Optica Applicata, Vol. XVI, No. 4, 1986

Double-modulation of the laser line

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Two possible kinds of an emission laser line modulation, called here the transverse and longitudinal ones, have been described. An idea of double-modulation of laser line and its application to the first harmonic analysis of spectral details appearing on the laser line have been presented. Such an analysis performed experimentally for the absorption peak power in He-Ne/CH_4 laser was compared with the classical phase-sensitive detection technique of analysis.

1. Introduction

Considering the shape of a single-mode gas laser emission line two possible kinds of modulation can be imagined. The first one, based on a laser cavity length tunning, involves a simultaneous frequency and intensity modulation. It can be called the longitudinal modulation of the laser line.

The other kind of modulation, the so-called transverse one, can be thought of as the modulation of the laser beam intensity at the constant laser frequency. It can be obtained by changing internal gain or losses as well as by applying an external intensity modulator. It should be noticed that the pure transverse effect can be obtained solely by the external modulation of intensity, because internal changes of gain or losses usually cause mode pulling effect [1]. The both, mentioned above, kinds of modulation are illustrated schematically in Fig. 1.

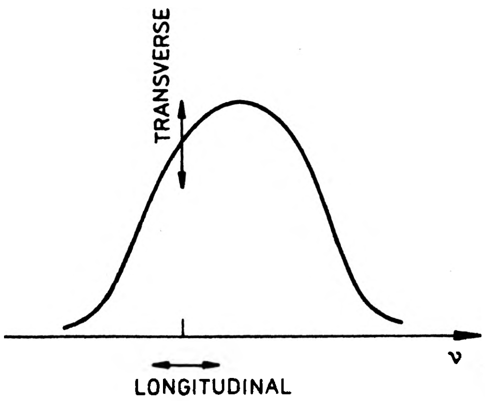

Fig. 1. Emission line with two possible directions of modulation marked schematically

In saturation spectroscopy a single-mode laser is used as a source of a spectral analysis. The analysis of spectral saturated details on the background of an emission laser line is usually done by means of the phase-sensitive detection (psd). The essence of this method lies in phase-sensitive detection of the longitudinal intensity modulation of the laser line; the lock-in amplifier being used commonly as the fundamental instrument of the laser saturation spectroscopy.

This paper presents a little different method, the so-called double modulation technique, which has been applied to the analysis of spectral saturated details in the range of the laser line.

2. Discriminant signal

As an example of a spectral detail we shall consider an emission Doppler-broadened laser line with an absorption peak power, shown in Fig. 2. It is a typical shape of output power of He-Ne 3.39 μm with an internal CH_4 absorption cell [2], [3], [4]. Similar effects can be obtained in CO_2/SF_6 [5] or He-Ne/J_2 [6] lasers.

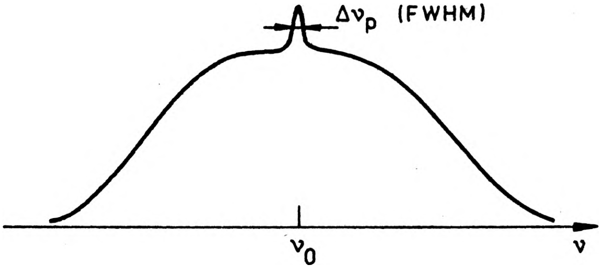

Fig. 2. Typical laser line with the absorption peak

The shape of the absorption peak is the Lorentzian one and can be described by

$$L(x) = \frac{1}{1+x^2} \tag{1}$$

where: $x = 2\frac{\nu-\nu_0}{\Delta\nu_p}$ – dimensionless frequency,

ν_0 – centre frequency of the absorption peak,

ν – frequency,

$\Delta\nu_p$ – full width at half maximum of absorption peak (FWHM).

In most experiments on saturated absorption the output laser signal is sine-wave modulated longitudinally by a piezoceramic driver, and the first harmonic signal is detected by psd technique. For the harmonic longitudinal modulation with the frequency f and the amplitude of the frequency deviation $\Delta\nu$ the signal

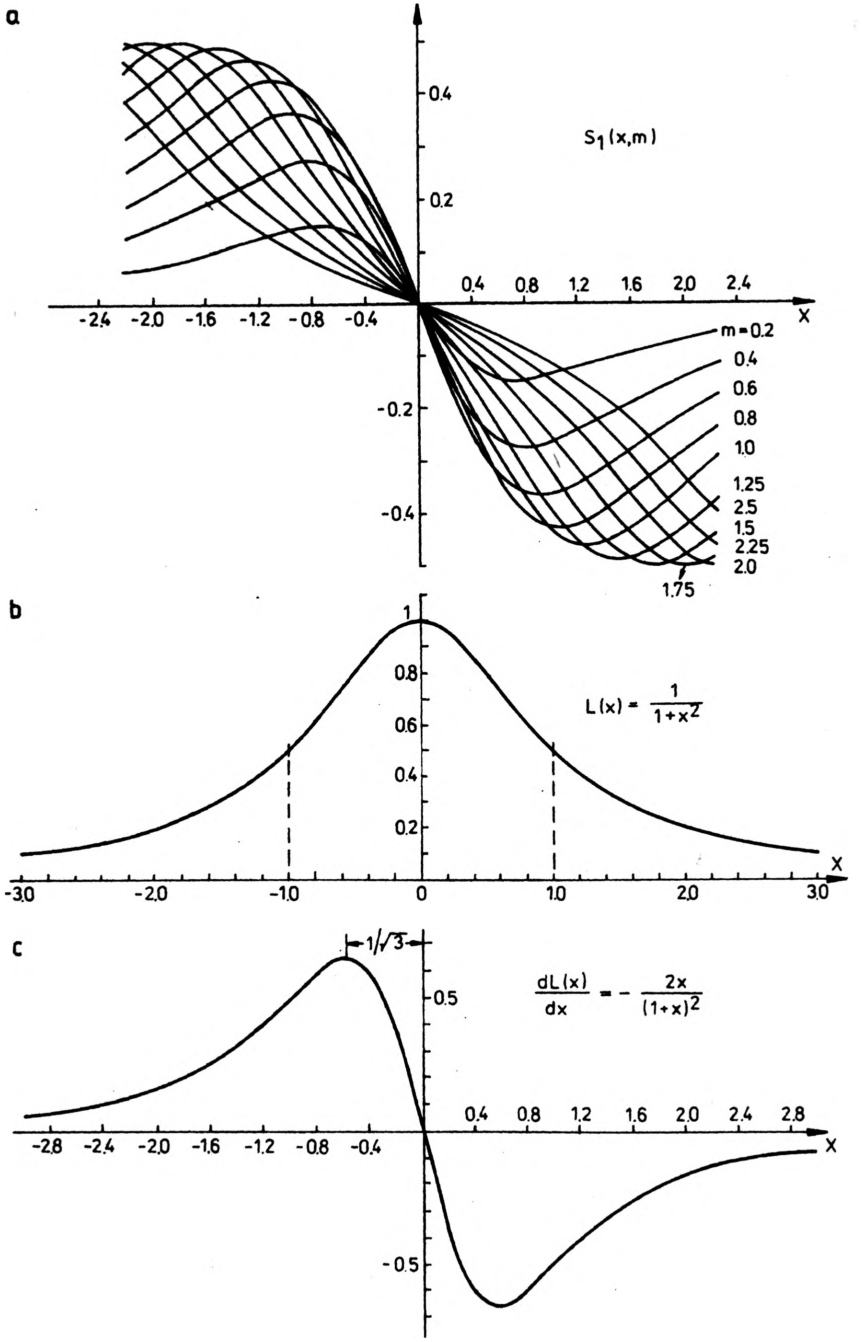

Fig. 3. Several discriminant shapes $S_1(x, m)$ vs the modulation amplitude m (**a**). For comparison a Lorentzian shape (**b**) and its first derivative (**c**) are presented

detected is determined by the expression

$$L(x, m, t) = \{1+[x+m\sin(2\pi f t)]^2\}^{-1} \tag{2}$$

where $m = 2\frac{\Delta\nu}{\Delta\nu_p}$ is the dimensionless amplitude of frequency modulation.

The first harmonic of $L(x, m, t)$ signal gives the necessary discriminant shape useful for saturation spectroscopy as well as for frequency stabilization devices. The amplitude $S_1(x, m)$ of the first harmonic of the analysed signal $L(x, m, t)$ was calculated by Arndt [7] and equals

$$S_1(x, m) = \frac{(2)^{1/2}}{m}\,\frac{x[(M^2+4x^2)^{1/2}+M]^{1/2}-[(M^2+4x^2)-M]^{1/2}}{(M^2+4x^2)^{1/2}} \tag{3}$$

where $M = 1-x^2+m^2$.

$S_1(x, m)$ well approximates the first derivative of the Lorentzian signal shape. This approximation is better when the value of the parameter m is lower, according to the relation

$$\lim_{m\to 0}\frac{1}{m}S_1(x, m) = \frac{dL(x)}{dx} - \frac{2x}{(1+x^2)^2}. \tag{4}$$

Figure 3 shows a few discriminant curves $S_1(x, m)$ for different values of parameter m, the Lorentzian shape and its first derivative, respectively. The first harmonic $S_1(x, m)$ is easily detected by generally practiced psd technique. We present here a somewhat different procedure which has been applied in order to detect the discriminant shape of an absorption peak. Its essence consists in a simultaneous application of the transverse and longitudinal output modulation of the same frequency f. If the amplitude $A_1(x)$ of the transverse modulation is constant within the whole tuned range and the transverse modulation phase-synchronized relatively to the longitudinal modulation, the first harmonic $S_1'(x, m)$ detected selectively after a photodetector is the sum of signals

$$S_1'(x, m) = S_1(x, m)+A_1(x). \tag{5}$$

It is self-evident that Eq. (5) is true when $A_1(x) > S_1(x, m)|_{\max}$. Assuming $A_1(x) = \text{const}$, the signal $S_1'(x,.m)$ has the same shape as $S_1(x, m)$ and they differ only in the zero level. So, we can see that the transverse modulation signal operates in double-modulation technique as the reference signal in psd technique.

3. Experimental

In this section we present the analyses of the absorption peak in the single-mode He-Ne/CH_4 laser performed by the two methods mentioned above, i.e., psd and double-modulation technique (Fig. 4). Laser cavity 60 cm long included dc-excited gain tube 32 cm long and absorption cell 20 cm long. The low noise discharge

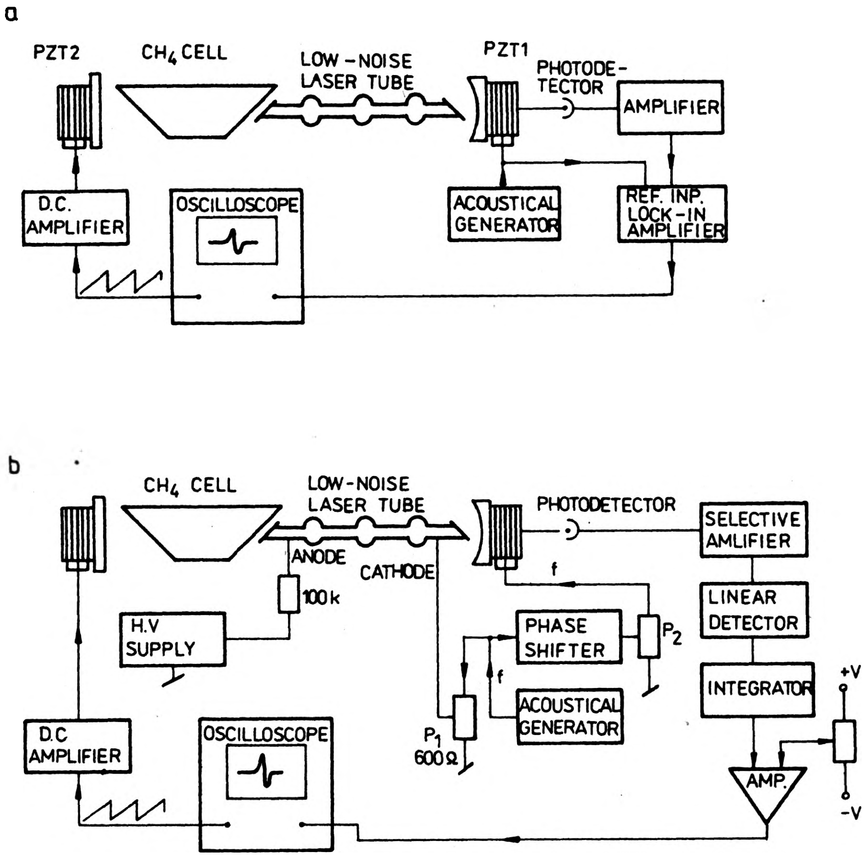

Fig. 4. Experimental arrangements applied to the first harmonic analysis of the absorption peak in He-Ne/CH_4 laser using: **a** – phase-sensitive detection technique, **b** – double-modulation technique

tube with spherical spacings [8] used in investigations was filled with 27 Pa (0.2 Torr) of Ne^{22} and 270 Pa (2 Torr) of He^3. This filling permits us to get the precise covering of the absorption line in methane with the emission line of neon.

As a result, the output power of He-Ne laser with an intracavity absorption cell filled with 1.3 Pa (10 mTorr) of methane gives a very narrow peak at the centre of ν_3, P(7) methane line. Figure 5 presents oscilloscope records of the output power with the absorption peak at the centre of the emission line of He-Ne/CH_4 laser under investigation. The half width at half maximum of absorption peak is about 350 kHz. The height of the saturation peak is about $1.2^0/_0$ of the total output laser power.

The analysis of peak power in He-Ne/CH_4 laser has been performed in two systems presented in Fig. 4. The first one (Fig. 4**a**) is the classical set-up based on phase-sensitive detection. The first harmonic signal is obtained by means of lock-in amplifier. A more detailed description of double-modulation set-up will be given below (Fig. 4**b**). An acoustical sine-wave signal from the acoustical generator is for both the transverse and longitudinal modulation a driving signal. It is passed through the phase shifter to PZT driver causing the longitudinal modulation of the laser cavity. The acoustical generator is also loaded by P_1 potentiometer which is connected in series to the cathode of the discharge tube. Typical discharge currents range within 5–6 mA. This range lies in the low-noise region of the pressure-current characteristic as well as in linear part of the output-current characteristic [8]. Hence, the transverse modulation of the output power can be easily carried out by means of discharge current modulation.

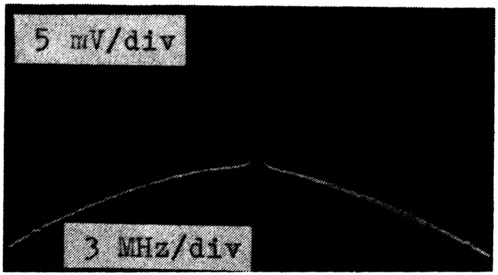

Fig. 5. Oscilloscope record of the output power with the absorption peak in He-Ne/CH_4 laser

The amplitudes of both the applied modulations can be regulated by potentiometers P_1 and P_2, respectively. Phase shifter permits the regulation of the relative phase between these two signals for optimal operation. Because the relative height of the peak power is about 1% we can assume that in the closest neighbourhood of the peak power the amplitude of the transverse modulation is constant.

The application of the discharge current modulation with 0.1 mA amplitude permitted us to obtain the intensity modulation (transverse modulation) with an amplitude of about 2%. The selected modulation frequency f ranged within 0.5–1 kHz. The signal after the photodetector was passed through the selective amplifier, linear detector and integrator. At the output of the integrator it has the required shape given by Eq. (5). A constant dc level obtained at the output of the integrator can be compensated by the differential amplifier with the regulation of dc voltage level.

Figure 6 presents two sets of oscilloscope records obtained as a result of the first harmonic (first derivative) detection of the peak power in He-Ne/CH_4 laser for psd and double-modulation techniques, respectively. All analyses have been carried out for the same laser operating in the same conditions. As we can see, both these methods give qualitatively comparable results.

4. Conclusions

In this paper two kinds of modulations of an emission laser line, called here longitudinal and transverse ones, have been distinguished. The first harmonic

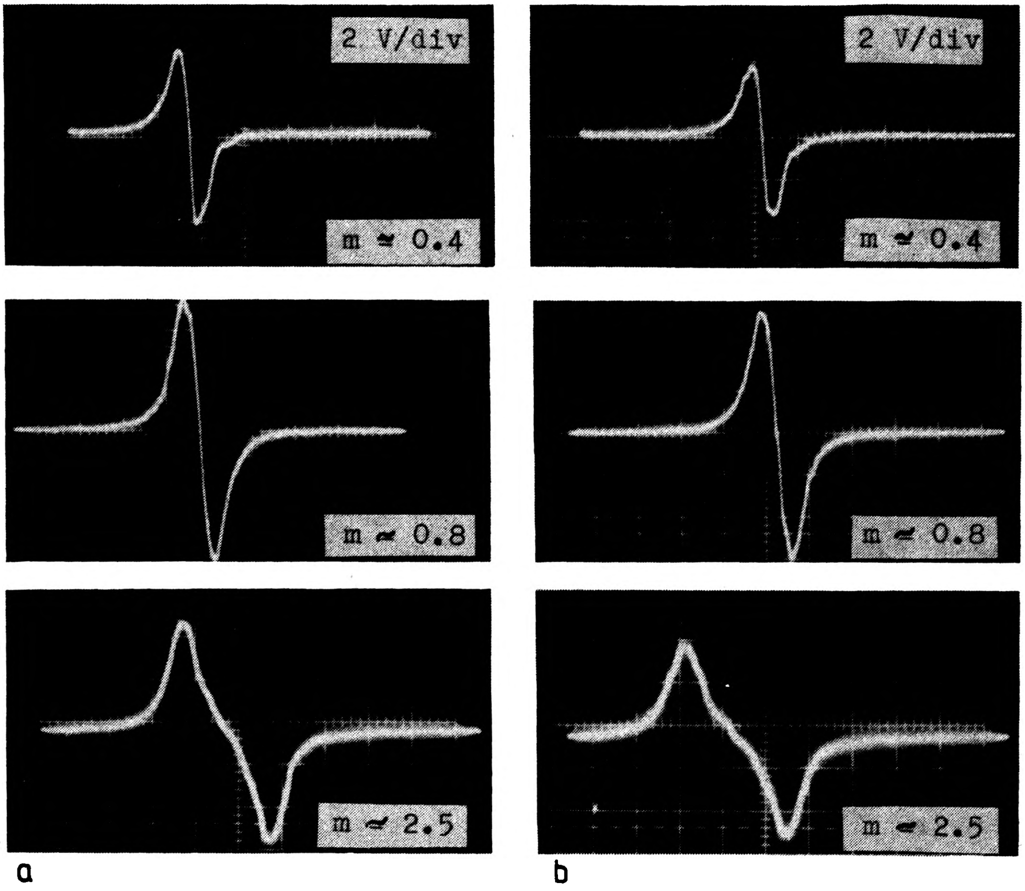

Fig. 6. Two sets of oscilloscope records presenting the first harmonic analysis of absorption peak in He-Ne/CH_4 laser for different values of parameter m: **a** – phase-sensitive detection, **b** – double-modulation technique. Frequency of modulation $f = 875$ Hz, speed of analysis 0.1 s/div, time constant of integration $\tau = 10$ ms

(or first derivative) technique has been used for the analysis of the saturation peak in methane. This analysis was performed by the double-modulation technique and compared to the psd technique. It has been shown that the first derivative analysis can be done by the double-modulation technique.

It is difficult to point out the practical advantages of this method with respect to psd technique. It should be added, however, that the main purpose of this paper is to emphasize the idea of double-modulation of laser line which, in author's opinion, seems to be perspective in laser spectroscopy.

Acknowledgement – The author would like to thank Mr B. Tyśnicki for his help in carrying out the experiments.

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Received March 20, 1986

Двойная модуляция лазерной линии

В работе представлены два возможных способа модуляции лазерной линин. Они названы поперечной и продольной модуляцией. Описано существо двойной модуляции лазерной линии. Двойная модуляция может быть применена для анализа спектральных деталей на фоне лазерной линии методом первой гармоники. Такой анализ был сделан экспериментально для поглощающего пика мощности в He-Ne/CH_4 лазере и сравнён с классическим методом снихронной детекции.