Self-modulation of the output intensity of a wide-band laser with strong absorption lines in the resonator

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(Submitted 14 October 1985)
Pis'ma Zh. Eksp. Teor. Fiz. **42**, No. 10, 416–418 (25 November 1985)

An anomalous intensification of the output of a wide-band dye laser has been detected near resonant absorption lines of potassium vapor in the cavity of this laser. A temporal modulation of the laser output with a period of 1 ns has been observed. A model of a coherent interaction of the wide-band laser output with the absorber is proposed.

The output spectrum of wide-band lasers has recently been the subject of many studies. Because of the pronounced sensitivity of the output spectrum to the presence of a frequency-independent loss, this spectrum is a weakly stable function of the frequency. On the one hand, this sensitivity underlies the method of in-cavity laser spec-

 0021-3640/85/220514-04$01.00

troscopy; on the other, various nonlinear processes cause a randomization of the spectrum and the appearance of several unexpected effects. One of these effects is an intensification of the output near a strong absorption line of a material inserted into the cavity (spectral "condensation" of the output). Although this effect has been observed by many investigators[1-11] during the past 20 years, we still lack an unambiguous model to explain it. Various hypotheses have been advanced: a dispersion of the refractive index,[4] the appearance of a lens due to the radial distribution of the absorbing particles,[5-7] the appearance of a nonlinear lens due to saturation of the absorption and the Stark effect in the intense light field of the laser,[8] a spatial grating of the refractive index of the material in the optical standing wave,[9] and coherent and cooperative effects in the interaction of the light with the absorbing material.[10,11] These hypotheses, however, fail to explain all of the experiments in which condensation of the spectrum has been observed.

In an effort to refine the roles played by the various mechanisms, we have studied the kinetics of the spectral distribution of the light with a subnanosecond time resolution. For the experiments we use a laser with a dimethylsulfoxide solution of the dye DOTS-iodide (emission range 762–773 nm), pumped by a Q-switched ruby laser. The energy of the pump pulse is 0.1 J, and its length is 20 ns. The length of the dye laser cavity is 36 cm. A small furnace holding potassium vapor, whose density is controlled by the temperature of the furnace wall, is positioned inside the cavity of the dye laser, near the center of this cavity. The cell is filled with a buffer gas (helium) at a pressure of 5 torr to prevent deposition of the potassium on the cold cell windows. The output from the laser is directed to a spectrograph with a resolution of 300 000. The kinetics of the output spectrum is simultaneously measured with an image converter using an UMI-95 tube. Since attempts to simultaneously achieve a high spectral resolution and a high temporal resolution run into a restriction imposed by the uncertainty relation, a spectral sweep with a resolution of 0.1 ns is taken at the exit from an STE-1 spectrograph with a resolution of 40 000. Figure 1 shows photographs of high-resolution spectra (top) and of sweeps of the output spectra (bottom) from experiments with potassium vapor of several densities in the cavity (a) 10^{13} cm^{-3}, (b) 3×10^{13} cm^{-3}, and (c) 1.5×10^{14} cm^{-3}.

It can be seen from the photographs that at the potassium vapor density of 10^{13} cm^{-3} the output intensity increases near the absorption lines (the brighter bands on the photographs). Since the photographs of the spectral sweep from the screen of the image converter were taken at a lower spectral resolution, the faint absorption lines are masked by the increase in the brightness near the absorption lines. We found that the spectral condensation of the output is accompanied by a simultaneous temporal modulation of the output intensity near the absorption lines, with a period of about 1 ns. On the photograph of the sweep (a), this modulation is particularly noticeable near the 769.9-nm line. Because of the high contrast of the recording apparatus, the modulation is seen on the photograph as a choppy track corresponding to an increased emission brightness near this line. With a further increase in the potassium density, the absorption lines become supersaturated and are seen not only in the time-integrated spectra but also on the sweep photographs (Figs. 1b and 1c). The temporal modulation of the emission in this case is not restricted to the vicinity of the absorption lines; it spans the entire output spectrum. The phase of the modulation shifts along the spectrum. In

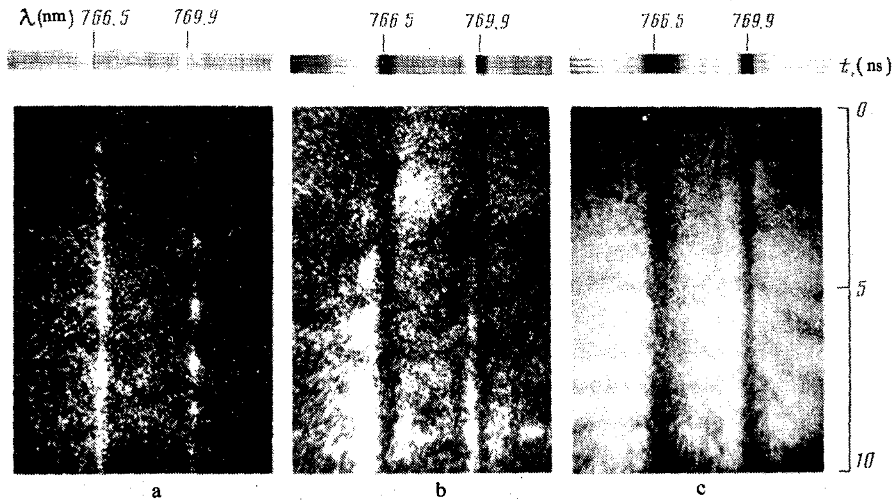

FIG. 1. Integral output spectrum of the dye laser with in-cavity potassium vapor (top); time sweep of this spectrum (bottom). The potassium vapor density is a—10^{13} cm^{-3}; b—3×10^{13} cm^{-3}; c—1.5×10^{14} cm^{-3}. The dark bands correspond to potassium absorption lines, while the bright bands correspond to an increase in the spectral brightness of the laser output.

parts of the spectrum far from absorption lines, the modulation phase lags behind the modulation phase in the region of maximum intensity near the absorption lines.

The observed effect can be explained in terms of a nutation of the polarization vector of the potassium atoms and a modulation of the population of the excited state of the potassium. The population oscillations cause a modulation of the refractive index near the absorption line; this modulation can cause a phase locking of the modes. When the period of these oscillations is close to the time required to traverse the resonator, there may be a self-consistent buildup of the modulation of the light intensity and of the population of potassium atoms. In our case, the time required to traverse the cavity is twice the modulation period. The reason is that the furnace holding the potassium vapor is at the center of the cavity, and the intensity is modulated simultaneously for both of the oppositely directed waves in the cavity resonator. Since several tens of modes fall in the allowed interval in our case, this modulation is seen on the time sweeps of the output spectrum. The phase shift of the modulation in the different parts of the spectrum can be explained in terms of a dispersion of the refractive index near the absorption lines of the potassium vapor.

These results are evidence that an explanation of the spectral condensation effect will require consideration of coherent effects of the interaction of the light in the cavity resonator of the wide-band laser with the absorbing material. This study will be pursued with the goal of developing a more accurate quantitative picture of the effect.

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Translated by Dave Parsons