Scaling Laws and Optimal Parameters for Plasma X-ray Lasers

D Bleiner[1] and L Masoudnia[1]

[1] *Advanced Analytical Technologies, Empa, Ueberlandstrasse 129, 8600 Duebendorf, Zürich, Switzerland.*
Contact Phone: +41587654934
Contact Email: davide.bleiner@empa.ch

Soft X-ray lasing across a Ni-like plasma gain-medium works strictly under optimum electron temperature and density for attaining to the Ni-like ion stage and population inversion in the $3d^9 4d^1 (J = 0) \rightarrow 3d^9 4p^1 (J = 1)$ laser transition. Various scaling laws, function of operating parameters were compared with respect to their predictions for optimum temperatures and densities. It is shown that the widely adopted local thermodynamic equilibrium (LTE) model underestimates the optimum plasma-lasing conditions. On the other hand, non-LTE models, especially when complemented with dielectronic recombination, provided an accurate prediction of the optimum plasma-lasing conditions. It is further shown that for targets with Z equal or greater than the rare-earth elements (e.g. Sm), the optimum electron density for plasma-lasing is not accessible for pump-pulses at $\lambda = 1\omega$. This observation explains a fundamental difficulty in saturating the wavelength of plasma-based X-ray lasers below 6.8 nm unless using 2ω pumping.

Further, it is critical to optimize the duration and time delay between pump pulses. In this study, we have done parametric simulations in order to systematically investigate the optimum time configuration of pump pulses. Here, we are mainly interested in soft X-ray lasers created using a Ar target irradiated with laser pulses, which operate at a wavelength $\lambda = 46.9$ nm in the $2p^5 3p^1 (J = 0) \rightarrow 2p^5 3s^1 (J = 1)$ laser transition. It is shown that the optimum time scale required to achieve Ne-like ions, as well as the time required to generate a population inversion, depend on the combined effect of the electron temperature and electron density. The electron density and temperature are respectively a factor of 2.1 and 5-times higher in the case of a short pulse of 0.1 ps in comparison to a long pulse of 1,000 ps (at a constant fluence). The most effective lasing happens with short pulses with a pulse duration comparable to the total relaxation time from the upper level, namely $\Delta\tau_p \leq 35$ ps. Power laws to predict the optimum laser intensity to achieve Ne-like Ar^{+8} are discussed.