Continuous Coherent Radiation in Methane at $\lambda = 3.39 \mu m$ in Spacially Separated Fields

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Abstract. Continuous coherent radiation in a gas observed in a spacially separated standing wave fields is reported for the first time. The radiation was observed in the center of line $F_{22}$ in methane at the interaction of atoms with two standing waves separated by the distance of 3.5 cm.

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Recently Baklanov et al. [1, 2] showed that it is possible to obtain a sharp resonance in the interaction of an atomic ensemble with widely separated optical fields. The resonance appears for two-level atoms in a three-beam system [1]. Two-photon absorption in a standing-wave field permits to use two beams [2]. These methods in the optical region are realized due to elimination of the Doppler effect in the nonlinear field-gas interaction. In their properties the resonances in the optical region are similar to the well-known Ramsey resonance in the radio-frequency range [3]. This year several research groups reported independently the first observations of the Ramsey-type absorption resonance in separated optical fields [4–7] for atoms with a short lifetime.

The preceding paper [8] revealed a possibility of observing coherent radiation from a gas in spacially separated optical fields. A low pressure gas interacts resonantly with two standing waves of frequency $\omega$ separated at the distance $L$. At low gas pressure when a free path length of atoms is comparable with the distance between light fields, coherent radiation is emitted at the distance $mL$ ($m=2, 3, \ldots$) from the first beam, which is generated by spatial polarization transfer at large distances. The radiation has the frequency of the standing wave field, and the radiation intensity has the width which is inverse to the time of atomic flight between the beams.

The present paper reports the first observation of this phenomenon in methane at $\lambda = 3.39 \mu m$.

1. Experiment

Coherent radiation in separated fields (CRSF) was observed in an external absorption cell on the $F_{22}$ line of methane by using the laser spectrometer shown in Fig. 1. The spectrometer consisted of a frequency-stabilized He–Ne/CH$_4$ laser 1 with a narrow line width of $\sim 7$ Hz, a tunable laser 3 and an auxiliary heterodyne laser 2. The principle of operation of this spectrometer was described in [9]. The output of the tunable laser was directed into an external absorption cell, where two parallel standing waves were formed with the aid of mirrors. The special procedure of adjustment permitted to make the waves parallel with an accuracy of about 1'. The light beam diameter was about 1 cm, the distance between beams 3.5 cm. The absorption cell was 115 cm in length. The methane pressure in the cell was about $10^{-4}$ Torr. The coherent radiation emitted at a distance of 3.5 cm from the second beam was detected and recorded.

Estimations of the CRSF intensity show that the intensity of coherent radiation in methane under our conditions is $I \sim 10^{-15}$ W. It is impossible to directly record such a weak signal because there is no highly sensitive photodetector; hence we made coherent heterodyne reception by using the laser 2 whose frequency was detuned from the tunable laser 3 by 1 MHz. The heterodyne laser power was $10^{-3}$ W. A beat signal between the coherent radiation and the laser 2 after synchronous detection at a frequency of 1 MHz was
Considerable difficulties in recording the signal of coherent radiation in methane were experienced by the inconstant time and spacial difference in phases between the two standing waves due to insufficient rigidity of optical elements of the scheme. This resulted in the fluctuations of amplitude and phase of the recorded signal of CRSF, and hence, to distortion of its shape (Fig. 2). The phase difference \( \phi_2 - \phi_1 \) between the standing waves was adjusted by means of mirrors mounted on piezoceramic elements, as can be seen in Fig. 1.

2. Interpretation of Results

As has been already mentioned, the observed phenomenon is based on the polarization transfer at the distance \( 2L \) from the first beam. In accordance with Maxwell's equations, polarization \( P \) gives rise to radiation with a field amplitude \( E = i2\pi klP \), \( k \) being the wave number, and \( l \) the cell length. In accordance with the results of [8] and using the atomic dipole moment to give the atomic polarization at the point \( z \), at the distance \( x \) from the first beam. We have

\[
P(x, z, t) = -d_{12}G_1|G_2|^2 \frac{T^3}{4} \left( e^{i2\pi x/U} + e^{i2\pi (x-2L)/U} \right)
\]

\[
\cdot \int_{-\infty}^{\infty} dV_1 f(V_1)
\]

\[
\cdot \cos \left[ k z - k \frac{V_1}{U} (x = 2L) + 2(\phi_2 - \phi_1) \right] e^{-i\omega t},
\]

(1)