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BRIEF COMMUNICATIONS

INFLUENCE OF SPECTRAL LINE BROADENING ON THE MODE STRUCTURE OF He–Kr and He–Ar GAS LASERS

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Using the semiclassical perturbation approach, Stark broadening parameters for Kr II 469.4 nm, Ar II 476.5 nm, and Ar II 480.6 nm spectral lines have been determined. The obtained results have been used for the investigation of the role of the Stark broadening mechanism on the mode properties of hollow cathode excited noble gas mixture lasers. It has been found that for the He–KrII 469.4 nm laser broadening by neutral atom collisions is large enough to explain the single-mode operation of this laser, as opposed to the He-ArII 476.5 nm laser where Stark broadening also has to be taken into account to explain this property.

Keywords: *spectral lines, profiles, Stark broadening, laser discharges, plasmas, hollow cathode lasers.*

Introduction. In this work, the full semiclassical perturbation approach [1, 2] has been applied for the determination of Stark broadening parameters of Kr II 469.4 nm, Ar II 476.5 nm, and Ar II 480.6 nm lines and a joint laser physical application of the results obtained; namely the role of Stark broadening on the mode properties of hollow cathode excited noble gas mixture lasers is discussed.

Stark Broadening Parameters Calculation. All details of the semiclassical perturbation approach [1, 2] used here for the Stark broadening parameter calculations are given in [3] and a comparison of the obtained results with existing experimental and theoretical calculations (see [4] and references therein) will be presented elsewhere. We note only that we checked the influence of the missing Kr II 7*p* levels and found it to be not important. The determined Stark broadening parameters for the Kr II 469.4 nm, Ar II 476.5 nm, and Ar II 480.6 nm lines are shown in Tables 1 and 2.

Stark Broadening in Hollow Cathode Laser Discharges. Ionic lines can be effectively excited in a hollow cathode (HC) discharge due to the presence of high-energy electrons. It has been used since 1970 for the excitation of a lot of noble gas-metal vapor and noble gas mixture ion lasers [5].

An interesting feature of the HC lasers is that they oscillate usually in a single axial mode without any optical selection. This property has been attributed to the large homogeneous line-width due to the relatively large filling pressures. Recent studies have shown, however, that, in several cases, broadening by collisions with neutral atoms is not large enough to explain single-mode operation [6], and Stark broadening has also to be taken into account [7]. Therefore it seemed to be reasonable to study the role of the Stark effect at the He–Kr^+ 469.4 nm and He–Ar^+ 476.5 nm HC lasers [8, 9].

The HC laser discharge. For laser purposes the discharge inside the cathode is used for the excitation. Different HC geometries are applied, most frequently "longitudinal" or "transversal" systems [10]. The typical pressure in the tube is 10–25 mbar. In a HC discharge the electron energy distribution function has generally a nearly Maxwellian low-energy part with a high-energy tail. The mean energy of the low-energy part amounts to E_e = 0.1–1.0 eV, while the high-energy tail can rise up to the cathode voltage, which is commonly several hundred V. For laser excitation the

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TABLE 1 Stark widths (full widths at half maximum) and shifts for the Kr II 469.4 nm line. Perturber density $1.0 \cdot 10^{14}$ cm^{-3}. The perturbers are electrons, protons, and ionized krypton

Transition	T, K	Electrons		Protons		Ionized krypton	
		Width 10^{-3} nm	Shift 10^{-4} nm	Width 10^{-5} nm	Shift 10^{-5} nm	Width 10^{-5} nm	Shift 10^{-5} nm
Kr II 5p–6s	1000	0.339	1.03	0.0492	0.159	0.200	0.147
	2000	0.251	0.782	0.158	0.313	0.348	0.245
	5000	0.167	0.622	0.455	0.564	0.546	0.370
	10,000	0.118	0.564	0.755	0.771	0.654	0.443
	20,000	0.0921	0.452	0.998	0.924	0.765	0.525
	50,000	0.0788	0.362	1.32	1.16	0.919	0.642

TABLE 2 Stark widths (full widths at half maximum) and shifts for the Ar II 476.5 nm and Ar II 480.6 nm line. Perturber density $1.0 \cdot 10^{14}$ cm^{-3}. The perturbers are electrons, protons, and ionized argon

Transition	T, K	Electrons		Protons		Ionized argon	
		Width 10^{-3} nm	Shift 10^{-4} nm	Width 10^{-5} nm	Shift 10^{-6} nm	Width 10^{-5} nm	Shift 10^{-6} nm
Ar II 476.5 nm							
$4s^2P$–$4p^2P^o$	1000	0.193	–0.429	0.0348	–0.249	0.131	0.248
	2000	0.132	–0.362	0.0919	–0.520	0.250	0.497
	5000	0.0859	–0.248	0.241	–1.18	0.408	0.957
	10,000	0.0633	–0.195	0.370	–1.82	0.482	1.32
	20,000	0.0474	–0.149	0.485	–2,50	0.544	1.61
	50,000	0.0368	–0.112	0.594	–3,20	0.599	2.03
Ar II 480.6 nm							
$4s^4P$–$4p^4P^o$	1000	0.147	–0.161	0.0250	–0.132	0.0980	–0.132
	2000	0.110	–0.125	0.0669	–0.277	0.194	–0.272
	5000	0.0728	–0.103	0.183	–0.662	0.331	–0.567
	10,000	0.0544	–0.0741	0.288	–1.10	0.399	–0.810
	20,000	0.0410	–0.0571	0.391	–1.54	0.452	–1.03
	50,000	0.0317	–0.0453	0.470	–2.05	0.502	–1.31

high-energy tail is of importance, but concerning Stark broadening the low electron energy part is important. It was found experimentally that in a HC laser discharge, in the middle of the cathode, the electron density amounts to $N_e = 5 \cdot 10^{13}$–10^{14} cm^{-3}, about two order of magnitude larger than that in the positive column of a glow discharge [11]. Different model calculations and measurements are available (see, e.g., [12–14]). Gill and Webb [11], however, have found that in noble gas-metal vapor systems N_e is about a factor of 2 larger than that in pure noble gas systems. Therefore, especially for He–Kr and He–Ar gas mixtures in a transversal HC discharge laser tube with 20–25 mbar filling pressure and at ~100 mA/cm^{-2} current density on the cathode surface, E_e ~ 0.2 eV and $N_e \sim 6 \cdot 10^{13}$ cm^{-3} can be assumed as a good estimation [15].

Line broadening data for the Kr^+ and Ar^+ lines in HC laser discharges. Results are summarized in Table 3. The line-widths are given in frequency units typically used in this field. Stark line-widths are calculated at a perturber

TABLE 3. Line-broadening data for Kr II 496.4 nm, Ar II 476.5 nm, and 480.6 nm lines in He–Kr and He–Ar hollow cathode laser discharges. Typical plasma parameters at ~100 mA/cm^2 current density and 23 hP pressure: $N_e \sim 6 \cdot 10^{13}$ cm^{-3} and T_e ~ 2300 K

	Kr II 469.4 nm [MHz]	Ar II 476.5 nm [MHz]	Ar II 480.6 nm [MHz]	Remark
Neutral atom collisions broadened natural line-width at 23 hP (measured at 50 mA/cm^2 current density) [8, 9]	490	585	141	Stark line-width at these experimental conditions deduced (factor: 0.35)
Stark line-width at laser conditions (23 hP, ~100 mA/cm^{-2})	199	101	83	Calculated from the present theoretical data
Homogeneous (neutral atom collisions + natural + Stark broadening) line-width	689	686	224	
Inhomogeneous (Doppler) line-width at laser conditions	1400	2100	2100	Estimated value based on experimental data at lower current densities [8, 9]
Ratio of homogeneous and inhomogeneous line-widths	0.49	0.33	0.11	

density of $N_e \sim 6 \cdot 10^{13}$ cm^{-3} and electron temperature $T_e \sim 2300$ K. Natural line-widths broadened by collisions with neutral atoms, given in row 2, have been measured earlier [8, 9] in a discharge tube of similar geometry but at smaller current densities, and have to be corrected now with Stark line-widths at these conditions. Smaller current density and an off-center observation direction together resulted here in an estimated decreasing factor of 0.35 compared to the Stark line-widths at laser conditions.

Discussion. The mode structure of a laser is affected by many parameters such as the resonator length L, the maximum of the gain coefficient g_0, the passive losses a, the saturation parameter p_s, and, first of all, the ratio of the homogeneous (Lorentzian) line-width to the inhomogeneous (Doppler) one in the frequency distribution of the gain curve $\Delta\nu_L/\Delta\nu_D$. The effect of these parameters on the mode structure of lasers was studied by Troicki' [16] on a He–Ne laser both experimentally and theoretically. He studied the laser mode pattern at different g_0/a and $\Delta\nu_L/\Delta\nu_D$ values by increasing the gas pressure in the gain tube. He derived critical values of $\Delta\nu_L/\Delta\nu_D$ depending on the ratio $X = g_0/a$, above which single-mode operation takes place. His calculations agreed well with the experiments. As the main parameters L, g_0, a and p_s of the HC He–Kr$^+$ and He–Ar$^+$ lasers do not differ significantly from those of a He–Ne laser, the results of Troicki' can be applied also for them. At g_0/a ~ 3–4, which values are typical for these lasers, the ratio of homogeneous and inhomogeneous line-widths should be larger than ~0.30–0.36. It can be stated that this condition is fulfilled at both laser transition. But while for the He–Kr$^+$ 469.4 nm laser the earlier assumption remains valid, i.e., broadening by neutral atom collisions is large enough to explain the single-mode operation of this laser, at the He–Ar$^+$ 476.5 nm laser, as at the He–Cd$^+$ 537.8 nm laser [7], Stark broadening also has to be taken into account to explain this property. At the Ar$^+$ 480.6 nm (not laser) transition both line-widths are significantly smaller.

REFERENCES

1. S. Sahal-Brechot. *Astron. Astrophys.*, **1**, 91–123 (1969).
2. S. Sahal-Brechot. *Astron. Astrophys.*, **2**, 322–354 (1969).
3. M. S.Dimitrijevic and S. Sahal-Brechot. *Phys. Scripta*, **54**, 50–55 (1996).
4. N. Konjevic, A. Lesage, J. R. Fuhr, and W. L. Wiese. *J. Phys. Chem. Refer. Data*, **31**, 819–927 (2002).
5. M. Janossy, L. Csillag, Z. Donko, K. Rozsa. *Acta Phys. Hung.*, **93**, 311–343 (1993).
6. L. Csillag and M. Janossy. *Appl. Phys. B*, **73**, 55–58 (2001).

7. L. Csillag and M. S. Dimitrijevic, *Appl. Phys. B*, **78**, 221–223 (2004).
8. L. Csillag, M. Janossy, and K. Rozsa, *Appl. Phys. B*, **52**, 90–95 (1991).
9. L. Csillag and M. Janossy, *Appl. Phys. B*, **55**, 401–404 (1992).
10. K. Rozsa, *Z. Naturforsch.*, **35a**, 649–664 (1980).
11. P. Gill and C. E. Webb, *J. Phys. D: Appl. Phys.*, **11**, 245–254 (1978)
12. J. Mizeraczyk and W. Urbanik, *J. Phys. D: Appl. Phys.*, **16**, 2119–2133 (1983).
13. V. Derzhiev, A. Karelin, O. Sereda, M. Stefanova, and S. Yakovlenko, *Appl. Phys. B*, **51**, 465–468 (1990).
14. K. Kutasi, P. Hartmann, and Z. Donko, *J. Phys. D: Appl. Phys.*, **34**, 3368–3377 (2001).
15. J. R. McNeil, G. J. Collins, and F. J. De Hoog, *J. Appl. Phys.*, **50**, 6183–6189 (1979).
16. Yu.V.Troicki', *Zh. Tekhn. Fiz.*, **42**, 395–397 (1972).