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LAMP
SERIES REPORT

(Laser, Atomic and Molecular Physics)

EXCITATION MECHANISMS FOR XUV AND X-RAY LASERS

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EXCITATION MECHANISMS FOR XUV AND X-RAY LASERS

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Abstract

Two excitation mechanisms leading to lasing action in the extreme ultraviolet and soft X-ray spectral regions are proposed. Boron- like ions of Mg VIII, Al IX and Si X plasmas are used as the active laser material. The upper laser level is the metastable $1s^2 2s^2 4p(^2P)$ state while the lower level is the short lived $1s^2 2s^2 3d(^2D)$ state.

Introduction

In recent years much attention has been paid by many scientists and engineers towards achieving lasing action in the extreme ultra-violet and soft X-ray spectral regions [1,2].

The main problem encountered when developing a laser of short wavelength ($\lambda < 300$ Å) is the fast depletion of the upper laser level and the consequent rapid termination of the population inversion. A solution of this problem was previously suggested through selective electron capture by highly charged ions [3]. It is expected that pronounced population of excited laser levels in ion- atom collisions (in dense plasmas) may give rise to population inversion. The multiply charged ion- plasmas can be formed by direct laser irradiation of the target atoms [4].

In this article we have performed self- consistent Hartree-Fock calculations for the energy levels of the $1s^2 2s^2 3s(^2S)$, $1s^2 2s^2 4s(^2S)$, $1s^2 2s^2 3p(^2P)$, $1s^2 2s^2 4p(^2P)$ and $1s^2 2s^2 3d(^2D)$ states in boron- like ions of Mg VIII, Al IX and Si X. We have also calculated oscillator strengths and transition probabilities for radiative transitions between the various levels and lifetimes of the upper levels. The results suggest two excitation mechanisms leading to lasing action in the three ions.

Method of Calculation

The method used for calculating the energy levels of the states under study has previously been described [5,6]. In brief, dipole matrix elements for the transitions between the various levels have been constructed in LS- coupling scheme and have been used in determing the line strengths of the relevant transitions. The dipole oscillator strengths (in a.u.) are obtained using the formula [7]

$$f_{ji} = 1.499 \times 10^{-16} \lambda^2 A_{ij} \frac{g_i}{g_j} \qquad (1)$$

where λ is the wavelength (in A°) and g_i and g_j the statistical weights of the initial and final levels respectively. A_{ij} is the transition probability (in sec^{-1}) and is given by

$$A_{ij} = \frac{64 \pi^4}{3h \lambda^3 g_i} S_{ij} \qquad (2)$$

where S_{ij} is the line strength for the transition (in a.u.).

The lifetime τ_i (in sec) of the upper level is related to the transition probability by the formula

$$\tau_i = 1 \Big/ \sum_j A_{ij} \qquad (3)$$

Results and Discussion

Excitation energies in cm^{-1} of the various states in the configurations under study relative to the ground state $1s^2 2s^2 2p(^2P)$ configuration are given in Table 1.

In table 2, we present our results of oscillator strengths and transition probabilities between the various excited states of Mg VIII, Al IX and Si X ions. It is apparent from the table that the probabilities for the $2s^2 3d(^2D)$ - $2s^2 2p(^2P)$ transitions in the three ions are about 11 times higher than those of the $2s^2 4p(^2P)$ - $2s^2 3d(^2D)$ transitions. This suggest that laser transition might occur between the $2s^2 4p(^2P)$ level and the $2s^2 3d(^2D)$ level.

The results of lifetime calculations for the levels involved in the laser transitions are given in table 3. Inspection of the table shows that the lifetimes of the lower $2s^2 3d(^2D)$ laser levels are about one order of magnitude shorter than those of the upper $2s^2 4p(^2P)$ laser levels. Moreover, the $2s^2 4p(^2P)$ level is not optically connected to the $2s^2 2p(^2P)$ ground level i.e. metastable against radiative decay to the ground level. Such a situation would lead to fast diminution of the lower $2s^2 3d(^2D)$ level with respect to the upper $2s^2 4p(^2P)$ level, which is an essential requirement for population inversion [8]. We suggest two possible mechanisms leading to population inversion in the three ions, namely:

i) A dense plasma of the multiply charged ions is allowed to expand rapidly into a buffer gas such as He or Ne. The multiply charged ion- atom collision will lead to selective capture into the $2s^2 4p(^2P)$ upper laser level [9], and hence population inversion is achieved by electron- capture pumping.

ii) Multiply charged- ion plasmas are produced by laser irradiation [10] or by arc discharge where electron collisional pumping is responsible for population inversion. In this case the population of the $2s^2 4p(^2P)$ upper laser level is through the non-dipole transition $2s^2 2p(^2P) \longrightarrow 2s^2 4p(^2P)$.

The population of the upper $2s^2 4p(^2P)$ level will be followed by lasing on a dipole transition $2s^2 4p(^2P) \longrightarrow 2s^2 3d(^2D)$ and a rapid final state depletion in a second dipole transition $2s^2 3d(^2D) \longrightarrow 2s^2 2p(^2P)$.

In Figure 1, we show an energy level scheme for Al IX ion illustrating the excitation and deexcitation mechanisms of the upper laser level and indicating the laser line emitted.

Finally, for a complete understanding of the lasing action in the three ions, work on population densities, pumping rates and collision cross sections is still in progress.

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Table 1. Energies of excited states in Mg VIII, Al IX and Si X ions (in cm^{-1}), relative to that of the ground state $1s^2 2s^2 2p(^2P)$.

State	Energy (in cm^{-1})		
	Mg VIII	Al IX	Si X
$1s^2 2s^2 3s(^2S)$	1216948.6	1507672.7	1828924.4
$1s^2 2s^2 3p(^2P)$	1284617.7	1583882.6	1913773.7
$1s^2 2s^2 3d(^2D)$	1340006.1	1646452.4	1983587.6
$1s^2 2s^2 4s(^2S)$	1647173.2	2040623.1	2475407.9
$1s^2 2s^2 4p(^2P)$	1673592.3	2070521.2	2508829.9

Table 2. Oscillator strengths (in a.u.) and transition probabilities (in s^{-1}) for transitions between the various excited states of Mg VIII, Al IX and Si X ions.

Transition	Mg VIII		Al IX		Si X	
	$f\times10^{-3}$	$A\times10^{8}$	$f\times10^{-3}$	$A\times10^{8}$	$f\times10^{-3}$	$A\times10^{8}$
$4p(^2P) - 4s(^2S)$	567	2.64	516	3.08	473	3.52
$4p(^2P) - 3d(^2D)$	13.0	9.65	13.0	15.60	12.0	22.10
$4s(^2S) - 3p(^2P)$	68.0	59.6	64.0	89.10	61.0	129
$4s(^2S) - 2p(^2P)$	3.6	65.20	3.6	100	3.6	147
$3d(^2D) - 3p(^2P)$	420	8.59	401	10.50	390	12.80
$3d(^2D) - 2p(^2P)$	9.0	108	9.0	163	9.0	236
$3p(^2P) - 3s(^2S)$	408	12.50	371	14.40	341	16.20
$3s(^2S) - 2p(^2P)$	19.0	188	19.0	288	19.0	424

Table 3. Radiative lifetimes of laser transitions in Mg VIII, Al IX and Si X ions.

Transition	Mg VIII		Al IX		Si X	
	$\lambda(\mathring{A})$	$\tau(ns)$	$\lambda(\mathring{A})$	$\tau(ns)$	$\lambda(\mathring{A})$	$\tau(ns)$
$4p(^2P) - 2p(^2P)$	metastable		metestable		metastable	
$4p(^2P) - 3d(^2D)$	299	1.04	236	0.64	190	0.45
$3d(^2D) - 2p(^2P)$	75	0.09	61	0.06	50	0.04

Figure Caption

Fig. 1: Energy level scheme for laser transition in Al IX ion.