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Analysis of the spectral structure of CuBr laser lines

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Abstract

The spectral structure of spontaneous emission of copper atom at 510.6 nm and 578.2 nm was calculated considering the hyperfine structure of energy levels and the isotope shift. The spectral structure of the 510.6 nm and 578.2 nm laser lines was measured in a sealed-off CuBr laser tube with periodic refreshment of the neon buffer gas under different work temperature and excited voltage. The spectral structure of the spontaneous emission of copper atom was found to have similar outline with its laser lines. The spectrum of the 510.6 nm laser line maintains similar outline with three peaks at various discharging parameters while the spectrum of the 578.2 nm laser line is strongly dependent on the reservoir temperature and the discharge voltage.

Keywords: Hyperfine structure; Spectral structure; CuBr laser

1. Introduction

It is well known that the knowledge of laser line shapes is important for understanding the laser mechanism, improving its output characteristics and some practical applications [1]. The spectrum of CuBr laser has been reported under the condition of flowing neon gas with high pressure in [2–4]. But the laser could not maintain stable neon gas pressure and work temperature for a long period in flowing condition. Moreover the impurity contained in the laser tube under lower vacuum degree would affect the measurement of spectrum of CuBr laser.

A new experimental facility including a high vacuum system, a laser tube with periodic refreshment of the neon buffer gas and a pressure-scanned F-P interferometer was designed to solve the above problems. The spectral outline of the CuBr vapor laser line was measured as a function of operating parameters such as the buffer gas pressure, the input power, the tube wall temperature and the pulse repetition frequency. For comparison, the 510.6 nm and 578.2 nm spontaneous emission line shapes were calculated considering the hyperfine structure and isotope shift according to the experiment parameters. The results show that the laser line and the spontaneous emission line have the similar profile for the 510.6 nm line, but the line shape of the 578.6 nm laser line greatly depends on the discharging condition.

2. Calculation of spectral line shapes of 510.6 nm and 578.2 nm lines

It is well known that the spectral structure of the laser radiation is governed by the hyperfine structure and isotopic splitting of the active levels of the copper atom as described in [5,6], so the line shape of the hyperfine structure of the copper atomic spontaneous emission can be taken as the basic consideration for the explanation of its laser spectral characteristics. The complexity of the hyperfine structure of CuBr laser lines is resulted from several factors such as the magnetic dipole, the electric quadruple splitting, the isotope shift and the Doppler broadening. The homogeneous broadening has been estimated to be negligibly small in comparison with the Doppler broadening in this work.

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Both of the two isotopes, ^{63}Cu and ^{65}Cu, have nuclear spin which will cause magnetic dipole and electric quadruple splitting. The 510.6 nm laser line is produced by a transition between $^2P_{3/2}$ and $^2D_{5/2}$ while the 578.2 nm line comes from the transition between $^2P_{1/2}$ and $^2D_{3/2.}$ The nuclear spin I of both isotopes is 3/2. The total angular momentum F of an atomic state is given by $|J-I| \leqslant F \leqslant |J+I|$, which is determined by selection rules, where J is the total electron angular momentum. The schematic energy level splitting of ^{63}Cu is shown in Fig. 1. The other isotope, ^{65}Cu, has the same number of splitting levels, though the frequency shift which is determined by the magnetic dipole A and the electric quadruple B is different. The frequency shift is given by the formula, $\Delta V = \frac{AC}{2} + \frac{B}{4} \cdot \frac{3C(C+1)-4I(I+1)J(J+1)}{2IJ(2I-1)(2J-1)}$, where $C = F(F+1) - J(J+1) - I(I+1)$. The relevant parameters above in the calculation are given in [7].

The averaged radial gas temperature T given in [8] should be considered in dealing with the Doppler broadening

$$T = \frac{4B}{2+a}(T_0^{2+a} - T_{\mathrm{w}}^{2+a})/(q_{\mathrm{v}}R^2),$$

where the center temperature $T_0 = (T_{\mathrm{w}}^{1+a} + \frac{1+a}{4B} q_{\mathrm{v}} R^2)^{1/1+a}$, T_{w} is the tube wall temperature, q_{v} is the power deposited per unit volume which is taken as 4 W/cm^3 commonly and $R = 3.6 \times 10^{-3}$ m is the radius of laser tube. The constants $a = 0.685$ and $B = 9.7 \times 10^{-4}$ for neon buffer gas and T_0 is the temperature at $r = 0$ in K. The spectrum profiles of 510.6 and 578.2 nm lines have been calculated at $T_{\mathrm{w}} = 700$ K while $T_0 = 840$ K and $T = 767$ K.

Figs. 2 and 3 show the calculation results of the hyperfine structure of the 510.6 nm and 578.2 nm copper atomic lines at 767 K, respectively. The bold profile is formed by the superposition of all the hyperfine line shapes with Doppler broadening which is expressed as $I(v) = \sum_{i=1}^{n} I(v_i) \exp[-4\ln 2(v - v_i)^2/V_d^2]$, where $I(v_i)$ is the relative intensity of the hyperfine component, $V_d = 7.16 \times 10^{-7} \cdot v_0 \cdot (\frac{T}{M})^{1/2}$ is the Doppler width and v_i is the center frequency of the hyperfine component, T is the average gas temperature, M is the atomic weight.

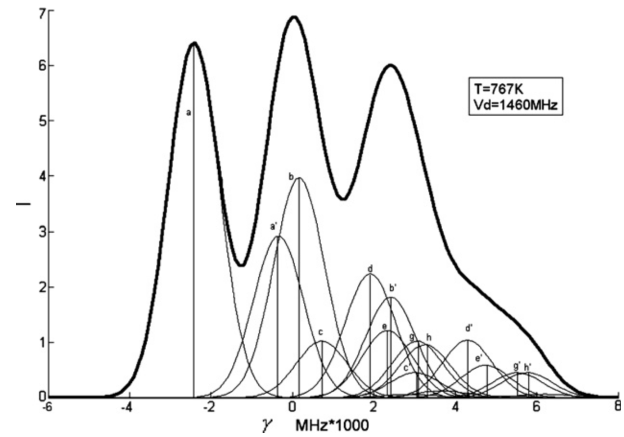

Fig. 2. Calculated line shape of the 510.6 nm at 767 K.

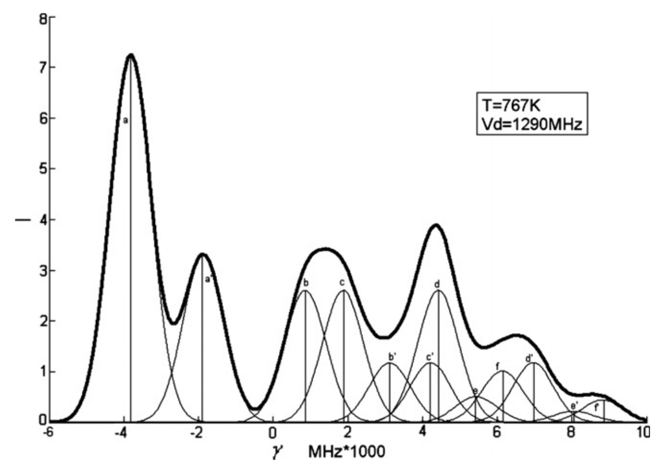

Fig. 3. Calculated line shape of the 578.2 nm at 767 K.

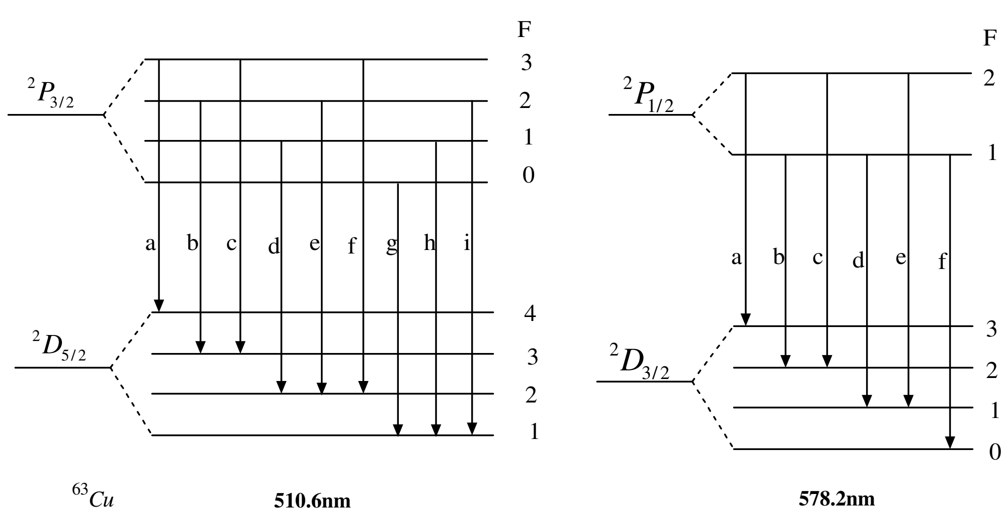

Fig. 1. Energy level splitting of copper atom and its transitions.