Laser/Plasma-Pumped Rare Gas Laser

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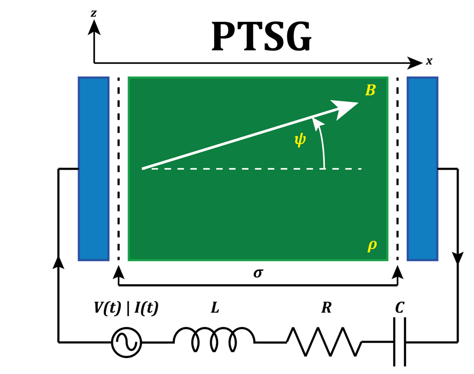


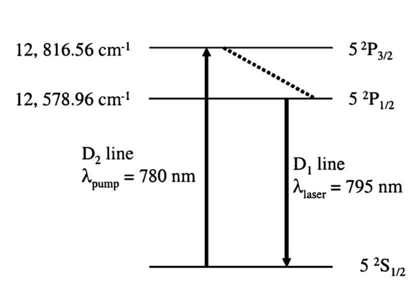
Extending from diode-pumped alkali vapor lasers (DPAL), Han and Heaven have shown that rare gas metastable states, $np^5(n+1)s[3/2]_2$, can operate as the base of a three-level laser with excition of the $(n+1)s \to (n+1)p$ transitions. Though both the rare gas lasers (RGL) and DPALs can be excited with incoherent optical pumping, RGLs do not suffer from the highly reactive behavior of alkali metals. Since metastable populations are maintained via electric discharge, we propose using a tuned electron energy distribution function (EEDF) to modify RGL efficiencies and drive the population inversion. The EEDF is maintained by the discharge along with the introduction of electron sources.

Using our kinetic global modeling framework (KGMf) and two gas systems (helium buffered argon and pure argon), we first validate the intracavity intensity laser model and then generate gain and energy efficiency baselines for each system. Parameter scanning methods are then used to find optimized EEDFs and system parameters for metastable production, generation of a lasing population inversion, and increasing RGL operation efficiencies. Finally, we determine if an RGL can operate without optical pumping.

DPAL → RGL

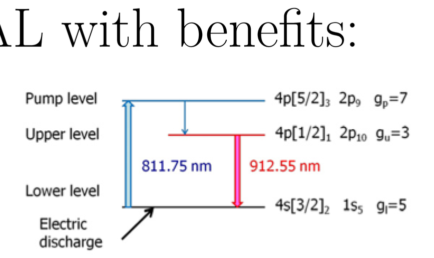
DPAL, first published by Krupke et. al. [1], demonstrating three-level laser oscillation between the $^2S_{1/2}$, $^2P_{1/2}$, and $^2P_{3/2}$ excited levels of Rb and Cs.

+ Wide-band incoherent pumping to drive
- Vaporized alkali metal
- Quench gas CH_3 leads to hydrides (“laser snow”)



Han and Heaven [2] showed transitions between the noble gas excitations $^3P_2$, $^3S_1$, and $^3D_3$ have the same spectral properties as DPAL with benefits:

- Inert reagents in system
- Lower temperature
- Neutral collision partners



Both systems are attractive due to the coherent nature of the output

Kinetic Global Modeling

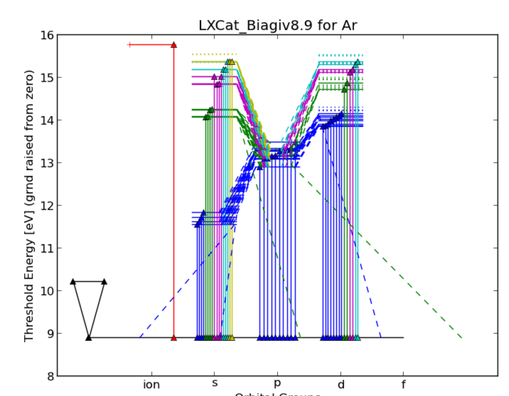
General species continuity and electron energy equation (solved for T_e) with reaction rates K_i

$$\frac{dn_\alpha}{dt} = \sum_i^R \nu_i^\alpha K_i \prod_j n_j - \frac{D_{\text{eff}}}{\Lambda^2}$$

$$\frac{d}{dt}\left[\frac{3}{2} n_e T_e\right] = \frac{P_{\text{eff}}}{V} - n_e \sum_i^{R_{\text{EI}}} n_i K_i \Delta E_{ij}$$

Integrated reaction rates (when cross section is known, e.g. [4]) with parameterized EEDFs

$$K_i(x, T_e) = \int_0^\infty d\varepsilon\, v(\varepsilon)\sigma_i(\varepsilon) f_e(\varepsilon, x, T_e)$$

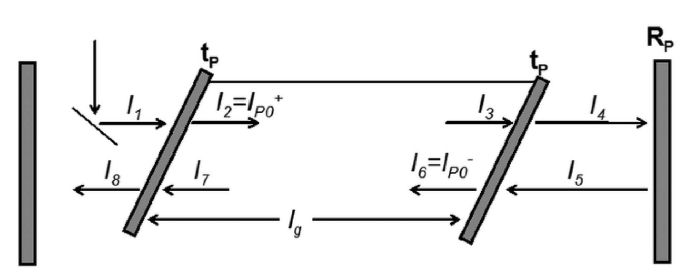


Otherwise fitted analytical forms or constants from the literature, e.g. [5], are used for reaction rates

MW power deposition: assumed power absorption or time-enveloped effective electric field convoled with EEDF

Laser Model: Pumping and Output

Two-way averaged plane-wave model with assumptions on spectral distribution [3].



Scaled gain term

$$\beta_{ji} = l_g \sigma_{ji}(n_j - \frac{g_j}{g_i} n_i)$$

Stim. emission

$$\tilde{K}_{ji}^{\text{stim}} = \frac{\beta_{ji}}{l_g} \frac{\Psi}{h\nu_{ji}}$$

Pumping intensity derived indepenent of the ν distribution

$$\Omega(t) = \frac{P_P(t)}{l_g} t_P (1 - \exp[\beta_{31}])(1 + t_P^2 R_P \exp[\beta_{31}])$$

The output intensity is defined from the two-way intracavity circulating intensity, with continuity equation

$$\frac{d\Psi(t)}{dt} = (t_L R \exp[2\beta_{21}] - 1)\frac{\Psi}{\tau_{\text{rt}}} + n_2 \frac{\sigma_{21} c^2 h\nu_{21}}{l_g}$$

Which is related to the output intensity as

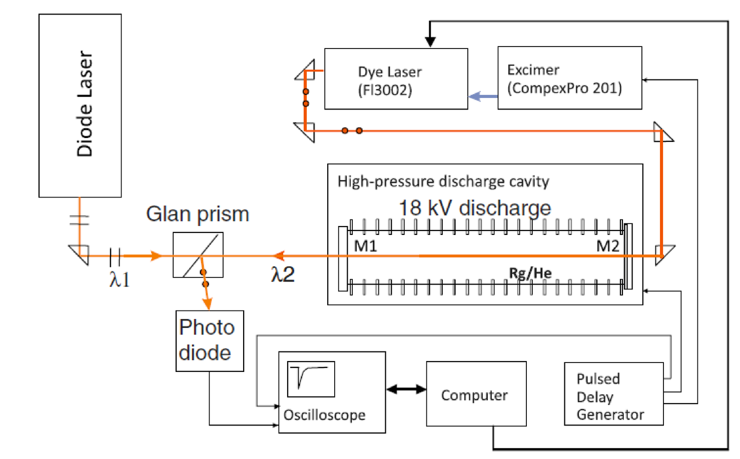
$$I_{\text{Lase}}(t) = \eta\Psi(t) \frac{\beta_{21} t_L (1 - R)\exp[\beta_{21}]}{(\exp[\beta_{21}] - 1)(1 + t_L^2 R \exp[\beta_{21}])}$$

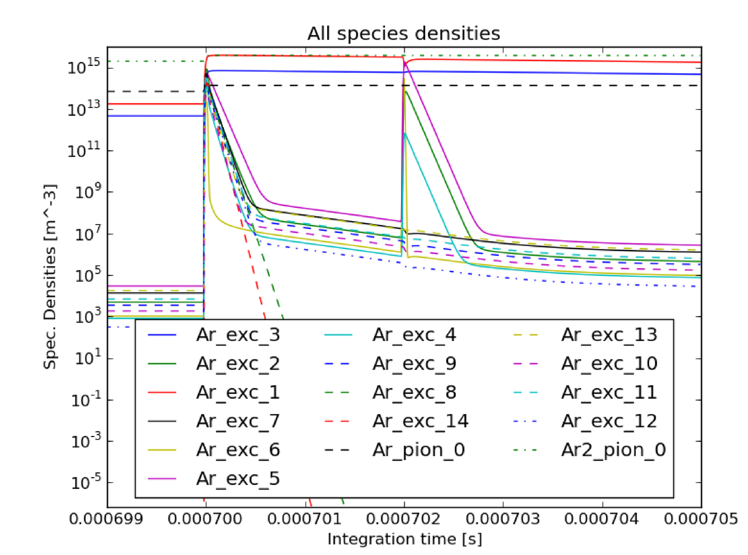
Note: R is the power reflectivity and t_* are the pump and laser gain cell window transmission coefficients

Optically-Pumped Argon Laser Models

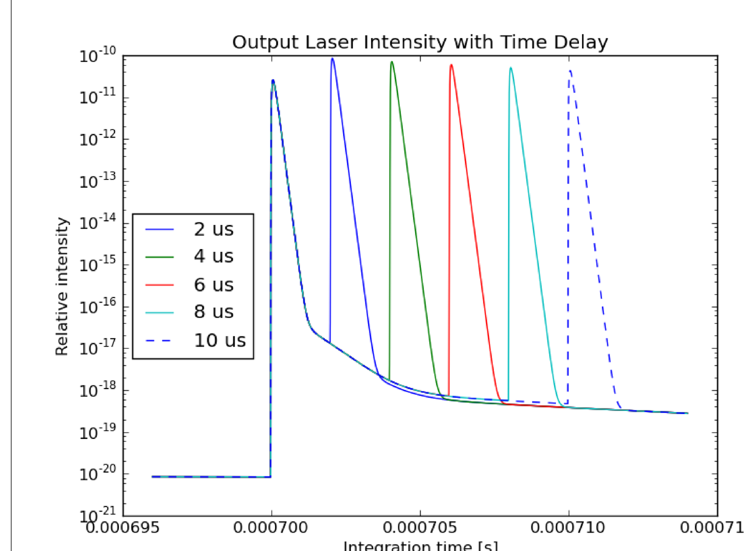
Recreating the experimental results of Han and Heaven

- Optical pumping: centered at 811.75nm, $\Delta\nu = 30$GHz, duration 10ns, and energy of 0.25mJ
- Gas cell: R = 2.5cm, L=60cm over a range of pressures
- RF power: 18kV separated by 2.5 cm for 10ns
- Observed optimized delay between discharge and laser pulses 5-25μs

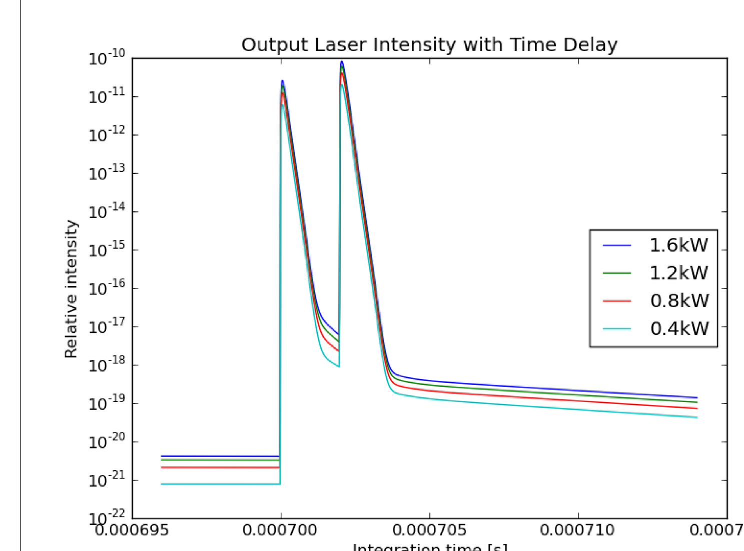




Equilibrated argon species responding to MW discharge followed by optical pumping pulse.



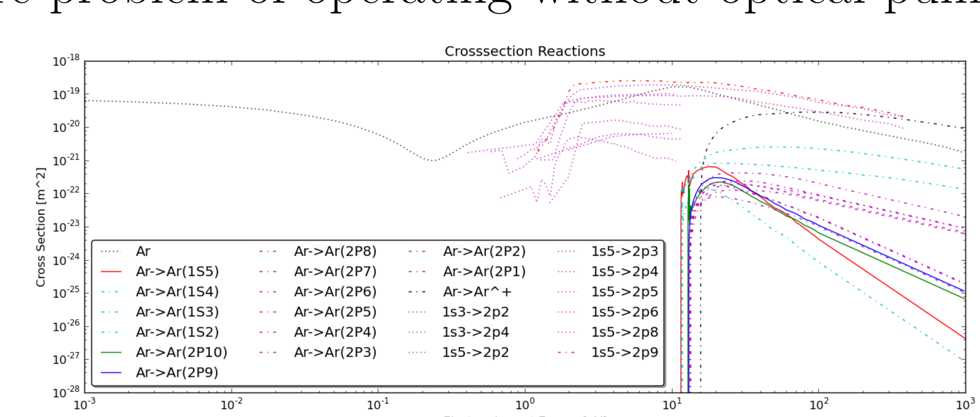
Optimum delay time between discharge and optical pump: $[\text{Ar}_g] = 4.\text{e}25m^{-3} \to 2.3\ \mu s$



MW discharge instead of RF: nominal non-zero background and 10ns gaussian discharge

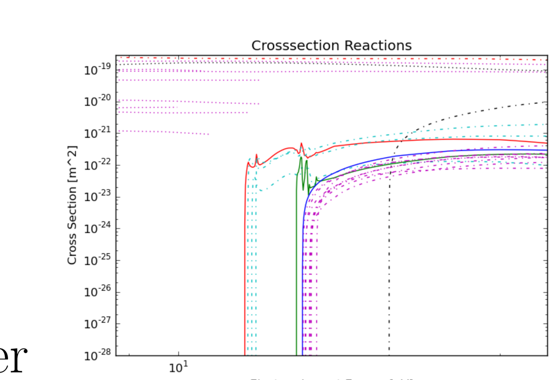
Pure Plasma Laser Concept

Plotting the Argon excitation cross sections reveals a core problem of operating without optical pumping



Not directly possible:

- Overlap between 1s5 and 2p10 occurs at ~40eV ⇒ ⇒ ⇒
- EEDF with bulk at ~40eV will excite higher (unwanted) 2p states



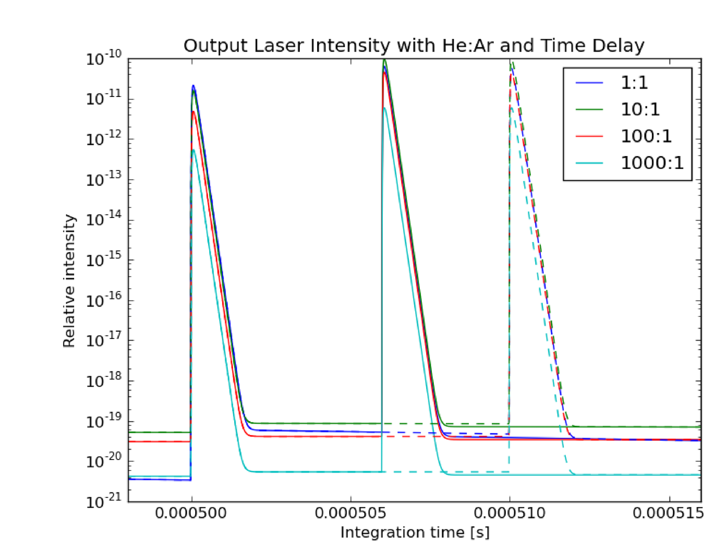
Future Work

- Tracking a discretized spectral distribution
- Indirect methods for plasma pumped laser
- Continuing He buffer study with Kr

Argon with Helium Buffer

Difficulty in exciting He yields a good buffer gas

- He species considered: He_g and He^+
- Non-linear relationship between He:Ar ratio and output intensity



Optimum He:Ar ratios and pulse delay times can be found for each background pressure.

References

[1] Kanz, Krupke, Beach and Payne. Opt.Lett., **28**, 2336

[2] J. Han and M.C. Heaven. Opt. Lett., **37**, 2157

[3] Rudolph, Zameroski, Hagar, Hostutler. J. Opt. Sc. Am. B, **28**, 1088

[4] Biagi-v8.9, http://www.lxcat.laplace.univ-tlse.fr, 7.4.12

[5] NIST, http://www.nist.gov/pml/data/asd.cfm, 7.13.12