Appl. Phys. B 47, 87–89 (1988)

Applied Physics B Photophysics and Laser Chemistry
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Multiple Spectral Structure of the 578.2 nm Copper Laser Line

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Received 18 March 1987/Accepted 25 November 1987

Abstract. The multiple spectral structure of the 578.2 nm copper laser line of a CuBr laser is investigated. By considering the special hyperfine transitions of the ^{63}Cu atom, the discharge disturbance and the competition of transitions, an explanation of the multiple line structure is given

PACS: 42.55.Hq, 42.72.+h, 32.70.Jz

The spectral structure of the 578.2 nm and 510.6 nm laser lines, which has been studied by Tenenbaum et al. [1], Isaev [2], Kreye and Roesler [3] and Wang et al. [4], is important both for laser characterization and applications. We found that the reproducibility of the shape of the 578.2 nm laser line under the same operation condition was not satisfactory over a long period of time in our laboratory. We have recently performed a series of experiments and the present paper reports for the first time that the 578.2 nm laser line has a complex spectral structure.

1. Experimental Method

The laser light was emitted from a CuBr laser identical to that used in [5]. The experimental conditions were: dc voltage 4.5 kV, buffer gas pressure 70 Torr, pulse repetition frequency 18 kHz and lasant reservoir temperature 450 °C. A pressure-scanned Fabry-Perot etalon of fineness greater than 30 was used with a 30000 MHz free spectral range. The etalon was operated in the scan mode by varying the air pressure between its mirrors. The spectrum was detected and recorded by a photocell and a $X-Y$ plotter.

2. Results and Discussion

Thirty nine measurements of the line structure of the 578.2 nm laser line were recorded under the same experimental conditions and these line shapes can be classified into three cases as shown in Fig. 1. From this figure the multiple spectral structure of the line is evident; peaks A, B, and C are three maxima of the line structure. Let us consider Fig. 1a as case 1 where peaks A and B are intense, while peak C is weak. We list all these lineshapes in Table 1. For the 510.6 nm laser line, however, no explicit multiple lineshape has been observed.

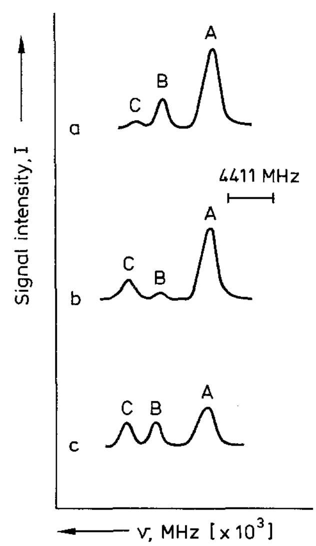

Fig. 1. Three cases of the 578.2 nm laser line shape

The schematic energy level diagram of ^{63}Cu and some of the main transitions of the 578.2 nm line are shown in Fig. 2a where hyperfine transitions a, c, and b, d start from the same upper levels $F=2$ and $F=1$

Table 1. Multiple line shapes of the 578.2 nm laser line

		Peak *A*	Peak *B*	Peak *C*
Case 1	Fig. 1a	Intense	Intens	Weak
Case 2	Fig. 1b	Intense	Weak	Intense
Case 3	Fig. 1c	Weak	Intense	Intense

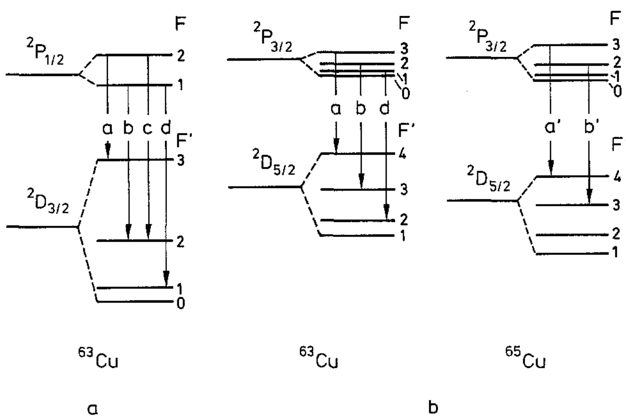

Fig. 2. Schematic energy levels of the copper atom and some of its transitions

respectively. Here F is the total angular momentum quantum number. However, the structure is quite different for the 510.6 nm laser line. Its schematic energy level diagram is shown in Fig. 2b where all transitions start from different upper levels.

From the above comparison we propose that for the 578.2 nm line two transitions starting from the same upper level, such as transitions b, d from $^2P_{1/2}(F=1)$ and transitions a, c from $^2P_{1/2}(F=2)$, compete in lasing action. If the population of the upper state is consumed by undergoing one of the stimulated transitions, then the relative intensity of another transition turns out to be weak due to competition. Let us pay attention to Fig. 2a. If, for instance, the intensity of the component b, I_b, is intense, then that of the component d, I_d, will be weak, and vice versa. It is expected that the competition will tend to become stronger if the relative intensities of the hyperfine components are nearly equal. In this way we can probably explain why no explicit multiple structure is observed for 510.6 nm copper laser line and 534.1 nm manganese laser line. For the 510.6 nm laser line, the main hyperfine components start from the different upper levels so no competition occurs. And for the 534.1 nm manganese laser line we can see from Figs. 1 and 2 of [6] that two or three hyperfine components start from the same upper levels but that their relative intensities differ significantly. Such competition between the hyperfine components is so weak that no obvious effects of competition can be observed.

From the above point of view, a qualitative explanation of the multiple line structure of the 578.2 nm laser line is suggested. As shown in Fig. 3, the relative intensities of the three peaks I_A, I_B and I_C are mainly the relative intensities of component a, $I_A \simeq I_a$, the superposition of that of components b and c, I_b and I_c, $I_B(I_b, I_c)$ and that of component d, $I_C \simeq I_d$, respectively. The estimated relative intensities of the peaks in

Table 2. Estimated relative intensities of the peaks in different cases

Peak *A* $I_A \simeq I_a$	Peak *B* $I_B(I_b, I_c)$	Peak *C* $I_C \simeq I_d$	Compare with experiment
I	*I*(*I*, *W*)	*W*	Consistent with case 1
I	*W*(*W*, *W*)	*I*	Consistent with case 2
W	*I*(*W*, *I*)	*I*	Consistent with case 3
W	*I*(*I*, *I*)	*W*	Has not been observed

Letters *I* and *W* in above table represent intense and weak relative intensities of the peaks respectively

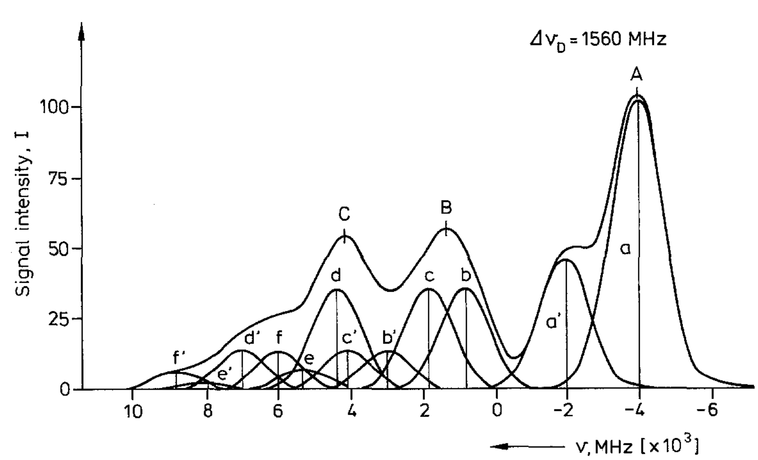

Fig. 3. Calculated lineshape of the 578 nm line at 850 °C

Table 3. Experimental peak frequency differences of 578.2 nm laser lineshapes

	$\Delta\nu_{AB}$, $\times 10^{13}$ MHz	$\Delta\nu_{AC}$, $\times 10^3$ MHz
Case 1	4.6	7.4[a]
Case 2	4.7[a]	7.7
Case 3	4.9	7.6

[a] These values are measured between two peaks. The intensity of the one of these two peaks is weak so its accuracy is reduced

different cases are presented in Table 2. If I_a is intense, I_c becomes weak due to competition. In this situation two possible distributions of intensity would be: (i) I_b is intense, I_d weak. That is $I_A \simeq I_a$ intense, $I_B(I_b, I_c)$ intense and $I_C \simeq I_d$ weak as shown in the first row of Table 2, which is consistent with case 1. (ii) I_d is intense, I_b weak. That is, I_A intense, I_B weak and I_C intense, which is consistent with case 2 as shown in the second row of Table 2. If, on the other hand, I_A is not so intense, then I_C will not be so weak. In this situation two possible distributions of intensity are: (i) I_b is weak, I_d intense. That is, I_A weak, I_B intense and I_C intense which is consistent with case 3 as shown in the third row of Table 2. (ii) I_b is intense, I_d weak. That is I_A weak, I_B intense and I_C weak, which is presented in the last row in Table 2. This kind of the relative intensity distribution of the peaks has not been observed yet.

Because $I_b > I_c$ in case 1, and $I_b < I_c$ in case 3, it is estimated that the frequency difference between peaks A and B, $\Delta\nu_{AB}$, should be larger in case 3 than in case 1. The experimental peak frequency differences are given in Table 3. It is interesting to note that the experimental results support the above inference. It can be seen from Table 3 that $\Delta\nu_{AB}$ in case 3 is 4.9×10^3 MHz and that in case 1 it is 4.6×10^3 MHz.

It should be pointed out that each case of the multiple structure of the 578.2 nm laser line is quite stable. The duration for case 1 is longer than that for case 2 and the duration for case 3 is about few minutes which is much shorter than that for case 2. This fact implies that, even in case 3, the line profile can maintain its structure for at least 10^6 pulses since the pulse repetition frequency of the CuBr laser is 18 kHz.

It is known that lasing action is intimately related to microscopic parameters such as electron density and electron temperature in a laser, so it is reasonable to suppose that the multiple linestructures reflect multiple sets of microscopic parameters referring to a given set of macroscopic parameters such as gas pressure, temperature and voltage. If this is true, certain sets of microscopic parameters are conductive to the appearance of different line shapes. When a disturbance exists in the discharge, one set of microscopic parameters has the opportunity to change into another set and this may be followed by a change in line shape.

The above explanation can be supported by reference to methods used in modelling the laser. When the macroscopic parameters are fixed, microscopic parameters can be deduced, enabling a self-consistent computer modelling of copper-vapor laser. If only self-consistency if required, it is not necessary that the model has only one solution. There are probably several solutions which correspond to different multiple sets of microscopic parameters. Furthermore, the competition between the hyperfine components makes the structure of the line more sensitive to the change of the set of these parameters.

3. Conclusions

(i) The multiple line structure of the 578.2 nm copper laser line has been found in the output of a CuBr laser under fixed operating conditions.

(ii) The multiple line structure can be explained by considering the special hyperfine transitions of the ^{63}Cu atom, the discharge disturbance and the competition between transitions.

References

1. J. Tenenbaum, I. Smilanski, S. Gabay, L.A. Levin, G. Erez, S. Lavi: Opt. Commun. **32**, 473 (1980)
2. A.A. Isaev: Sov. J. Quantum Electron. **10**, 336 (1980)
3. W.C. Kreye, L. Roesler: Appl. Opt. **22**, 927 (1983)
4. Wang Yongjiang, Shen Shengpen, Xia Tiejun, Wu Zhehua: Appl. Phys. B **43**, 1 (1987)
5. Wang Yongjiang, Chen Hongpin, Xia Tiejun: Opt. Commun. **61**, 387 (1987)