3D Modeling of a Planar Discharge in a CO2 Laser Using a Multilevel Approach

J. Schüttler[1]

[1]Rofin-Sinar Laser GmbH, Hamburg, Germany

Abstract

High power CO2 lasers have been the workhorses for sheet metal cutting, welding and many more applications in materials processing during the past decades. Even though a significant replacement by fiber coupled lasers takes place, there are still many applications that benefit from the characteristics of CO2 lasers with a high beam quality [1]. Therefore, further pushing the limits regarding power, stability, modulation etc. is in the focus of current development work.

CO2 lasers are operated using a gas discharge to excite the CO2 molecules in order to populate the upper lasing state. In Rofin's diffusion-cooled slab laser design (Fig. 1), the plasma is formed between two planar electrodes that simultaneously serve as an optical waveguide and provide a proper gas cooling [2].

Modeling the plasma behavior is essential for optimizing, e.g. the homogeneity of the discharge, cooling design, gas dynamics inside the laser and the electrical properties of the system. Due to the complex pumping scheme of a CO2 laser, many species and collisions have to be considered. CO2 laser discharges have been studied in detail [3, 4, 5], but no directly transferable data is available for today's highly optimized laser gas mixtures.

In this paper, a multilevel approach to a full 3D model of the planar discharge is presented. Due to the dimensions of the system under investigation, a fully coupled 3D plasma and RF simulation is no feasible approach due to limitations of the computational resources. Instead, the problem is partitioned into manageable tasks in a hierarchical way using COMSOL Multiphysics®.

First, the "zero dimensional" electron energy distribution function is calculated for the complex gas chemistry of the premixed laser gas, using the Boltzmann Equation, Two-Term Approximation interface.

Next, the plasma discharge is modeled in a 1D approximation using a Plasma interface over a wide range of parameters (e.g. current density and pressure). By interpolating the U-I-curve of the 1D discharge (Fig. 2) and extracting characteristics like sheath thickness and carrier density, a surrogate model is built up for the electrical properties (e.g. impedance) of the plasma.

This surrogate model is then used as a (strongly nonlinear) material model in a 3D RF simulation of the complete CO2 laser.

With this approach it is now possible to determine the homogeneity of the discharge (Fig.

3), power and temperature distributions, optical properties of the gas including the laser pump rates and the resulting gain. The RF simulations do not only provide macroscopic information, but also local information on the microscopic level via re-substitution. With these results and the available simulation tools, it is possible to identify further development potentials and to optimize our current and future products.

A future perspective is to extend the model with respect to the transient spatiotemporal behavior during the ignition of the plasma. This would allow to investigate e.g. pressure variations during switch-on of the laser and to further optimize the performance of the laser in pulsed operation.

Reference

[1] W. Rath et al., Industrial Laser Materials Processing, Laser Technik Journal, Vol. 11, p. 23 (2014)
[2] R. R. Nowack et al., High-Power CO2 Waveguide Laser of the 1-kW Category, Proc. SPIE, Vol. 1276, p. 18 (1990)
[3] R. Wester, Hochfrequenzgasentladungen zur Anregung von CO2-Lasern, Dissertation, RWTH Aachen (1987)
[4] P. P. Vitruk et al., Similarity and Scaling in Diffusion-Cooled RF-Excited Carbon Dioxide Lasers, IEEE Journal of Quantum Electronics, Vol. 30(7), p. 1623 (1994)
[5] J. Schulz, Diffusionsgekühlte, koaxiale CO2-Laser mit hoher Strahlqualität, Dissertation, RWTH Aachen (2001)

Figures used in the abstract

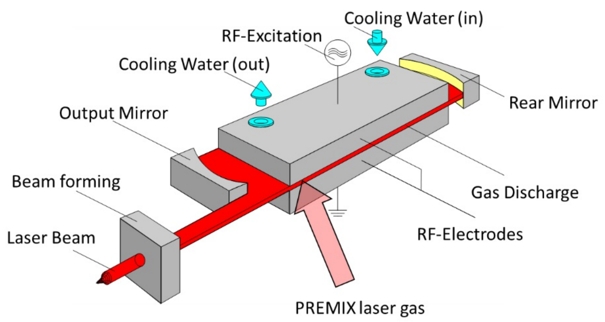

Figure 1: Slab laser principle.

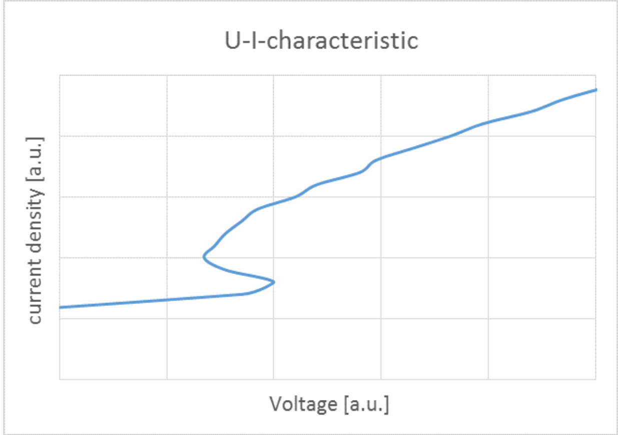

Figure 2: U-I-characteristic of the discharge.

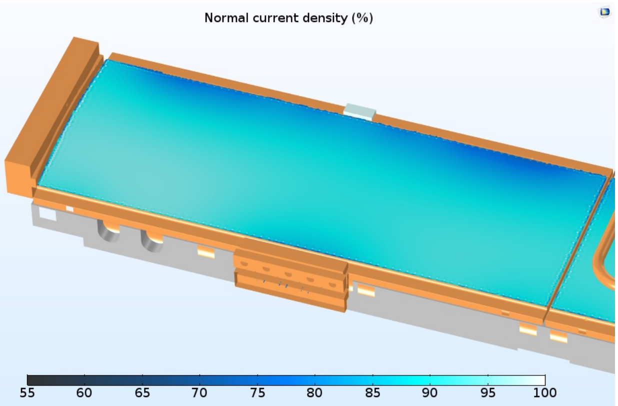

Figure 3: Current density distribution (example).