Ablative capillary discharge plasma as a preformed medium for soft x-ray laser

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CONTENTS

INTRODUCTION

- A close as possible homogeneous plasma with well defined and controlled parameters is required as an active medium for the X-ray lasers.
- During the last decade it was demonstrated that a double- or multi-pulse laser pumping scheme are very interesting.
- An extreme improvement has been achieved when the pumping scheme combining a long (ns) laser pulse with a following extremely short (ps) one was demonstrated. Nickles, et al, PRL, 76, 2748 (1997).
- Owing to the separation of the plasma ionization and heating processes it becomes possible to tailor the ionization onset to the optimal ionization state.

•Hence, the plasma preparation before the heating becomes crucial for such schemes of x-ray lasers. The preforming process relies on the preparation of the plasma with a prescribed electron temperature, ionization stage and density.

•The plasma channels for the x-ray lasers could be created either in a free space filled with a gas, ablative or prefilled by gas capillaries.

•In the ablative, or evacuated capillaries plasma is generated in the capillary due to the ablation of capillary walls. The energy needed to ablate the wall material is delivered either by an electric discharge or by a long (ns) laser pulse.

•All these methods lead to a concave radial electron density profile with the minimum on the axis of the channel, which is a precondition of the guiding effect.

- In the present report we concentrate on the preforming process with a fast capillary discharge. This fast capillary discharge results in a highly ionized plasma, which is especially suitable as a preformed medium for x-ray lasers.

- We demonstrate lasing at 60.8 nm (Ne-like S) in a hybridly (electrically preformed and optically heated) pumped x-ray laser scheme applied to a solid sulphur capillary.

- Plasma used as a preformed medium for a hybrid x-ray lasers should fulfil two basic criteria:

it has to be ionized to to the required stage

it has to possess a density distribution suitable for guiding of the pump laser pulse.

Physical model

We use the approximation of two-temperature, one-fluid MHD.

Owing to the large length-to-radius ratio of the capillary $l / R_0 >> 1$ a one-dimensional approximation is considered .

We take full account of all dissipative effects in the plasma electron component. At low temperatures we take into account the contribution of neutral particles.

The model description of the equation of state and the ionization degree has been elaborated. The plasma-wall interaction is modeled by considering the material of the wall as a cold neutral gas of high density.

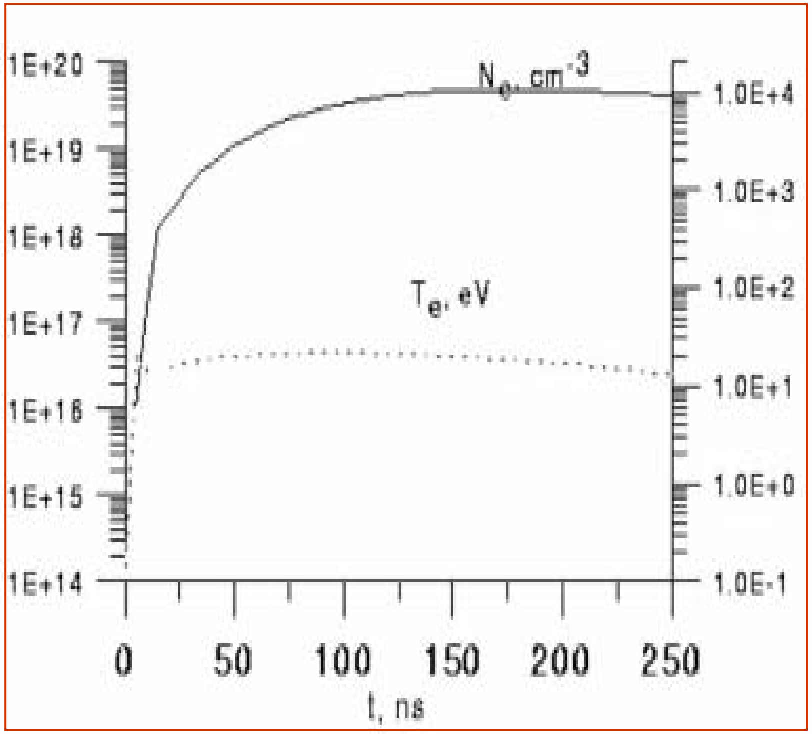
After the breakdown voltage is reached, nonuniform discharge develops at the surface of the wall. This stage of the discharge cann't be described by 1D approximation, but is short and doesn't affect the plasma parameters at later moments.

THE RESULTS OF MHD SIMULATIONS

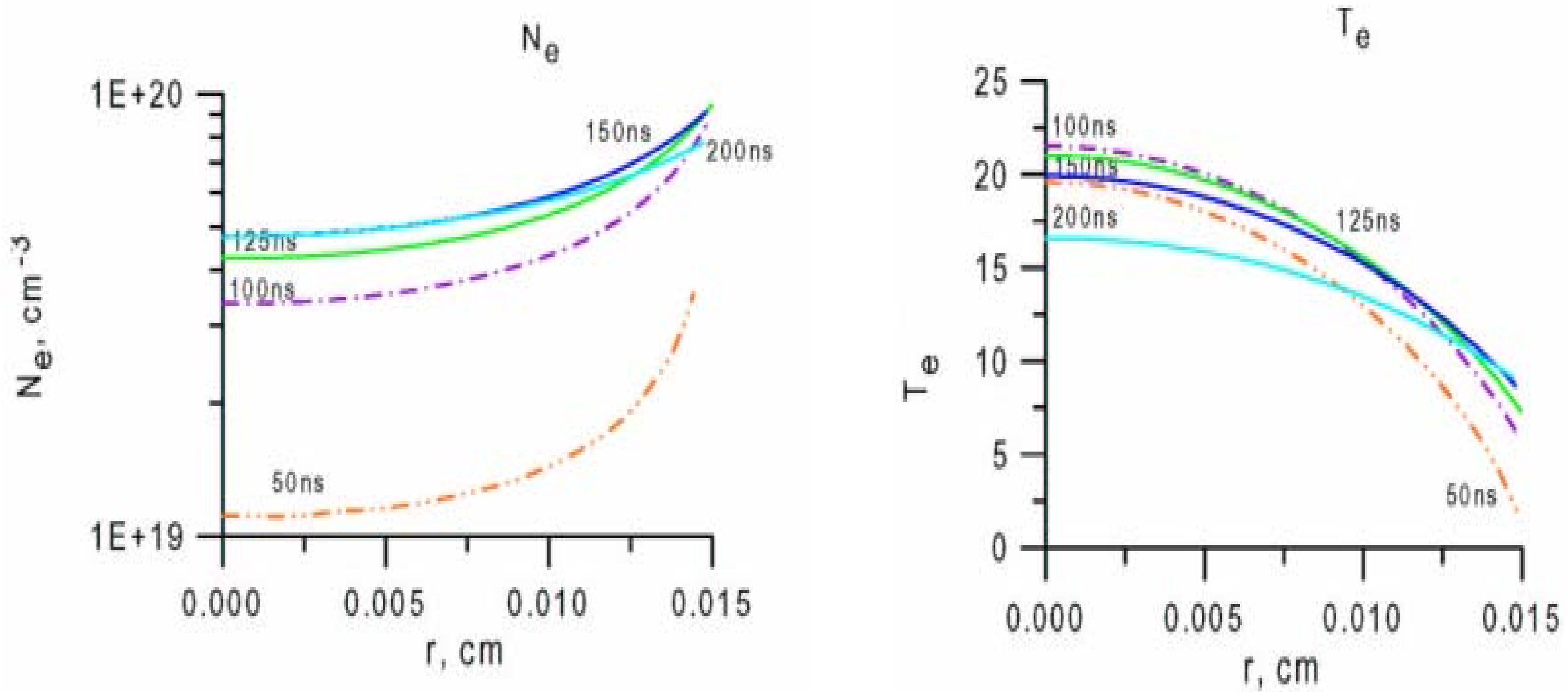
Capillary diameter $0.3\,mm$, $0.5\,mm$, $1\,mm$

The capillary plasma is perturbed by a current pulse

$$I(t) = I_0 \sin(\pi t / t_0), \quad I_0 = 3kA, t_0 = 125\,ns$$



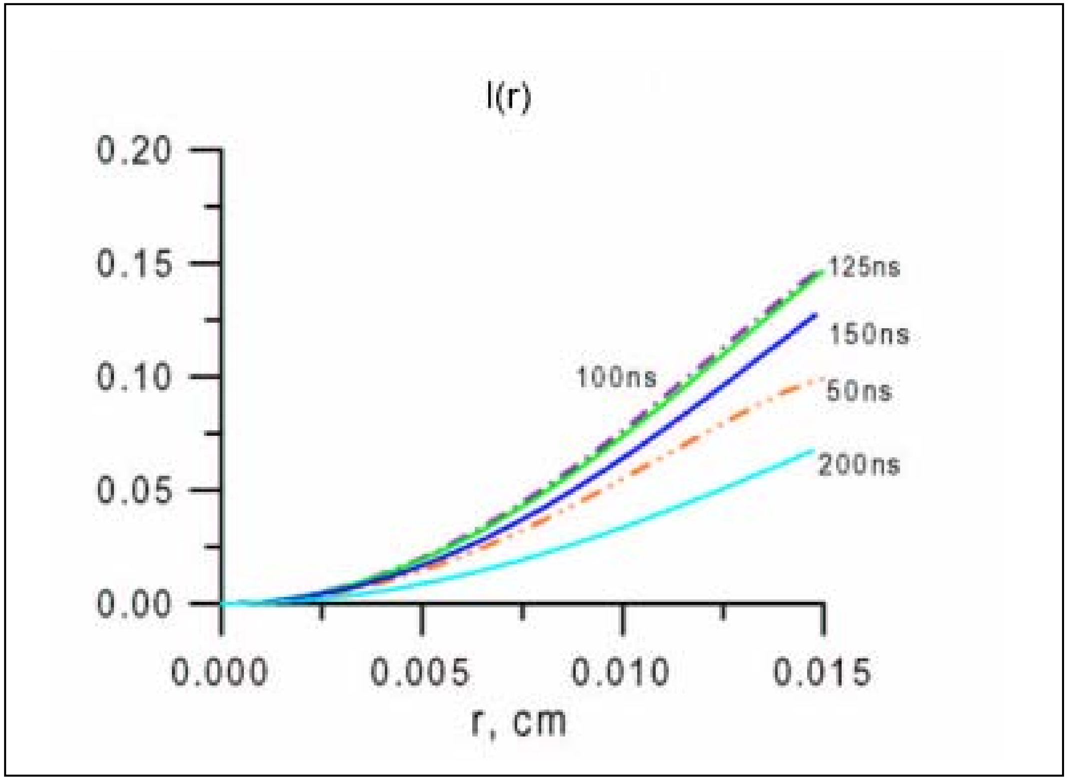
1. t=5-10ns - the fast plasma compression
2. the ablation of the wall is due to the heat flux from the central region
3. the quasi-equilibrium stage:
   mechanical equilibrium (the Ampere force is balanced by gradient of the plasma pressure)
   thermal quasi-equilibrium (Joule heating is balanced by the heat outflow due to thermal conductivity and radiative energy losses)



The radial distributions of electron density and temperature for different moments of time

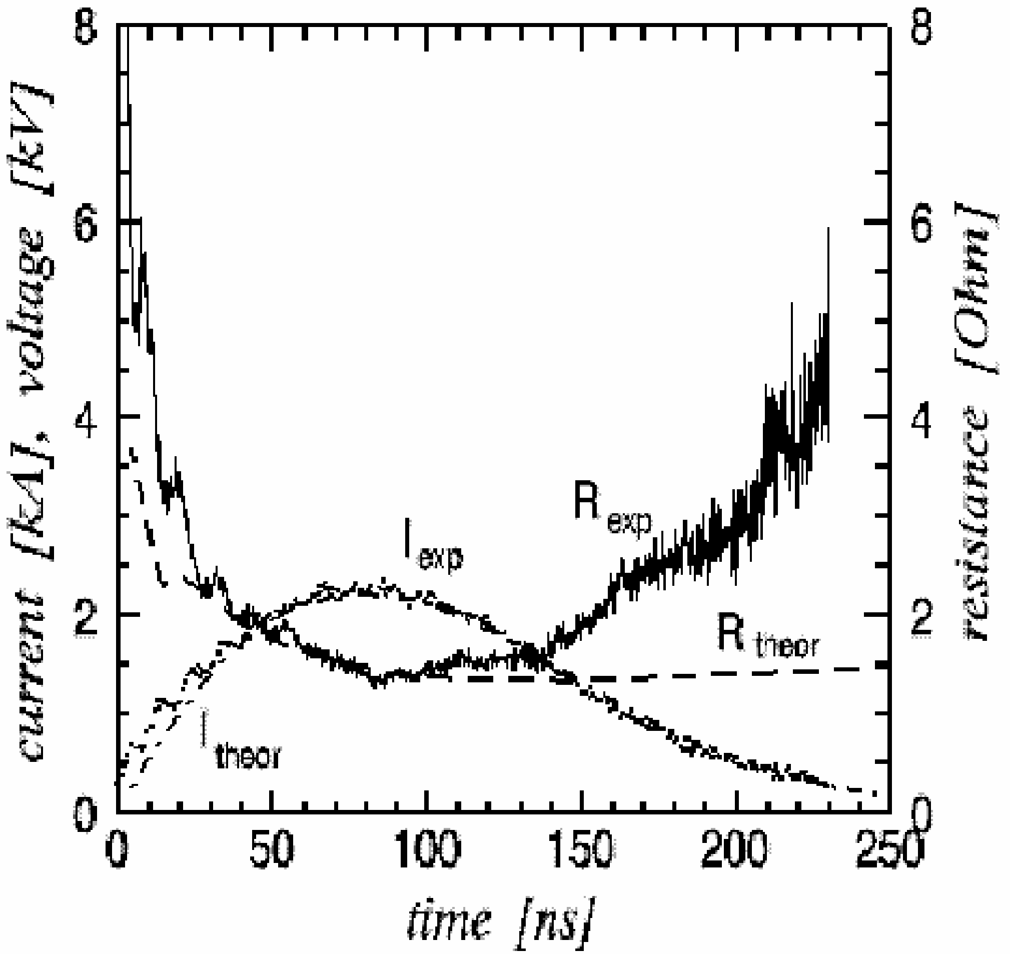
1. The density profile is concave with the minimum on the axis, which insures the pump laser guiding.
2. The density on the axis increases with decrease of the capillary diameter.
3. For 1mm capillary $N_e \approx 10^{18}\, cm^{-3}$

   For 0.5 mm capillary $N_e \approx 2\times 10^{19}\, cm^{-3}$



The radial distribution of the electric current, flowing inside the channel of radius r.

The time history of the discharge circuit resistance of the sulphur capillary of 30mm length



Distinct spike at the end of the first half-period was caused by resistance discontuinity, when the current tends to zero.

CONCLUSION

- We analyzed some aspects of using the capillary discharge as a source of the preformed plasma for collisionally pumped x-ray lasers.
- The concave electron density profile is established in the course of discharge dynamics.
- This profile ensures the pump laser guiding.
- The temporal history of the discharge resistance confirms that the physical model used in simulations of the discharge dynamics is valid for the case under consideration.