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SATURATED DISPERSION EXPERIMENT IN IODINE WITH AN ARGON LASER

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Résumé

On décrit un montage interférométrique en anneau à polarisations croisées permettant d'obtenir un signal de dispersion saturée directement utilisable pour la stabilisation en fréquence d'un laser.

Abstract

We describe a ring interferometric set-up with crossed polarizations stable enough to give a saturated dispersion signal that can be used for the frequency stabilization of lasers.

Saturated absorption in a molecular gas provides narrow resonances free of first-order Doppler broadening and finds therefore an important application in the frequency stabilization of lasers [1]. To the saturated absorption signal corresponds a change in the index of refraction of the gas that we shall call saturated dispersion and whose third-order simplified expression was given by W. Lamb [2] in his theory of gas lasers. The saturated dispersion of an absorbing gas in the laser cavity was first demonstrated by R. Barger and J. Hall [1] as a frequency hang-up as the length of the laser is varied. It is tempting to use the saturated dispersion signal for the frequency stabilization of lasers since it has the right shape for an error signal without any modulation. This is achieved readily in the microwaves, where the stability of interferometers gives no problem; this led to the Pound's scheme for klystron stabilization [3]. At optical frequencies it is necessary to use a self-stable interferometer to avoid the stabilization of the interferometer itself. A set-up fulfilling this condition is the ring interferometer represented on Fig. 1, where S is a splitter dividing the beam into two beams of equal intensity, and M_1 and M_2 are two plane mirrors. This interferometer is sensitive only to a non-reciprocal phenomenon introducing a difference between the two optical paths SM_1M_2S and SM_2M_1S. A saturable gas in the cell C enables one to introduce a non-reciprocity if it is illuminated by two waves of different intensities whose common frequency is detuned from the line center : the strong wave saturates the dispersion for the probe wave, whereas the probe wave has very little effect on the strong wave. By introducing an attenuating plate At in the interferometer one creates in the cell an asymmetry between the intensities of the two waves; one expects therefore to observe the saturated dispersion signal on each of the photomultipliers PM_1 and PM_2. Since these two detectors see complementary interference states, one monitors the difference between the two photocurrents. As we shall see below, it is useful to introduce an adjustable phase difference between the two waves. An easy way to produce that phase difference is to make use of a difference in polarization between the two waves. This is simply achieved by illuminating the interferometer with linearly polarized light by aid of the polarizer P. A half-wave plate with axes at 45° of the polarization is placed in the ring; it gives two orthogonal polarizations for the two waves on the whole optical circuit SM_1M_2S, but the two waves come out with the same polarization and can thus interfere. Furthermore, the light reflected back to the laser cavity is stopped by the polarizer P, which provides the required optical isolation. It is now possible to adjust the phase difference by means of a plate L_φ having adjustable birefringence and axes parallel to the polarisations of the two beams. Let $\alpha_s(\nu)$ be the absorption of the strong wave and $\alpha_p(\nu)$ that of the probe wave. The output electric fields are proportional to $(1-\alpha_s)^{1/2}$ and $(1-\alpha_p)^{1/2}$ respectively; they present a phase difference $\varphi_0+\varphi(\nu)$, where φ_0 is given by the plate L_φ and $\varphi(\nu)$ is the saturated dispersion.

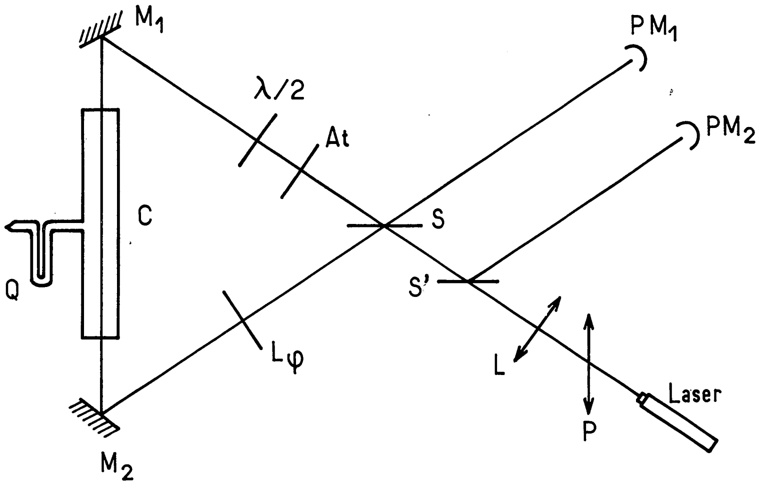


FIG. 1

The intensities detected on the photomultipliers are thus :

$$I_{\pm} \propto (1 - \alpha_s) \pm (1 - \alpha_p) \pm 2\sqrt{(1 - \alpha_s)(1 - \alpha_p)} \cos(\varphi_0 + \varphi).$$

The *difference* of the two photocurrents is then

$$S(\nu) \propto \sqrt{(1 - \alpha_s)(1 - \alpha_p)} \cos(\varphi_0 + \varphi) .$$

Since α_s , α_p and φ are small, to lst order this reduces to

$$S(\nu) \propto \cos\varphi_0 - \frac{\alpha_s(\nu) + \alpha_p(\nu)}{2} \cos\varphi_0 - \varphi(\nu) \sin\varphi_0 .$$

According to the value chosen for φ_0 one observes dispersion, absorption or a mixture of both. In particular, for $\varphi_0 = -\pi/2$ one obtains

$$S(\nu) \propto \varphi(\nu) ;$$

the saturated dispersion is obtained directly on zero background, i.e. with minimum noise.

The experiment has been performed with an argon ion laser as the source delivering about 500 mW in a single mode at 5145 Å. One of the laser mirrors was driven by a piezoelectric ceramic, allowing a tuning of the frequency over a 200 MHz range. $^{127}I_2$ was chosen as the saturable gas because of its many absorption lines in the frequency domain covered by the laser. A lens L (focal length 90 cm) was used in order to get an appreciable saturation parameter by focusing the light at the center of the cell.

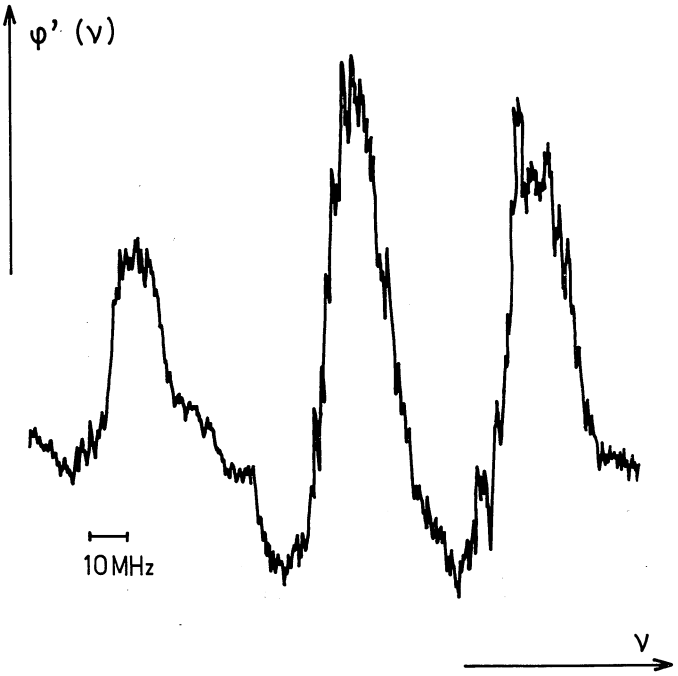
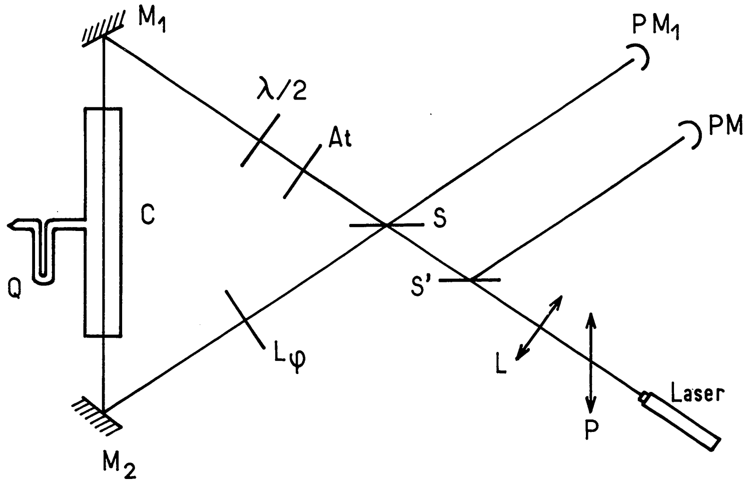


FIG. 2



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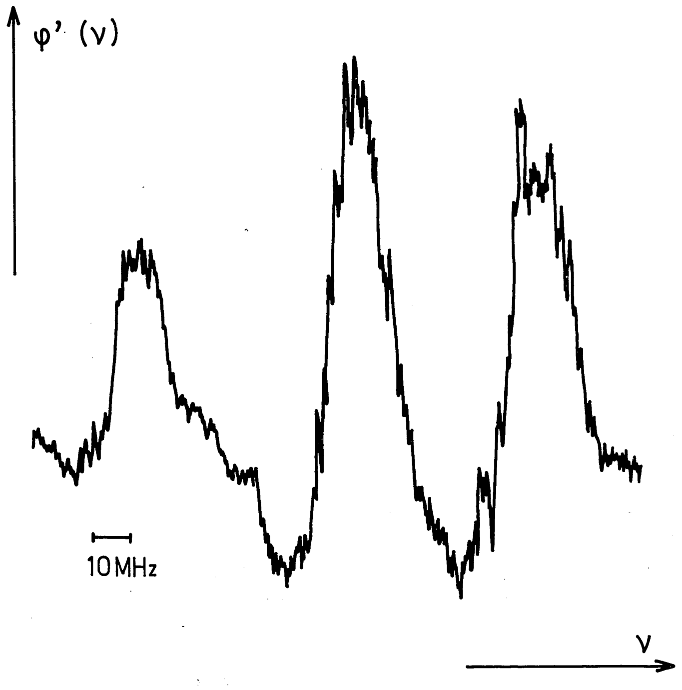

FIG. 2

In a first step the laser frequency was modulated an a phase sensitive detection was performed (modulation frequency 310 Hz). Fig. 2 shows a typical record of the derivative $\varphi'(\nu)$ of the saturated dispersion signal for three adjacent lines (I_2 vapor pressure 0.2 torr; sweep time 15 mn; integration time constant 1 sec). The relatively broad width obtained for these peaks (∿ 20 MHz) is mainly due to the frequency jitter of the argon laser, the only real limit being the natural linewidth estimated to be around 100 kHz [4]. The results of this preliminary experiment can therefore be considerably improved with respect to the signal-to-noise ratio as well as to the width of the lines by a better control of the laser frequency.

References

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