

USE OF A COPPER VAPOR LASER FOR REMOTE SENSING OF IODINE RADIONUCLIDES

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Absorption of copper vapor laser radiation by the iodine vapor ($^{127}\text{I}_2$) has been studied. It is shown that the copper vapor laser selective to the iodine isotopes can be constructed using the method of on and off resonance selection with a cell containing the iodine vapor. The isotope-selective copper vapor laser also has high power. The results can be used for remote sensing of radionuclides of I_2 in the atmosphere.

The iodine isotopes ^{129}I and ^{131}I are products of technological chains of nuclear production installations and are dangerous pollutants of the industrial environment as well as the free atmosphere because of high volatility of the iodine vapor.

Local radioactive contamination caused by technological violations of the nuclear production can be a long-term source of the iodine radioactive isotope emission into the atmosphere. Development of the methods for monitoring of I_2 in the atmosphere by nonradiometric techniques is an extremely urgent problem. The high-sensitive remote methods are of a special interest, because they allow the sources of I_2 emission into the atmosphere to be revealed in real time.

Among the feasible remote methods of detection of I_2 isotopes the optical ones based on radiation absorption and fluorescence are much promising. A considerable volume of investigations had been carried out for the case of closed industrial space and low pressures of a buffer gas.¹ These investigations showed a possibility of detecting the isotope $^{129}\text{I}_2$ in the industrial space from the fluorescence excited by a laser radiation.

In the present paper the spectroscopic properties of the copper vapor laser are studied from the point of view of prospects for its use in optical detection and sounding of vapor of the iodine radionuclides $^{129}\text{I}_2$, $^{131}\text{I}_2$, $^{131}\text{I}^{129}\text{I}$ in gas halos of radiochemical plants. Density of the iodine radionuclide vapor in the gas halos of radiochemical plants operating under standard conditions is within the range of 10^5 – 10^9 cm^{-3} , and spatial dimensions of the halo are 100–1000 m.

To understand the prospects of the copper vapor laser use to solve this problem, let us consider the spectroscopic properties of the I_2 molecule and copper

vapor laser emission. Figure 1 demonstrates the scheme of the I_2 terms and transitions which are resonant to the emission lines of the copper vapor laser.

Figure 2 shows a position of the copper vapor laser lines relative to the absorption spectrum of the iodine molecule band $A, B \leftarrow X$ recorded by the photoacoustic method.² As one can see from Figs. 1 and 2, the green (510.6 nm) and yellow (578.2 nm) lines of the copper vapor laser are close to the band $A, B \leftarrow X$ maximum.

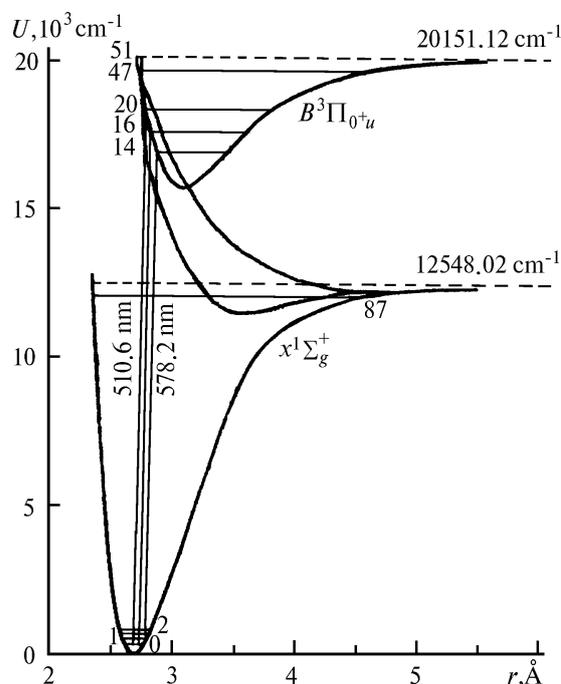


FIG. 1. Scheme of I_2 terms: U is the power; r is the internuclear distance.

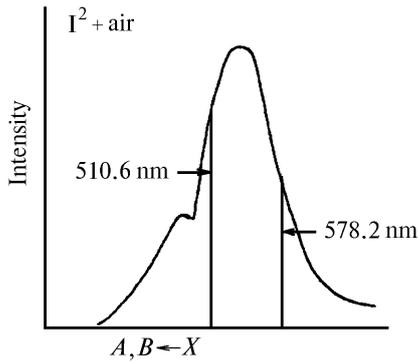


FIG. 2. Position of the copper vapor laser lines relative to the maximum of the absorption band $A, B \leftarrow X$ of I_2 .

Analysis of the data from Refs. 3 and 4 shows that at the maximum of the absorption band $A, B \leftarrow X$ the $^{127}I_2$ lines density is about $10/cm^{-1}$. Hence, there are several lines of $^{127}I_2$ within the contours of the Cu lines at $\lambda = 510.6$ and 578.2 nm.

Figure 3 presents symbolically the fine structure of the Cu lines of natural isotopic composition and corresponding portions of the band $A, B \leftarrow X$ of the $^{127}I_2$ molecule. These data are taken from Ref. 4. As one can see from Fig. 3, the spectral density of the rovibronic lines of I_2 is so high that several absorption lines of $^{127}I_2$ are within the contours of every Cu line. As a result, the copper vapor laser radiation is absorbed by the $^{127}I_2$ vapor and excites the fluorescence in the band $A, B \leftarrow X$ (Refs. 4 and 5).

The same is true for the band $A, B \leftarrow X$ of the $^{129,131}I_2$ radionuclides. Taking into account that the lines of all the three isotopes are inside the line contours of the copper vapor laser, the selective copper vapor laser tuned at any frequency of these isotopes emission can be constructed. For example, to tune the copper vapor laser at resonance with $^{129}I_2$ lines only, a cell with the $^{129,131}I_2$ isotopes ought to be introduced into the construction of this laser and placed either outside or inside the laser resonator by analogy with Ref. 6.

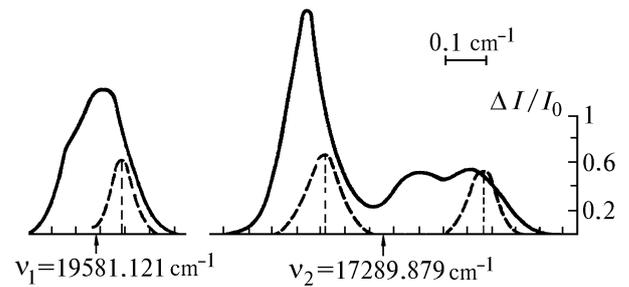


FIG. 3. Contour of $4p^2P_{3/2} - 4s^2D_{5/2}$ (510.6 nm) and $4p^2P_{1/2} - 4s^2D_{3/2}$ (578.2 nm) lines of the copper spontaneous emission. Solid lines show the contours of copper lines without their absorption by the iodine vapor; dashed lines show the contour of $^{127}I_2$ absorption lines, $\Delta I/I_0 = (I_0 - I)/I_0$; I_0 is the incident light intensity, I is the intensity of light passed through the cell; ν_1 and ν_2 are the frequencies of radiation at $\lambda = 510.6$ and 578.2 nm.

To test this statement, we have carried out an experiment on selection of copper vapor laser radiation with the isotope $^{127}I_2$. Figure 4 presents the experimental setup. The setup contains a copper vapor laser 1, a filter set for selecting between yellow and green lines of the laser radiation 2, absorption cell with the vapor of $^{127}I_2$ 3, fluorescent cell with the vapor of $^{127}I_2$ 4. Two channels of signal recording are used. The fluorescent channel records the fluorescence intensity in the cell 4, and the second channel controls the power of laser radiation passed through both cells.

The setup has been operated as follows. The absorption cell branch with the iodine was cooled, and signals in both channels were measured. Then the cell and branch with the iodine were heated by warm air up to $40^\circ C$. In this case change in signals in both channels was observed. The experimental results are presented in Table I.

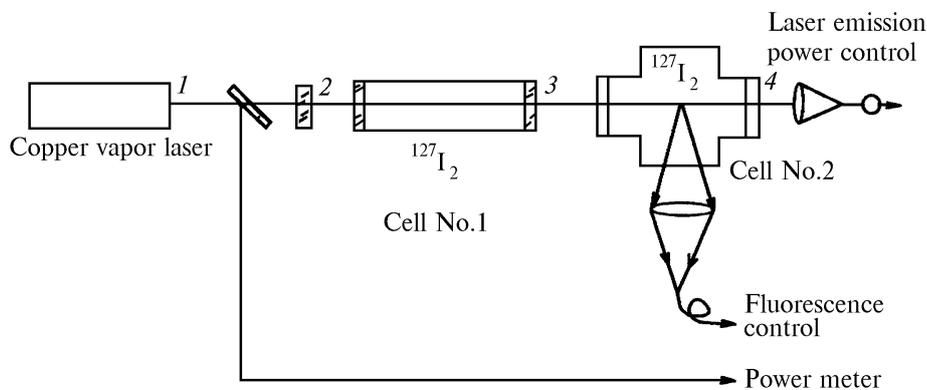


FIG. 4. Experimental setup.

TABLE I.

Wavelength, nm	Temperature in the cell No. 1, °C	Laser power, rel. units	Fluorescence intensity, rel. units
510.5	0	1	1
	40	0.25	0
578.2	0	1	1
	40	0.75	0

As one can see from Table I, when introducing the iodine vapor in the absorption cell 3, the fluorescence signal in the cell 4 is completely attenuated, but the laser radiation, as expected, is not absorbed completely according to Fig. 3. The absence of fluorescence in the cell 4 in the presence of the $^{127}\text{I}_2$ vapor in the cell 3 is indicative of a complete selection of the laser radiation by the $^{127}\text{I}_2$ vapor. Naturally, the radiation passed through the heated cell with the $^{127}\text{I}_2$ vapor is absorbed by vapor of the $^{129,131}\text{I}_2$ iodine radionuclides only, and it excites the fluorescence in this vapor.

Let us note some peculiarities in the absorption of the laser yellow and green lines by $^{127}\text{I}_2$ vapor. First, the radiation at $\lambda = 510$ nm is absorbed stronger than that at $\lambda = 578$ nm, second, the vapor transmittance for the green radiation is determined by the level of laser power excess over the threshold (threshold effect). A possible cause of the strong absorption of the green line is the continual absorption taking place in this spectral region.⁷ Figure 5 illustrates a contribution of the line and continual absorption over the band $A, B \leftarrow X$ (Ref. 5). The threshold effect indicates the coincidence of the iodine line with the most strong component at $\lambda = 510$ nm.

Note that at least two ways can be shown to optimize the spectrum (and effectiveness as well) and hence the resonance properties of the copper vapor laser with respect to the isotopes of I_2 . One of the ways is connected with the use of the monoisotopes ^{63}Cu and ^{65}Cu or isotope mixture with a desired composition instead the natural isotope composition in a copper vapor laser. The second way is connected with the selection of optimal pressures of a buffer gas in the laser and the absorption cell.

Taking into account that copper vapor laser is the best laser source operating within the $A, B \leftarrow X$ band the results of the present paper enable this laser to be applied for monitoring of the iodine radionuclides in the atmosphere.

Fluorescence being excited by laser radiation provides a possibility of detecting I_2 in the atmosphere. But the fluorescence of atomic and molecular components of the atmosphere is subjected to quenching due to intermolecular collisions.

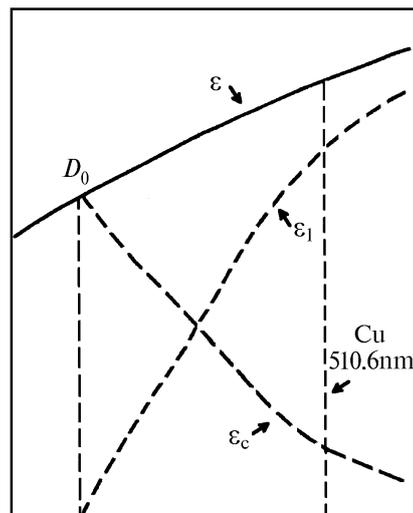


FIG. 5. Contribution of the line ϵ_1 and continual ϵ_c components into the absorption ϵ in the region of the copper green line for the yellow line $\epsilon_c \rightarrow 0$. Solid line shows the vibrational levels of I_2 , dashed lines show the dissociation boundaries.

To estimate the I_2 vapor fluorescence signals in the Radiochemical Plant pollutions, the factors of I_2 fluorescence quenching over the $A, B \leftarrow X$ band were measured. For the atmospheric conditions the quenching factor equals 10^{-4} . With the allowance for this fact, the expected signal level is about one photon per second for the above-specified radionuclide concentrations in the air for sounding distance of 1000 m, sounding layer depth of 10 m, receiving antenna area of 0.25 m^2 , and for the selective radiation of a copper vapor laser of 1 W power.

REFERENCES

1. S.V. Kireev, E.D. Protsenko, and S.D. Shnyrev, *Atmos. Oceanic Opt.* **7**, No. 3, 199–201 (1994).
2. K. Narayanan and S.N. Thakur, *Appl. Opt.* **31**, No. 24, 4987–4994 (1992).
3. V.E. Golikova and V.E. Privalov, *Calculation of Absorption Lines for Iodine Bench Mark Stabilized Lasers*, Preprint No. 53, Institute of Analytical Engineering, St. Petersburg (1992).
4. V.M. Kaslin, G.G. Petrash, and O.F. Yakushev, *Zh. Eksp. Teor. Fiz.* **78**, No. 4, 1349–1364 (1980).
5. P. Printsgeim, *Fluorescence and Phosphorescence* (Foreign Literature Press, Moscow, 1951).
6. T.W. Hansch, A.L. Schawlow, and P.E. Toschek, *JEEE J. Quant. Electron.* **QE-8**, No. 10, 802–804 (1972).
7. Y. Tellinghuisen, *J. Chem. Phys.* **59**, No. 2, 849–852 (1973).