The Quest for High-Power Lasers:

Investigating Amplified Spontaneous Emission in Diode Pumped Alkali Lasers

Jonathan Wurtz

University of New Hampshire, URC 2013

Advisor: Bill Hersman

Introduction

Gas lasers hold great promise as being stable, high-power laser systems for various directed energy applications. Diode Pumped Alkali Lasers (DPALs), a type of gas laser, have grown in interest in the past few years; however, there are still many problems that have to be sorted out.

Problem: Efficiency

DPALs have high theoretical efficiency (>98%), but actual optical-optical efficiencies are around 50%. Inspecting sources of energy loss is then crucial. One of the sources energy loss that has so far gone unexamined is the phenomina of Amplified Spontaneous Emission (ASE).

This effect is due to radiant light from *spontaneous emission* in the gas being amplified by the surrounding positive-gain medium, creating extra losses. This is the effect inspected in this project.

Research

It was initially proposed that the geometry of the gain medium (gas) played a role ASE; this was the phenomenon that was inspected. It was discovered that there was little relation to the dimensions of the medium, although ASE was found to account for over ½ the total energy loss in some instances.

Methodology

The initial inspection was to determine the factors involved with ASE. Thus, a numerical simulation was made to determine geometric relationships between ASE and the length of the gain medium.

Using the principles of laser physics, an equation was developed to describe the extra loss due to ASE. A laser medium in the shape of a symmetric ellipse was formed, and the waste energy for each small cube of gas was summed. This then resulted in a 5-dimensional integral: three over the spatial components, and 2 to measure the "direction" of light rays leaving each small cube, shown in Equation 1.

This integral was impossible to compute analytically and very difficult to compute numerically, so some simplifications were made. Even with simplifications, calculations could take upwards of 7 hours using MATLAB.

$$\mathrm{P} = A_0 \int\int\int\int\int e^{GL} \sin(\theta)\, dx dy dz d\theta d\varphi$$

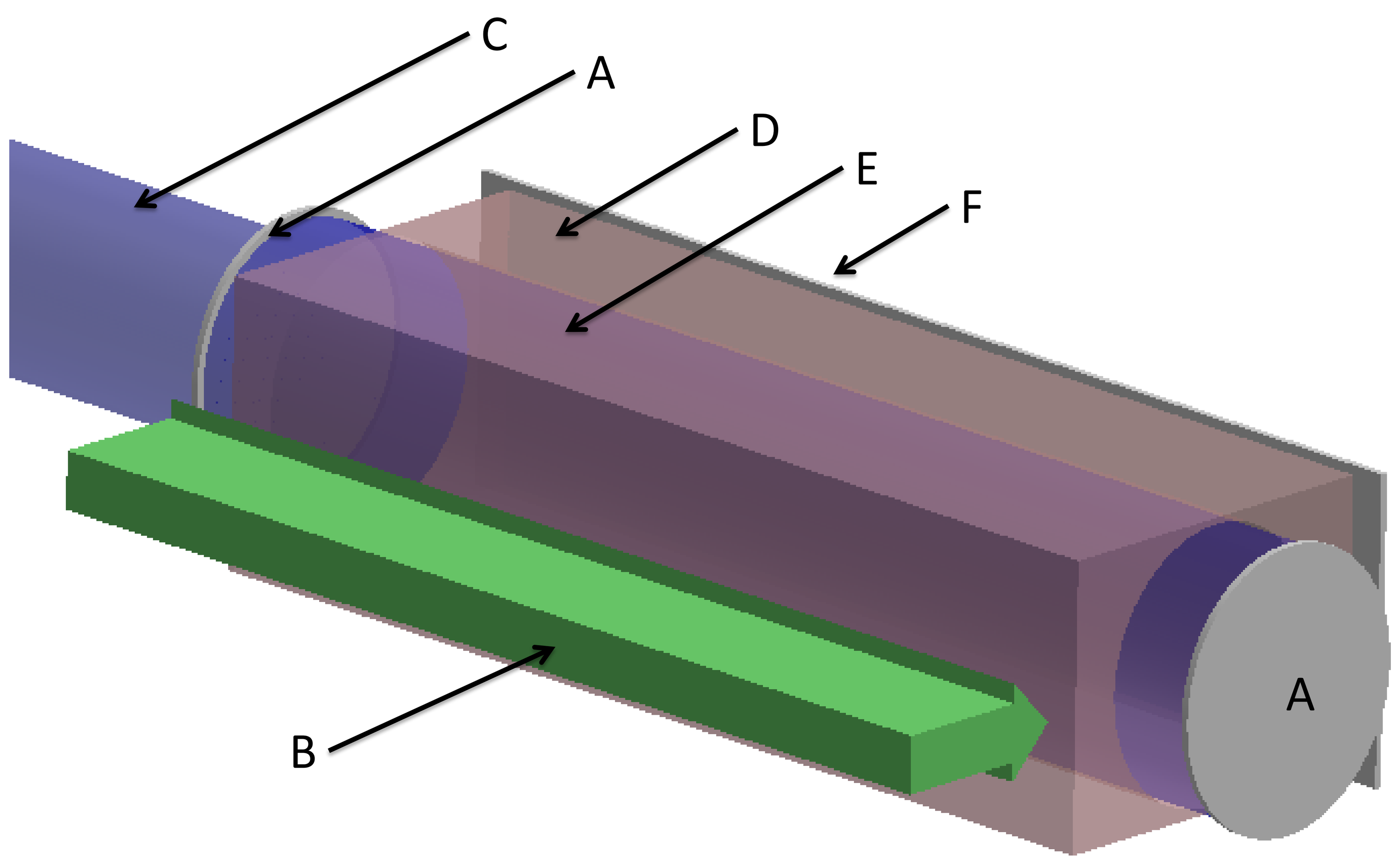
Equation 1: Brute-force Integral

G is the gain of the medium, A_0 is the spontaneous emission term and L is the distance from the point (x,y,z) to the edge of the medium along a path determined by (θ,ϕ)

How does a laser work?

A laser is a quantum mechanical device which operates off of the principle of *population inversion*. An energy source (such as light or chemical reactions) kicks valence electrons of atoms in a *gain medium* (which could be a gas, crystal or various other mediums) into an excited state.

If there are more electrons in the excited state than the ground state, then population inversion is achieved, creating *positive gain*. This means that putting a little bit of light into the medium results in a lot of light out the other. In this situation, lasing occurs, resulting in a tight coherent beam to use in a massive number of applications such as DVDs, price scanners, shooting down missiles, entertaining cats, etc.



Courtesy of Antoine Procyk

Figure 1: Typical DPAL Side-Pumped Configuration

A. Reflective Mirrors – create a lasing cavity inside medium
B. Pump Beam – from Diode Laser stacks
C. Output Beam (Goal is larger than one mega-watt)
D. Non-lasing medium – High Gain regime (High power loss)
E. Lasing medium – Low Gain regime (Low power loss)
F. Pump Beam reflective mirror

References

1) Komashko, A.M. and Zweiback, J.,Modeling laser performance of scalable side pumped alkali laser.
2) Hagar, G.D. and Perram, G.P., Extended saturation analysis and analytical model of diode-pumped alkali lasers.
3) Juan, W.Y., Liang, P.B., and Jing, Y., A kinetic model for diode pumped Rubidium vapor laser.
4) Hersman, F.W., Proposal: Numerical Simulations of Confined Vapor Jet Geometries for Diode Pumped Alkali Lasers.

Figure 2: High-Gain Regime

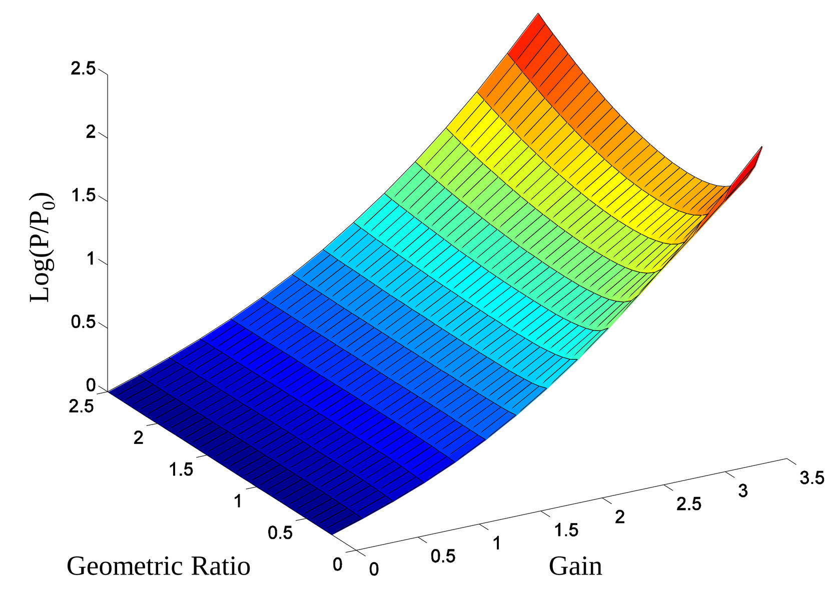
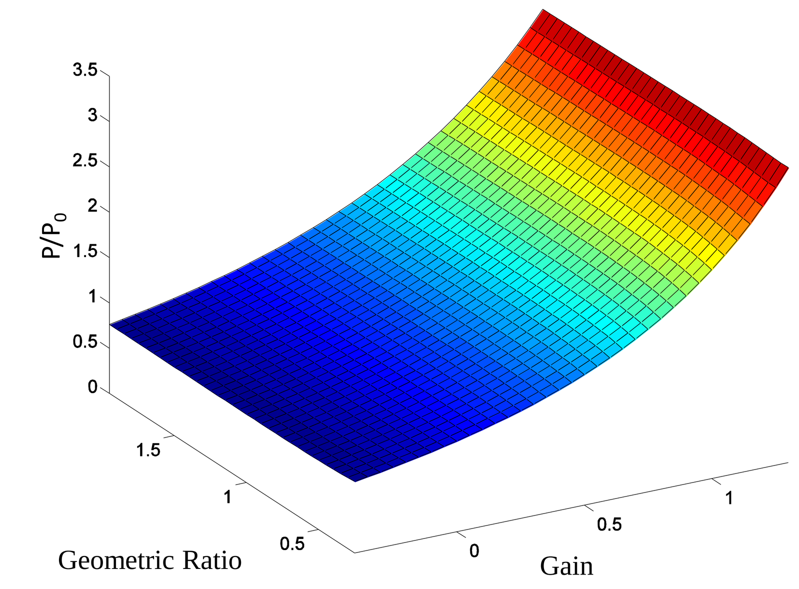


Figure 3: Low-Gain Regime



Results

Above are the numeric results from calculating Equation 1 for various geometric ratios and gains. All values are scaled and unitless.

- The geometric ratio is the ratio of the dimensions of the medium—0.2 would be a "flattened tire", where 2.0 would be a "long cigar".
- P is the power with ASE, and P_0 is the power with no ASE. P/P_0 is then a measure of the "extra" loss due to ASE.
- Note that a gain of 0.0 accords with P/P_0 of 1.0. A gain of 1.0 means that a light ray increases in power by ~2.71 over unit length.
- Note the difference in the Z-axis between Figures 2 and 3. Figure 2 has an axis of $\log(P/P_0)$, indicating orders of magnitude higher losses.

Analysis

There are two main regimes for a DPAL cell to operate in:

- The first is in low gain mode occurring in the presence of lasing, shown in figure 1E. This mode is equivalent to gains between 0.01 and 0.03. This results in approximately **15% extra power loss** due to ASE. There is little relation to the geometry of the gain medium. This amount of power loss means that existing simulations are accurate but underestimate power loss.
- The second regime for a DPAL is high gain mode, where there is no lasing and thus excited electron densities are very high. This occurs in figure 1D. Gains are around 0.5 to 1.0. In this regime, upwards of half the power lost is due to ASE. There is some dependence on geometry, as can be shown in Figure 2, but occurs at non-physical gains higher than 1.5. The current paradigm in the community is that geometry plays an important role in ASE; this research suggests the opposite.

Conclusions

This research suggests that a large source of waste power in DPALs is completely ignored by contemporary simulations in the community. Furthermore, the current thought about ASE in relation to geometry is contrary to results.

Future research will include inspecting ASE for more complicated geometries, as well as examining different physical parameters for optimization of a scalable DPAL capable of operating in the 100kW+ regime.