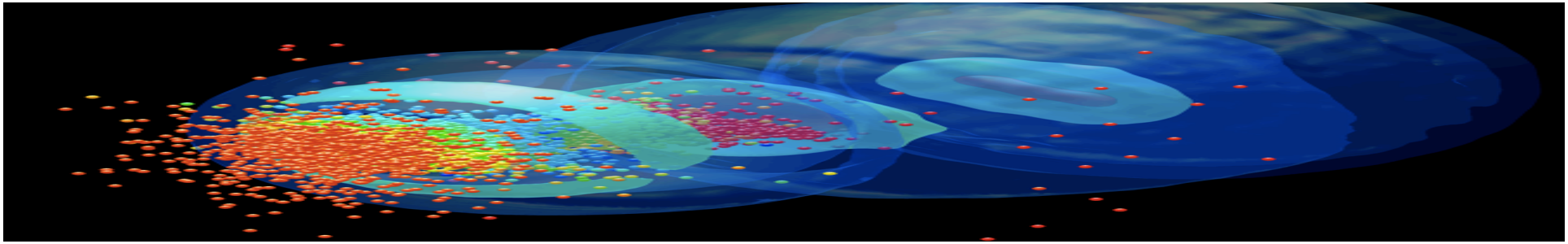

AF69 Feasibility Study Report: Key Physics Study of Laser Plasma Interaction (LPI) with Near Critical Density (NCD) Plasma Using Laser Machined Plasma Structure

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Outline

- **Rich Physics of LPI with NCD plasma**
- **Advantages of using CO2 laser interacting with NCD gas target**
- **Laser machined Plasma structure**
- **Planed LPI experiment with current ATF capabilities (1-2 TW 2ps CO2 + 7mJ 180fs 800nm laser)**
  - **Study of laser radiation pressure acceleration (RPA) with gaseous plasma target with very sharp boundary and the relevant transverse stability**

Rich Physics of LPI with NCD Plasma

- **The physics of relativistic laser plasma interaction with near critical density plasma is very rich, to name just a few:**

  laser self-focusing and channeling of plasma, laser filamentation, laser heating of hot electrons, fast electron transportation, magnetic field generation, radiation pressure acceleration and transverse instabilities, laser launched shockwave and shock acceleration ……

- **The detailed physics strongly depends on the plasma density profile, the scale length and the laser intensities, therefore a clear understanding of the physics requires great control of these conditions**

- **Important for ion acceleration and radiation generation schemes**

Issues with laser interacting with solid thin foils

- Target flatness and repeatability
- impurities on surface
- laser contrast and prepulses
- no easy optical diagnostic to see through the dense plasma

Programmable Gas Target using Laser Machining Method

- Flatness and purity can be controlled
- Optical diagnostics to see what is going on
- Less demanding on laser contrast
- Prepulse effects can be diagnosed
- Sharp features can be made
- Tunable structure with great flexibility
- Ultrafast electron probes can also be used to see the field and its evolution

Current limits of gas target

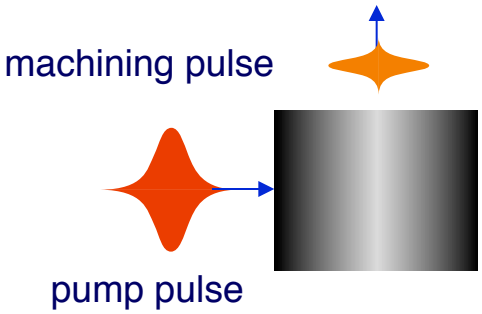
- Not easy to make very thin target or very sharp boundary for RPA study

- Hard to control or tune the density profile

Laser machining of gas target has the potential to address these two issues elegantly

Reduction of local plasma density by laser machining

Step 1: A prepulse ionizes and heats up the gas target.

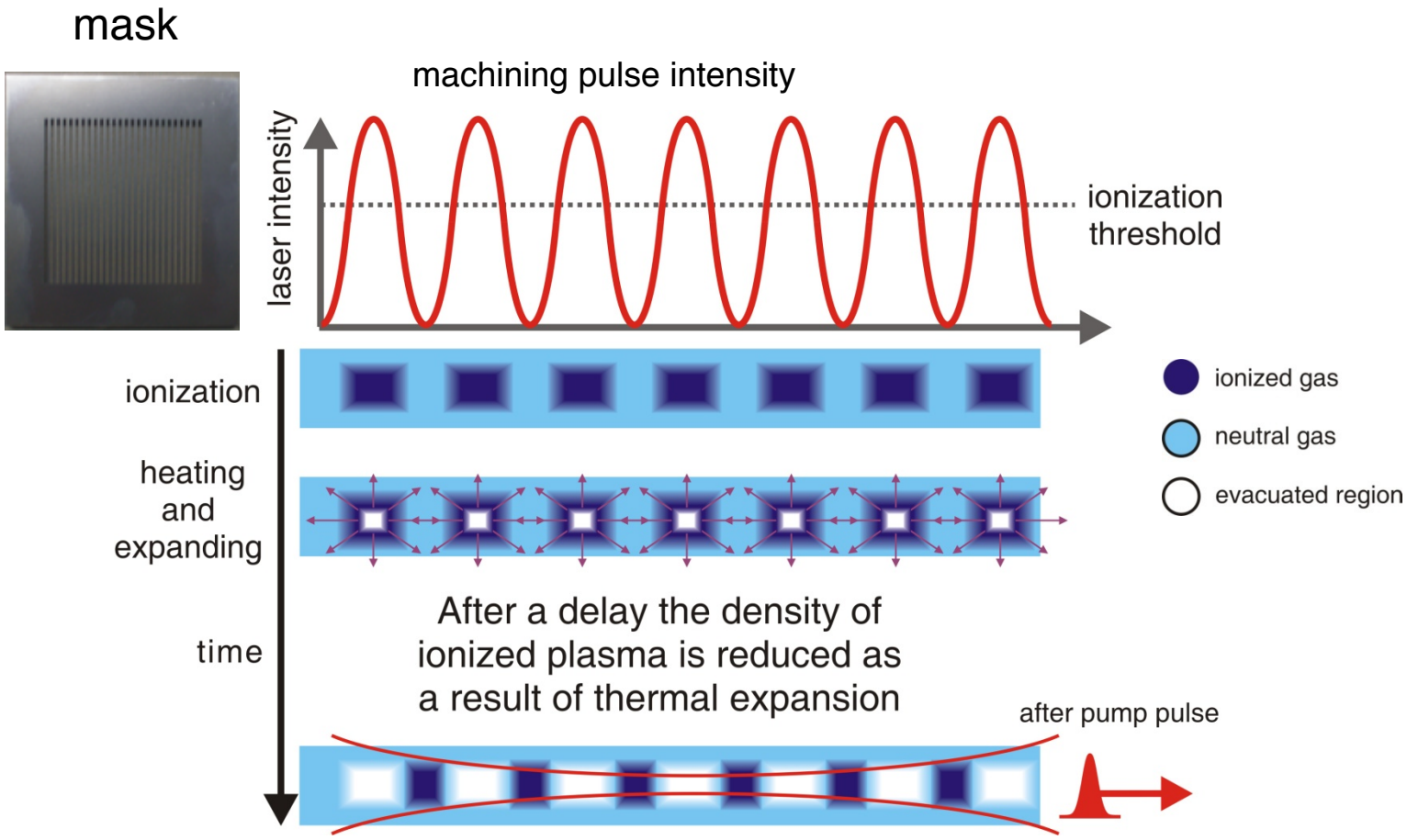


Step 2: The hot plasma expands. The density of the irradiated region is reduced.

Step 3: The pump pulse ionizes the rest of the gas and interacts with a plasma well.

Phys. Plasmas **11**, L21 (2004)
Phys. Rev. Lett. **94**, 115003 (2005)

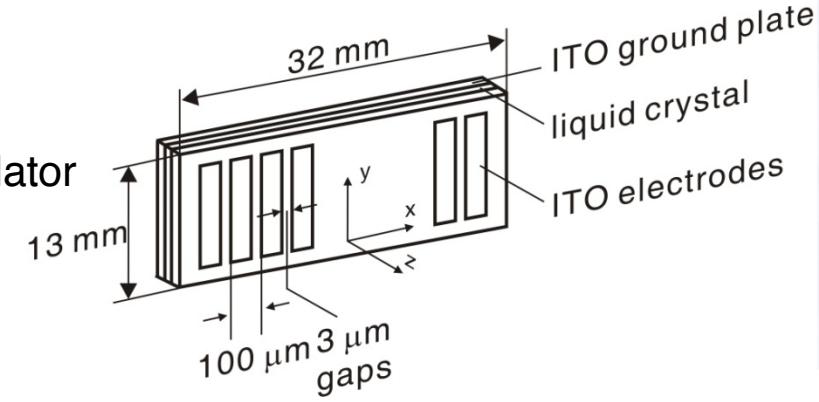
Fabrication of transient periodic plasma structures

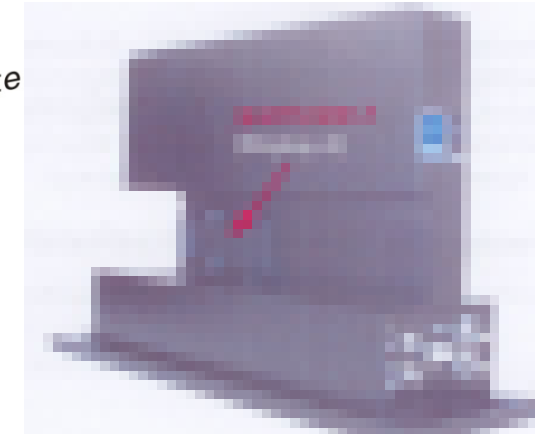


- The machining pulse plays both the roles of ionizing the gas through optical-field ionization and heating the plasma by above-threshold-ionization heating and inverse bremsstrahlung heating.

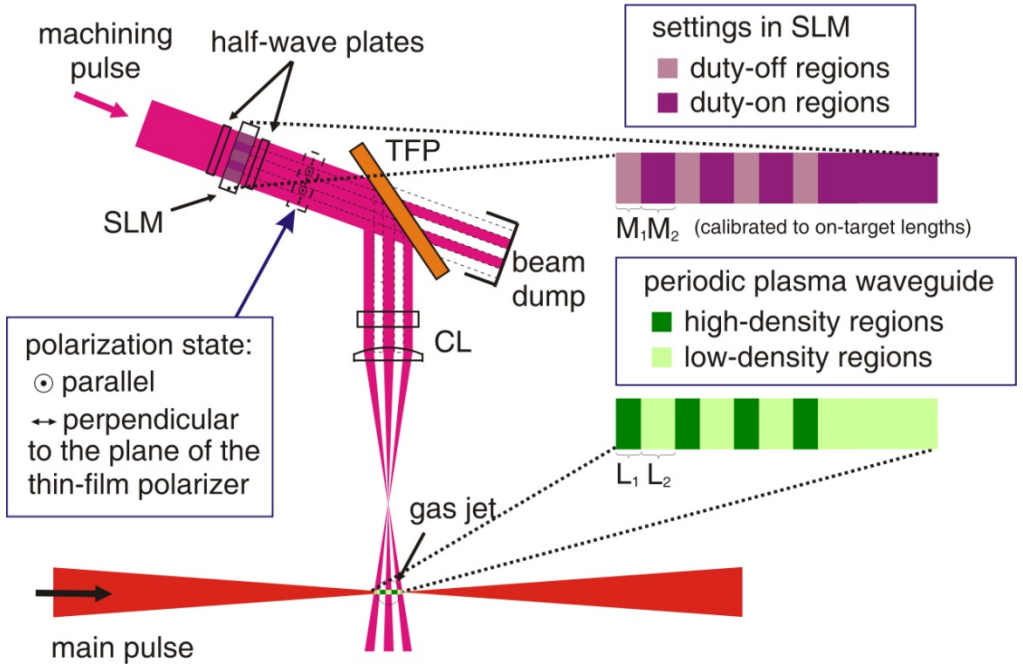
Programmable spatial amplitude modulator

liquid-crystal
spatial light modulator





Jenoptik
SLM-S320

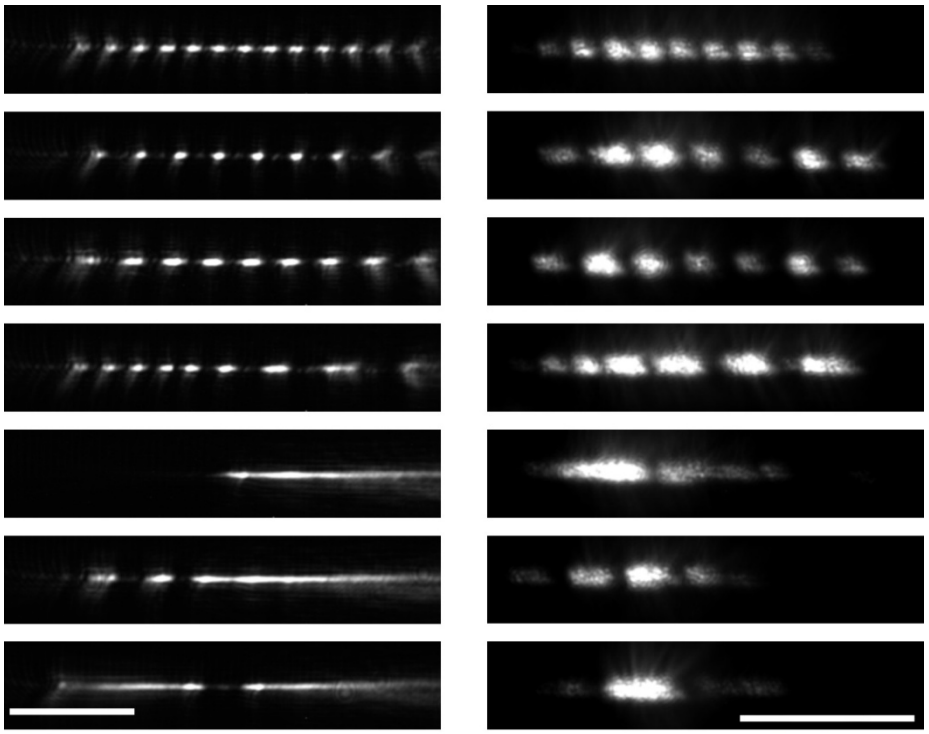


Programmable fabrication of arbitrary structures

intensity patterns set with a spatial light modulator

side scattering images

atom density: 3.2×10^{18} cm^{-3}



pattern parameters

duty-on region: 50 um
period: 100 mm

duty-on region: 50 um
period: 150 um

duty-on region: 100 um
period: 150 um

aperiodic pattern
period: 50 → 300 um

blocking half

on after the third period

a well of 200-um width

Structures with features about 10um can be fabricated

Density range: 10^18cm-3 to 10^20cm-3

Proposed Experiment with current ATF capabilities

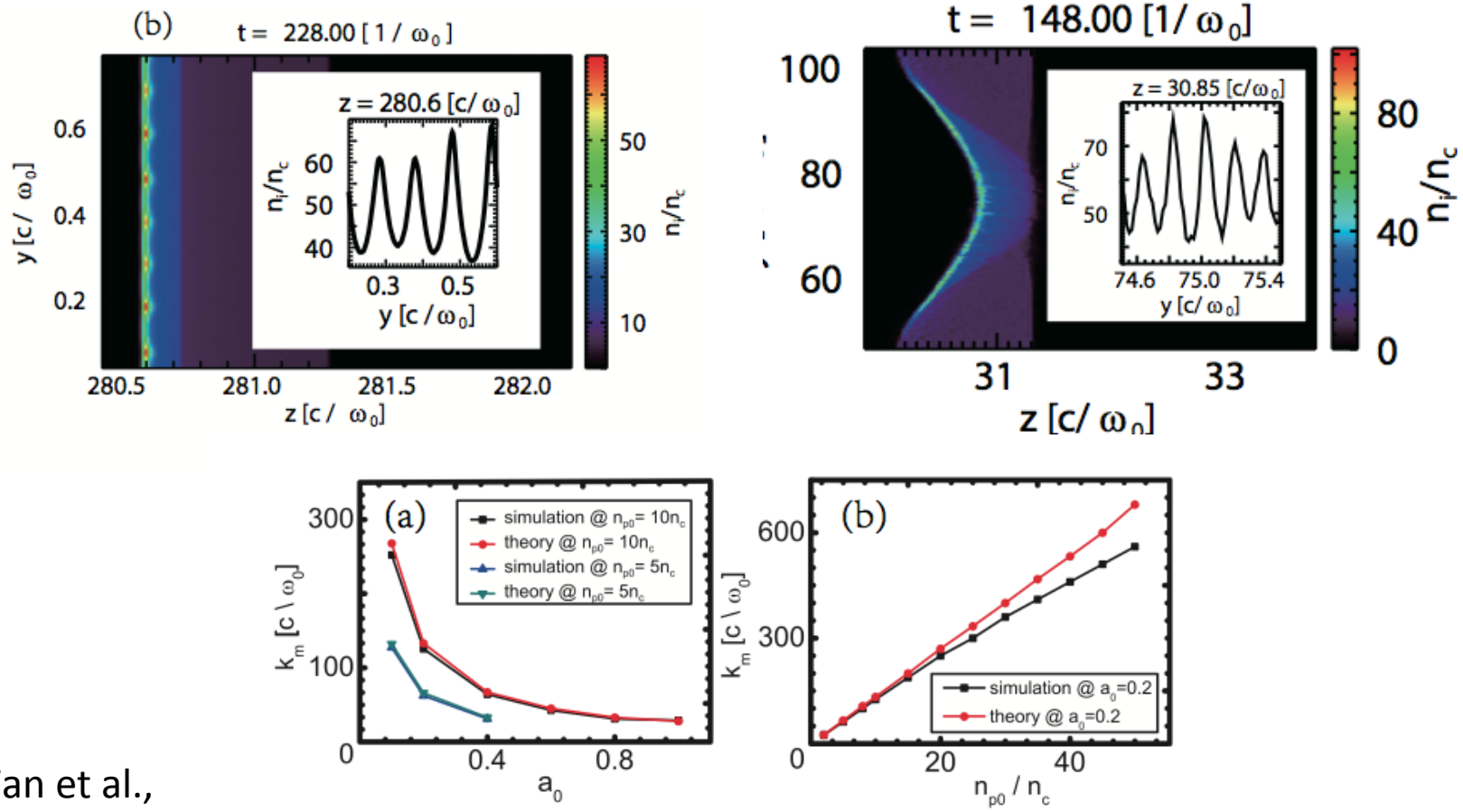
- Study of laser radiation pressure acceleration (RPA) of ions using gaseous plasma target with sharp boundary (~10um)

Method: using the 7mJ 180fs 800nm laser as the machining laser pulse, combining with a simple mask, to make a sharp edge at the front of the gas jet

- Study of the transverse instability of RPA using optical probe

- Electron probe may also be used in future

A new theory for RPA transverse instability



Yang Wan et al.,

To be published

FIG. 2. (a) The relationship between k_m and a_0 when $n_{p0} = 10n_c$ and $5n_c$. (b) The relationship between k_m and n_{p0} when $a_0 = 0.2$. Both indicates that our theory has good agreement with 2D simulation results.

The goal of this experiment

- To try the RPA ion acceleration in well controlled plasma condition (sharp front edge): **2-3ps 0.1-1TW circularly polarized laser pulse is OK for this study**

- To observe the mode structure of the transverse instability and to compare with theory and simulation

Feasibility Discussion

- using a 0.5mm diameter H gas jet target with a rising edge of 100um (available)
- focusing the 5mJ 800nm laser with cylindrical lenses (also with a simple mask) to form an tunable ionized region in the front of the gas jet (50-100um by 100um), **intensity well beyond the ionization threshold of H**
- Transverse optical probe to measure the density features
- 2 or 3 weeks for setup, 1-2 weeks for data taking

Summary

- Combining high power CO2 laser with laser machining gas target may open up many new interesting physics study of LPI with NCD plasma at ATF and ATFII
- We propose to do sharp boundary RPA physics study with current laser parameters, focusing on the ion acceleration feature and transverse instability physics

Thank you for your attention!