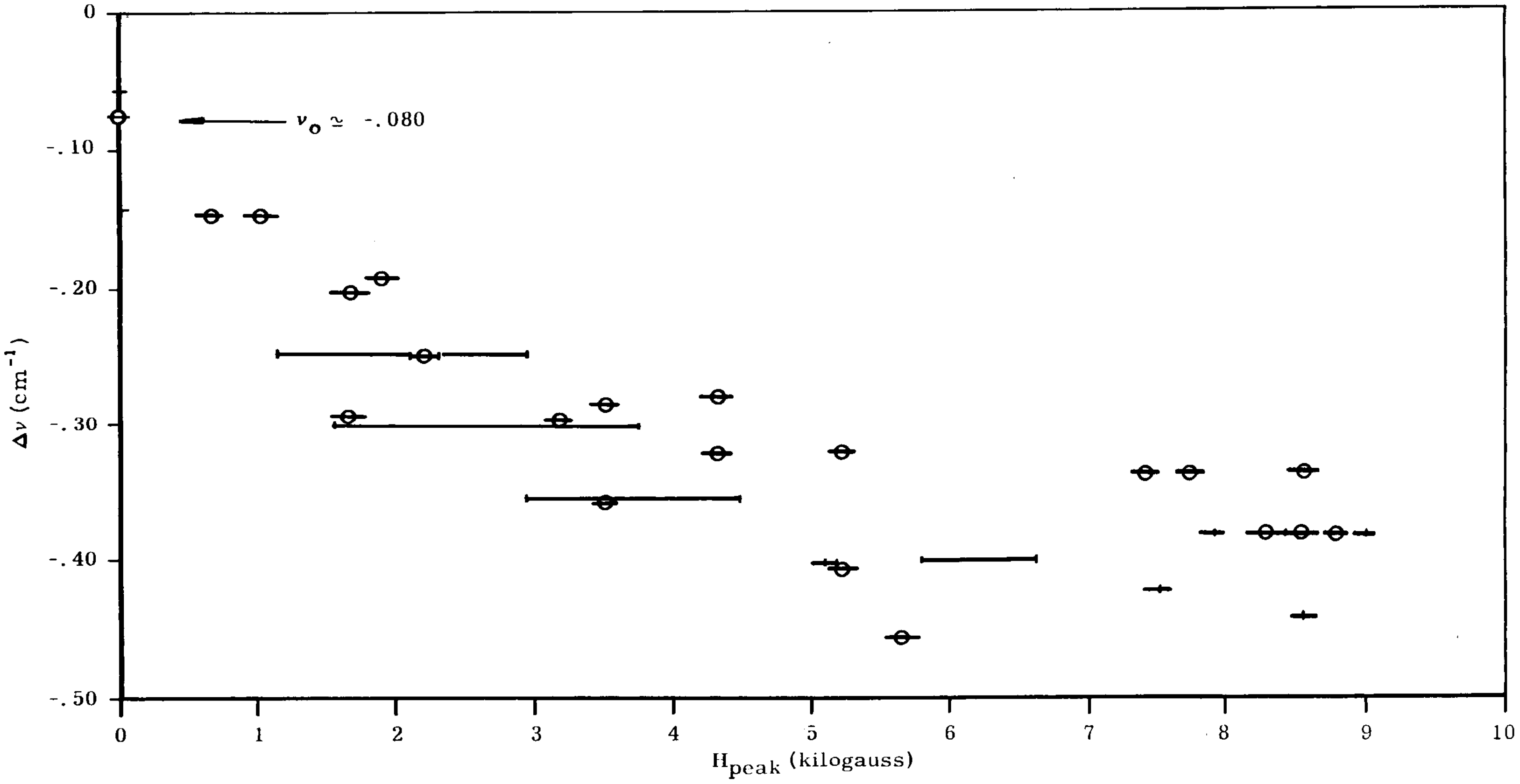

Fig. 2(b). Laser oscillation frequency as a function of peak inhomogeneous field for 0° ruby rod.

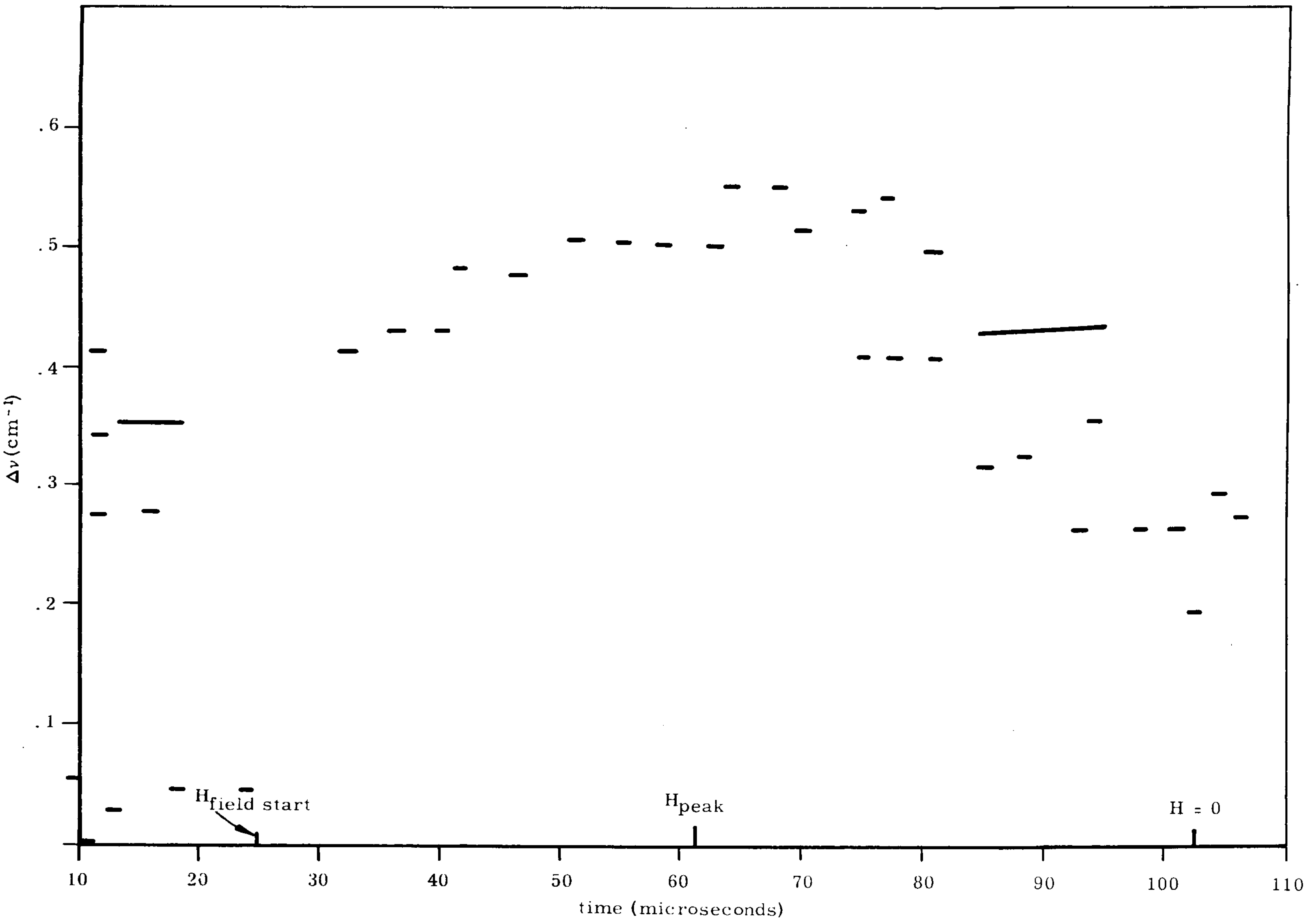

Fig. 3(a). Time resolved spectrum of 90° ruby in inhomogeneous pulsed magnetic field of 4.7 kgauss peak intensity.

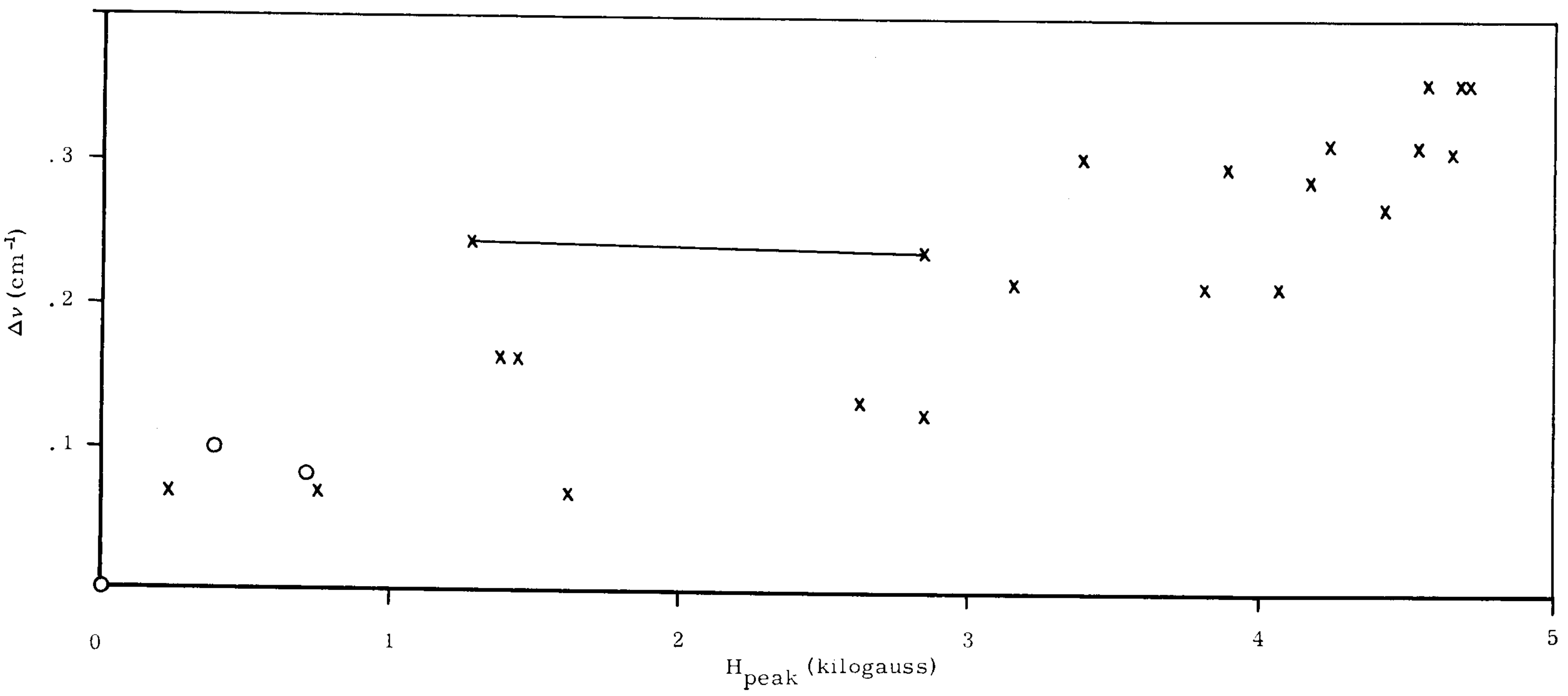

Fig. 3(b). Laser oscillation frequency as a function of peak inhomogeneous magnetic field for 90° ruby rod.

II. Nd^{3+}:YAG

A. Status of Experimental Work

The study of magnetic field interaction with the Nd^{3+}:YAG laser transitions was not resumed during this reporting period. Problems encountered by Linde in refinishing the broken end of the rod, and a mishap occurring during mounting of the rod delayed resumption of experimental work past the end of the present reporting period. The length of the rod, as returned to us, was 24 mm; the original length was 30 mm. This shortening would be quite detrimental to CW operation, but it should cause no problem in pulsed operation. The shorter length will improve the homogeneity of the magnetic field within the laser volume, since the active length is now considerably shorter than the radius of the Helmholtz coils.

B. Influence of Crystal Field at Nd^{3+} Sites on Zeeman Splitting

In the previous report calculations of predicted energy level splittings of the free ion terms of Nd^{3+} relevant to the laser transitions were reported. The "crystal field" will have an influence on the Zeeman splitting which is of the same order of magnitude as the free ion splitting, so we must give some consideration to its probable influence on the spectrum. The crystal structure of YAG is isomorphous with yttrium iron garnet studied by Geller and Gilleo.[2] The Nd^{3+} ion substitutes for yttrium, as confirmed by the fairly good agreement between calculated and observed term splittings obtained by Koningstein and Geusic[3] on the basis of yttrium site symmetry. The point symmetry at the Y site is 222, which implies an orthorhombic crystal field symmetry. If the symmetry were orthorhombic, each energy level produced by removal of Kramers degeneracy would appear as three levels in the crystal, due to the three equally probable orientations possible for the orthorhombic axes with respect to the cubic crystal axes at the Nd^{3+} sites. It was found[3] that the actual symmetry appeared to be almost tetragonal. A pseudo-tetragonal symmetry would reduce the number of non-equivalent sites to two, one type having twice the probability of the other.

The axis of the YAG rod used in our experiments coincides with the cubic (111) direction, which has no particular significance with respect to the orthorhombic site symmetry axes. This should lead to splitting into

---

[2] S. Geller and M. A. Gilleo, Phys. and Chem. Solids, 3, 30 (1957).

[3] J. A. Koningstein and J. E. Geusic, Phys. Rev., 136, A711 (1964).

the maximum number of components allowed for the general case. Since we can only observe the magnetic field shifts of those components which have sufficient gain to exceed laser threshold, and can only measure the effect for $H_o \perp E$, where H_o is parallel to the (111) direction, our present experiment can only give a partial picture of the rather complex Zeeman spectrum to be expected for the laser transitions. It is expected, however, that it will be possible to draw some conclusions regarding the extent to which tetragonal site symmetry is a valid approximation in calculating crystal field splitting.