Precision measurements of the infrared Zeeman spectrum of methane with a ring laser

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"Competition" power resonances of a ring laser were used to measure the Zeeman splitting of the methane 2947.912 cm^{-1} absorption line of the $F_1^{(2)}$ component of branch $P(7)$ of group ν_3 with resolution 3×10^{-6} cm^{-1}.

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1. Introduction of a nonlinearly-absorbing medium into the resonator of a ring laser leads to an abrupt change in the generation conditions of the traveling and standing waves in a narrow frequency region at the center ω_- of the absorption line, as a result of which the dependence of the laser power on the frequency contains high-contrast and exceedingly narrow "competition" resonances.[1]

We report here the first successful experiments in which the "competition" resonances are used for high-frequency measurement of the Zeeman splitting of the methane 2947.912 cm^{-1} absorption line of the $F_1^{(2)}$ component of the $P(7)$ branch of group ν_3 with resolution $\sim 3\times10^{-6}$ cm^{-1}. We succeeded in effecting for the first time, ultrahigh-resolution spectroscopy of an absorbing medium, based on the wave-competition effects. The advantages of the proposed spectroscopy method are the following: a) there is no need for sensitive recording apparatus, since the wave-competition effects makes it possible to transform the inverted Lamb dips of low amplitude into high-contrast "competition" resonances; b) the accuracy of the spectral measurements is increased by several orders of magnitude, since the width of the "competition" resonances can be negligibly small.

2. The experimental setup consisted of a three-mirror ring laser ($\lambda = 3.39$ μ), the resonator of which contained, besides the gas-discharge tube, a methane absorbing cell placed in a solenoid. The solenoid produced a constant magnetic field of intensity up to 1.4 kOe over a section 1 meter long. The diameter of the gas-discharge tube was 15 mm and that of the methane cell 40 mm. The length of the active and passive cells was 1 meter. At these system parameters, the homogeneous absorption line width (at a methane pressure $P_{\mathrm{CH}_4} = 5\times10^{-4}$ Torr) was 90 kHz. Application of a 500-Oe magnetic field splits the methane line into two σ components, the spacing between which is $\delta = 2g\mu_{\mathrm{nuc}}(H/\hbar)$, where μ_{nuc} is the nuclear magneton and H is the magnetic field intensity. The splitting at $H = 500$ Oe is 230 kHz. Since the level-crossing effect[2] gives rise to a resonance also at the central frequency, the distance between the spectral components was 115 kHz. Figure 1a shows an oscillogram of the output power of the ring laser as its length was scanned. The spike 1 shows the methane competition resonance with a contrast close to 100%. The shape of the resonance 1 at small scanning amplitudes is shown in Fig. 1b. Its half-width Δ is 30 kHz, much less than the homogeneous width. When the magnetic field is turned on, the methane peak splits into three components (Fig. 1c). The two side resonances correspond to the σ^+ and σ^- Zeeman components of the line, while the central resonance is due to the crossing effect.[2] By measuring, with accuracy $\pm 10^{-2}\Delta$, the distance between the side resonances, and by the same token the value of the Zeeman splitting of the methane line, we can determine the values of the g-factor much more accurately and more simply (in comparison with the experimental procedure in[3]). As a result we have $g = 0.312 \pm 0.003$, and this is in agreement with earlier work.[3,4]

3. The feasibility of spectroscopy of an absorbing medium with the aid of "competition" contrasts follows directly from an analysis of the equations for the time variation of the amplitudes $E_{1,2}$ of the traveling waves of a ring laser if the absorption line contains N spectral components:

$$\dot{E}_{1,2} = \kappa_+ E_{1,2} \{ \eta_{1,2} - a_+ [(\alpha_+ - \sum_i^N \mu^{(i)} \alpha_-^{(i)}) E_{1,2}^2 - (\beta_+ - \sum_i^N \mu^{(i)} \beta_-^{(i)}) \times E_{2,1}^2] \}; \quad (1)$$

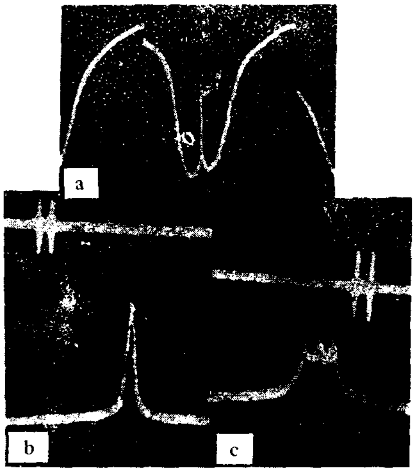

FIG. 1. The oscillograms of the output power of one of the waves of a ring laser; $P_{\mathrm{He\text{-}Ne}^{22}} = 2.2$ Torr, $P_{\mathrm{CH}_4} = 5\times10^{-4}$ Torr; a) General view of scanning zone: 1—methane "competition" resonance. b) Shape of methane peak in the case of a small scanning amplitude; distance between markers 50 kHz. c) Splitting of "competition" resonance in magnetic field $H = 500$ Oe; distance between markers 100 kHz.

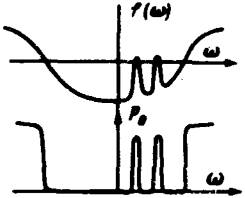

FIG. 2. Formation of "competing" ring-laser power resonances in the presence of two spectral components in the absorption line.

here $\varkappa_{+(-)}$ are the linear amplification (absorption) coefficients, $\eta_{1,2}$ is the excess of the pump over threshold, $\mu^{(i)} = a_-^{(i)}\varkappa_-^{(i)}/a_+\varkappa_+$, $a_{+(-)}$ is the saturation parameter, while $\alpha_{+(-)}$ and $\beta_{+(-)}$ are the saturation coefficients of the amplifying and absorbing media by the proper field and by the field of the opposing wave.[5] There exists for Eq. (1) a stationary solution that describes generation of a standing wave ($E_1 = E_2 \neq 0$), under the condition

$$f(\omega) = \{(\alpha_+ - \beta_+) - \sum_i^N \mu^{(i)}(\alpha_-^{(i)} - \beta_-^{(i)})\} > 0. \qquad (2)$$

Analysis shows that $f(\omega)$ is maximal at the central frequencies $\omega_-^{(i)}$ of the absorption-line components. If $f(\omega_-^{(i)}) > 0$, then "competition" resonances connected with the transition of the generation from the one-wave to the two-wave regime will be observed separately at frequencies $\omega_-^{(i)}$ under the condition

$$\delta^{(i)} > \gamma_- , \qquad (3)$$

where $\delta^{(i)}$ is the distance between the spectral components and γ_- is the homogeneous width of the absorption line. The form of the function $f(\omega)$ in the presence of two spectral components in the absorption line is shown in Fig. 2. This figure shows also the theoretical plot of the power $P_0(\omega)$ of one of the traveling waves of the ring laser when the frequency is scanned with the "competition" resonances that occur at the frequency $\omega = \omega_-^{(i)}$.

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