29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-1.021 (2002)

Enhancement of the x-ray lasing by controlling the Stark width of the lasing transition by using an elliptically polarized optical laser radiation

V.P. Gavrilenko[a,b], E. Oks[c]

[a] *General Physics Institute, Russian Academy of Sciences, Vavilov Street 38, 119991 Moscow, Russia*
[b] *Center for Surface and Vacuum Research, Russian State Committee for Standards, 117334 Moscow, Russia*
[c] *Physics Department, 206 Allison Lab., Auburn University, Auburn, AL 36849, USA*

Introduction

One of the popular schemes for soft x-ray lasing is the scheme based on recombination pumping of H-like ions which are first stripped of electrons by optical field ionization [1-3]. The gain of an x-ray laser is determined by the product of the width of the lasing line and oscillator strength for the lasing transition. In our earlier works [4,5] we showed that by applying a high frequency electric field of electromagnetic radiation to a H-like emitter, it is possible to substantially decrease the Stark width of its spectral lines. The reason for such a decrease is that the high frequency electric field changes the character of interaction of a H-like emitter with plasma electric microfield. Based on this idea, it was shown in Ref. [6] that a linearly polarized electric field of an optical laser can significantly narrow the profile of the absorption coefficient for some x-ray lasing spectral lines of H-like ions, thus increasing the gain of the x-ray laser.

This paper presents the detailed calculations of the effect of the elliptically polarized intense field of an optical laser (EPIFOL) on the Stark broadening of some x-ray spectral lines of H-like ions. It is shown that the use of the EPIFOL can provide not only a significant enhancement of the gain on some x-ray lasing transitions, but also a possibility of tuning the x-ray laser in a wide range of frequencies.

Results and discussion

We consider the combined action of an EPIFOL $\vec{E}(t) = \varepsilon_0[\vec{e}_z \cos(\omega_0 t + \gamma) + \xi \vec{e}_x \sin(\omega_0 t + \gamma)]$ and plasma electric microfield $\vec{F}(t)$ on an H-like ion having the nuclear charge Z. Here $\vec{e}_x$ and $\vec{e}_z$ are the unit vectors along the x- and z-axes, and ξ is the ellipticity degree ($0 \le |\xi| \le 1$). The wave functions (WFs) for the level with the principal quantum number

$n = 2$ of the H-like ion interacting with the EPIFOL were obtained in Ref. [7]. They have the following form

$$\Psi_1 = \varphi_1(t), \quad \Psi_2 = \varphi_2(t), \quad \Psi_3 = \exp(-i\kappa t)\varphi_3(t), \quad \Psi_4 = \exp(i\kappa t)\varphi_4(t) \quad (1)$$

where the WFs $\varphi_p(t)$ $(p = 1,2,3,4)$ are the functions periodic in time (with the period $2\pi/\omega_0$), $\kappa = \omega_0 \xi w J_1(w)$, $w = 3\hbar\varepsilon_0/(Zem_e\omega_0)$, and $J_1(w)$ is the Bessel function. It follows from Eq. (1) that the quasienergies of the H-like ion interacting with the EPIFOL are as follows: $\lambda_{1,2} = 0$, $\lambda_{3,4} = \pm\kappa$. This means that the level of n=2 splits into three sublevels having the energies 0, $\pm\kappa$ with respect to its unperturbed position. Such a splitting results in the appearance of the shifted components in spectrum of the Lá line (cf. Fig. 2). We use the Model Microfield Method [8] for describing the evolution of a H-like ion under a stochastic plasma microfield $\vec{F}(t)$.

In the present work we calculate the modification of Stark profiles of the Lá line of the H-like ions LiIII ($\lambda = 13.5$ nm) in a plasma due to the interaction of the LiIII ions with the electric field of a CO_2-laser. We assume that the plasma is described by the following parameters: the electron density $N_e = 5.0 \times 10^{19}$ cm^{-3}, and the temperature of ions and electrons $T = 3$ eV. The perturbing particles are assumed to be Li^{3+} ions. Figure 1 demonstrates the modification of the Stark profile of LiIII ions under the linearly polarized electric field $\vec{E}(t)$ of a CO_2-laser ($\zeta = 0$) for three values of the amplitude of the electric field: $\varepsilon_0 = 0$, $\varepsilon_0 = 3.4 \times 10^7$ V/cm, and $\varepsilon_0 = 4.5 \times 10^7$ V/cm. It can be seen that the narrowing of the Lá line occurs when the field amplitude ε_0 is increasing. This can lead to the enhancement of the gain of the x-ray laser at the Lá line transition. Figure 2 shows the transformation of the Lá line profile of the LiIII ion under the action of the EPIFOL $\vec{E}(t)$ of a CO_2-laser for $\varepsilon_0 = 3.4 \times 10^7$ V/cm. It follows from Fig. 2 that for x-polarization the line Lá splits into three components, the central and two lateral components, when the value of ξ is not too close to zero. The central component corresponds to the unperturbed frequency $\omega_{21}^{(0)}$ of the Lá transition, whereas the lateral components are at the frequencies $\omega_{21}^{(0)} \pm \kappa$. When the population difference between the levels $n = 2$ and $n = 1$ is sufficiently high, the x-ray generation at the shifted frequencies $\omega_{21}^{(0)} \pm \kappa$ is possible for the radiation with *x*-polarization. Since the quasienergy κ is proportional to the ellipticity degree ξ, it is possible to tune the frequency of the x-laser by varying the value of ξ. One more important result of the present work is that the EPIFOL can control the polarization of the generated x-ray radiation. In particular, the x-ray radiation generated at the shifted frequencies $\omega_{21}^{(0)} \pm \kappa$ will have *x*-polarization, while the generated x-ray radiation at the frequency $\omega_{21}^{(0)}$ will be polarized predominantly in the *y*-direction.

ACKNOWLEDGEMENTS

This work was partially supported (for V.P.G.) by the Russian Foundation for Basic Research (project No. 01-02-17810).

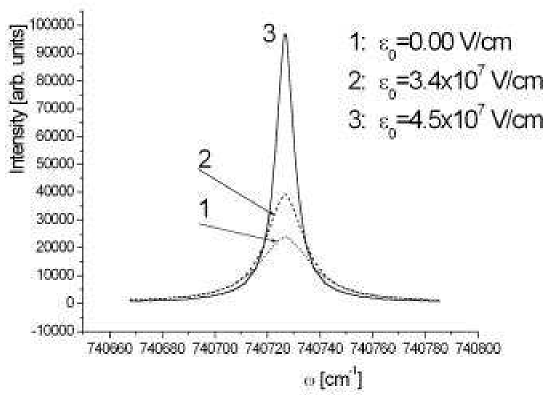
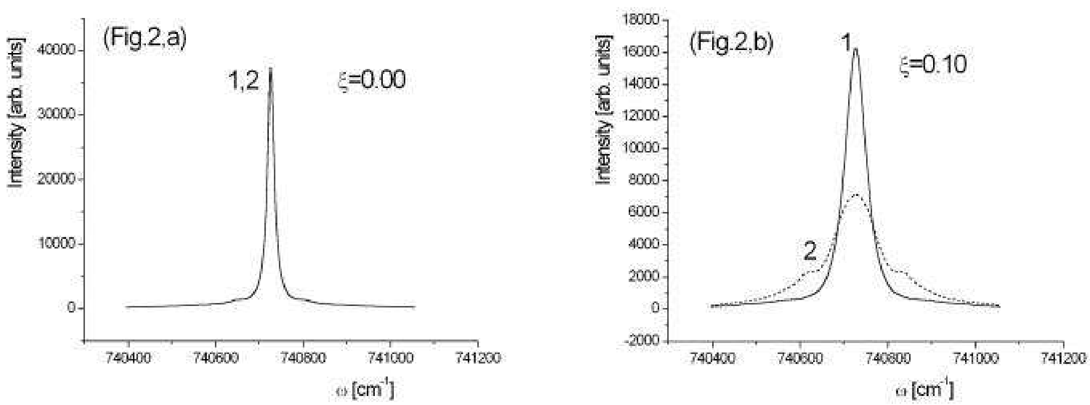


Figure 1. Transformation of the Stark profile of the Lá line for the H-like LiIII ions ($\lambda = 13.5$ nm) under the linearly polarized electric field $\vec{E}(t) = \vec{\varepsilon}_0 \cos(\omega_0 t + \gamma)$ of a CO_2-laser. The plasma parameters are as follows: $N_e = 5.0 \times 10^{19}$ cm^{-3}, $T = 3$ eV. Polarization of the photons emitted is orthogonal to the vector $\vec{\varepsilon}_0$. Curve 1 corresponds to $\varepsilon_0 = 0$, curve 2 corresponds to $\varepsilon_0 = 3.4 \times 10^7$ V/cm, and curve 3 corresponds to $\varepsilon_0 = 4.5 \times 10^7$ V/cm .



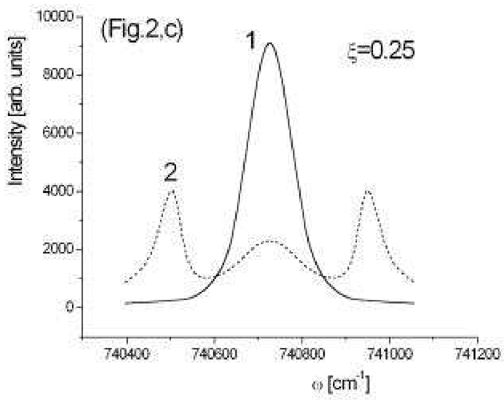


Figure 2. Transformation of the Stark profile of the L_α line for H-like LiIII ions ($\lambda = 13.5$ nm) under the elliptically polarized electric field of a CO_2-laser with the ellipticity degree in the range $0 \le \xi \le 0.25$. The plasma parameters are the same as for Fig. 1. Profiles 1 and 2 correspond to the *y*- and *x*-polarizations of the photon emitted, respectively. (a) $\xi = 0$; (b) $\xi = 0.10$; (c) $\xi = 0.25$.

References

1. Y. Nagata, K. Midorikawa, S. Kubodera, M. Obara, H. Tashiro, K. Toyoda, *Phys. Rev. Lett.* 1993; **71**: 3774.

2. T.D. Donnelly, L. Da Silva, R.W. Lee, S. Mrowka, M. Hofer, R.W. Falcone, *J. Opt. Soc. Am. B* 1996; **13**: 185.

3. D.V. Korobkin, C.H. Nam, S. Suckewer, A. Goltsov, *Phys. Rev. Lett.* 1996; **77**: 5206.

4. V.P. Gavrilenko, E. Oks: Proc. *17th Int. Conf. on Phenom. in Ionized Gases* (Budapest, Hungary 1985) p. 1081.

5. V.P. Gavrilenko, E. Oks: *Proc. 19th Int. Conf. on Phenom. in Ionized Gases* (Belgrade, Yugoslavia 1989) p. 354.

6. E. Oks, *J. Phys. B: At. Mol. Opt. Phys.* 2000; **33**: L801.

7. E. Oks, V.P. Gavrilenko, *Optics Commun.* 1983; **46**: 205.

8. A. Brissaud, U. Frisch, *Journal of Quantitative Spectrosc. and Radiat. Transfer* 1971;**11**: 1767.