Simulating Multi Layer Targets for Grazing Incidence Small Angle X-ray Scattering

Bachelorthesis

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Structure

1. GISAXS
   What is GISAXS? What motivated the thesis?

2. Target Setup
   What does the Setup look like?

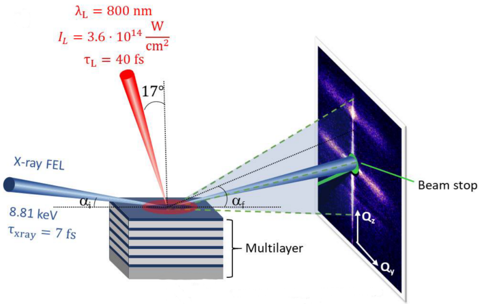
3. Target Dynamics
   What kind of plasma dynamics can we observe in the target?

4. Density Oscillation
   What is Density Oscillation? How does it allow to determine T_e?

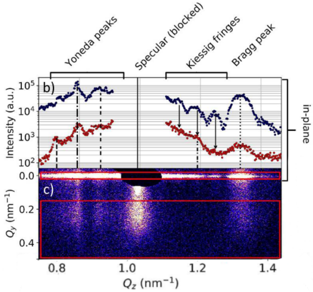
5. Summary and Outlook
   What did we learn? What are the next steps?

GISAXS - grazing-incidence small-angle x-ray scattering

Laboratory Setup



Scattering Pattern



"Nanoscale subsufrace dynamics of solids upon high-intensity laser irradiation obserevd by femtosecond GISAXS" - Lisa Randolph et.al.

- x-ray scattering pattern $\rightarrow$ layer density profile in the target
- intensities paper: $10^{14} - 10^{16}$ Wcm^{-2}
- required: **intact layer structure**, dynamics within **time resolution** (500 fs)

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Thesis Questions

1. **Is GISAXS feasible for high intensities?**

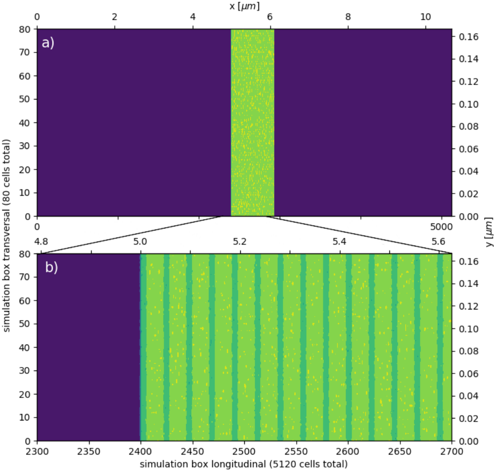
2. **What should a target look like?**
   How long do the layers survive? How thick should they be? How many layers do we need?

3. **What time resolution do we need?**

4. **What dynamics can we observe?**
   Can we observe ablation, compression, density oscillation?

5. **What parameters can we extract?**
   Can we learn about the ablation velocity v_{abl} or electron temperature T_e?

Target Setup



Simulation Parameters

Laser

$I = 10^{17} - 10^{22}\ \mathrm{Wcm}^{-2}$

$\tau = FWHM = 40$ fs

Target

layer 1: tantalum

layer 2: copper nitrite

$n_{layer} = 12$

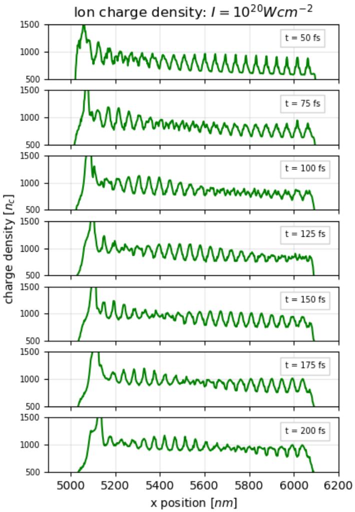
$d_{Ta} = 12.55$ nm

$d_{Cu_3N} = 33.33$ nm

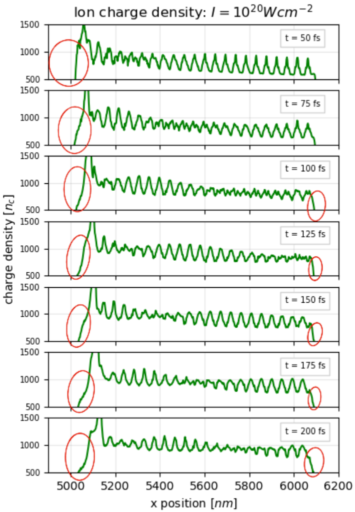
$d_{total} = 1100$ nm

Target Dynamics

dynamics



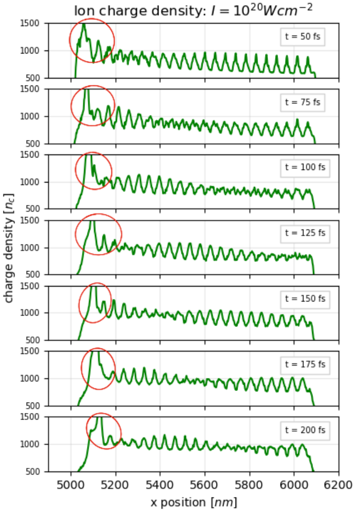
Target Dynamics



dynamics

- plasma expansion front and back $\rightarrow$ ablation, ion acceleration

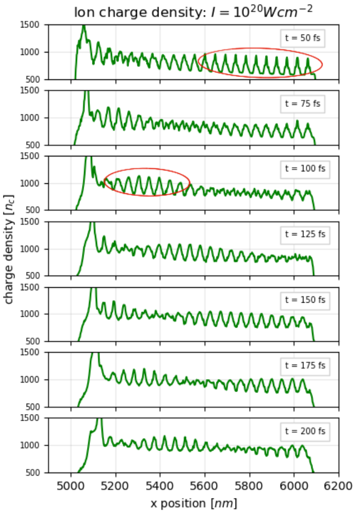
Target Dynamics



dynamics

- plasma expansion front and back → ablation, ion acceleration
- compression

Target Dynamics



dynamics

- plasma expansion front and back → ablation, ion acceleration
- compression
- bulk effects → melting layers

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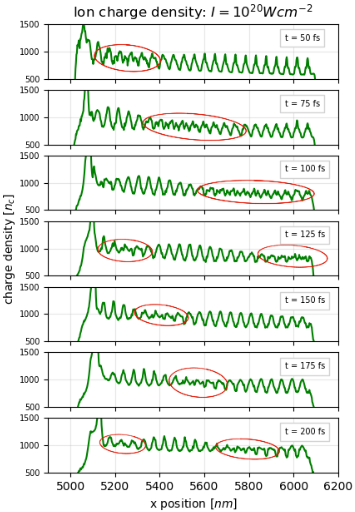
Target Dynamics



dynamics

- plasma expansion front and back → ablation, ion acceleration
- compression
- bulk effects → melting layers
- density oscillation

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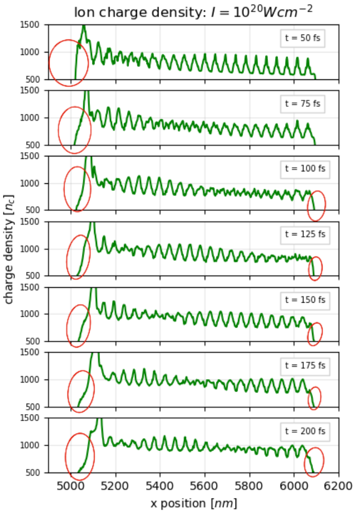
Target Dynamics



dynamics

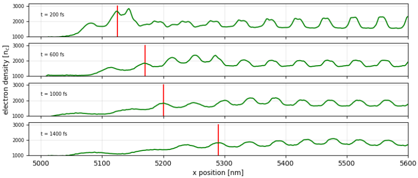
- **plasma expansion front and back → ablation, ion acceleration**
- compression
- bulk effects → melting layers
- density oscillation

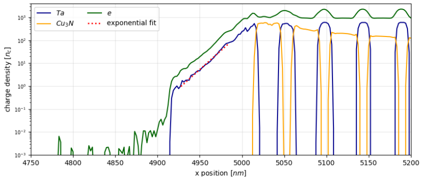
Target Dynamics - Ablation velocity

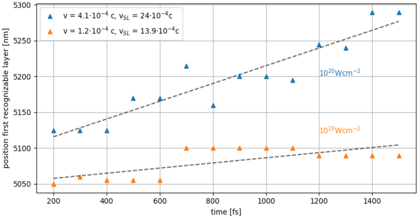
→ the **front layer position** does **not** correlate to the **ablation velocity**

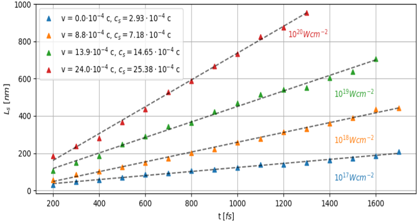
vel. of first recognizable layer

vel. of scale length L_s









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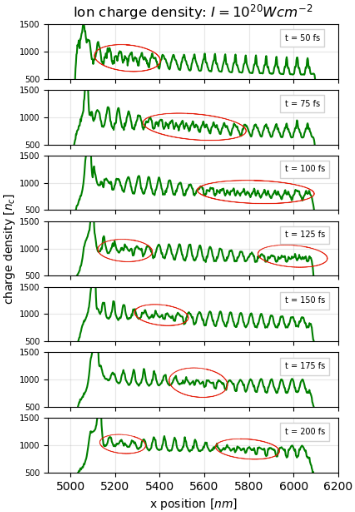
Target Dynamics



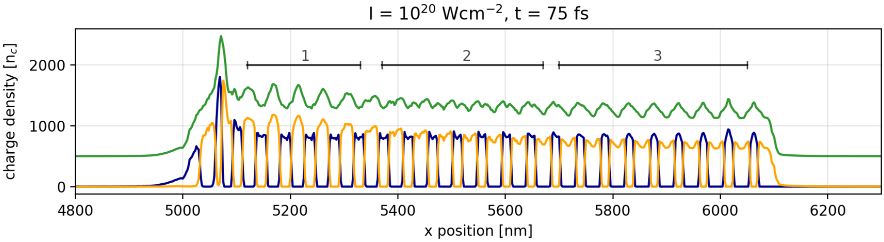
dynamics

- plasma expansion front and back → ablation, ion acceleration
- compression
- bulk effects → melting layers
- **density oscillation**

Density Oscillation - Basics

What is oscillating?

→ the **single** layers oscillate in density

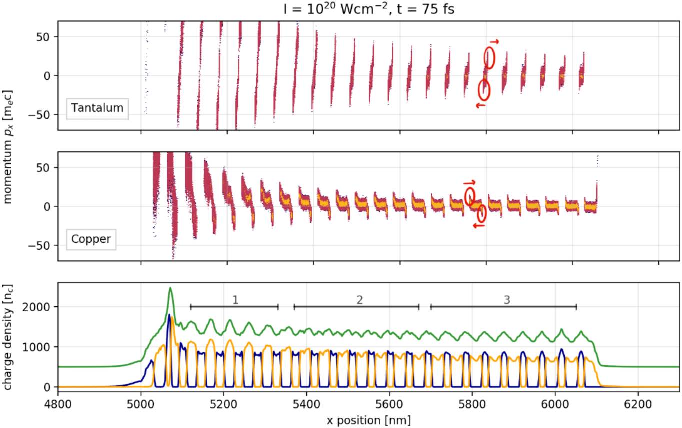


1. Cu_3N charge density (orange) exceeds
2. Cu_3N and Ta charge density are fairly equal
3. Ta charge density (blue) exceeds

Density Oscillation - Basics

Why are the layers oscillating?

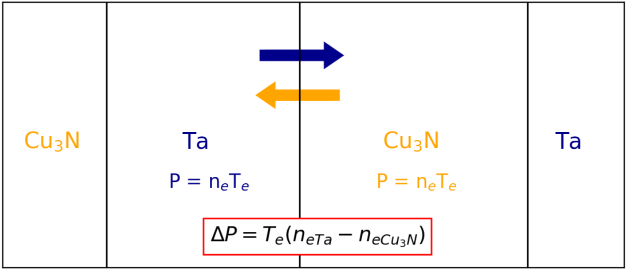
→ the layers repeatedly **compress** each other



Density Oscillation - Process

What causes the compression?

→ the **pressure difference** between the layers ΔP causes a force



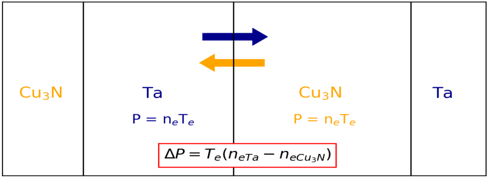
Assumptions:

$T_i \ll T_e$

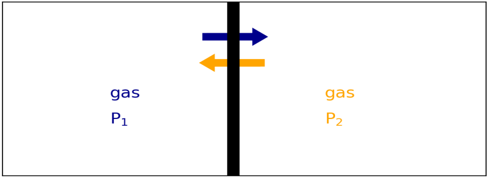
$T_{e,layer1} = T_{e,layer2} = T_e$

Density Oscillation - Modeling

How can we model the process?



layers in target



gases in cylinder separated by heavy piston after E.Gislason in "A close examination of the motion of an adiabatic piston"

$\rightarrow$ gases with pressure P = energetic electrons with pressure P
$\rightarrow$ heavy piston = heavy, considerably cold ions

Density Oscillation - Oscillation Frequency

$$\omega_{osc}^2 = \frac{T_e}{f\tilde{m}} \left[n_{1e}^0 \frac{x_0}{x_\infty^2} + n_{2e}^0 \frac{(L-x_0)}{(L-x_\infty^2)} \right]$$

$n_{i,e}^0$ - initial electron density of layer i
x_0, L - layer thickness parameters
$x_\infty(n_{i,e}^0, x_0, L)$ - final position layer boundary (final position piston)
$\tilde{m}(m_{i,ions})$ - mass factor heavy ions

T_e - electron Temperature
f - geometry factor ions ($0 < f \leq 1$)

Density Oscillation - Oscillation Frequency

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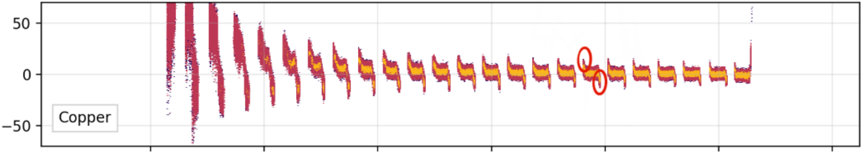

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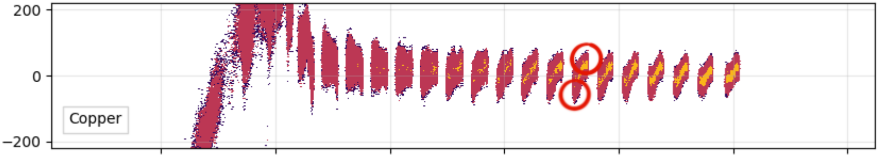

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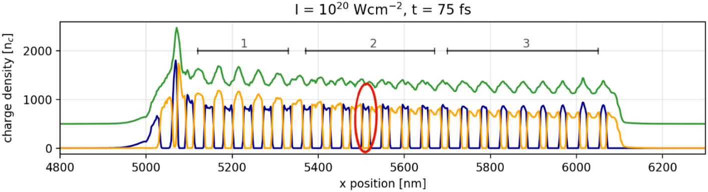
Density Oscillation - Intensity Scan

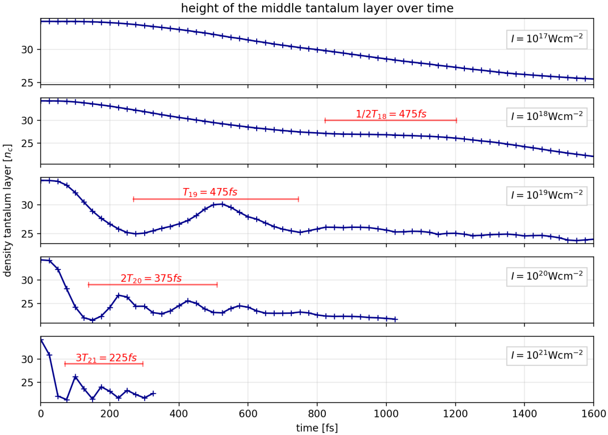
height of the middle tantalum layer over time



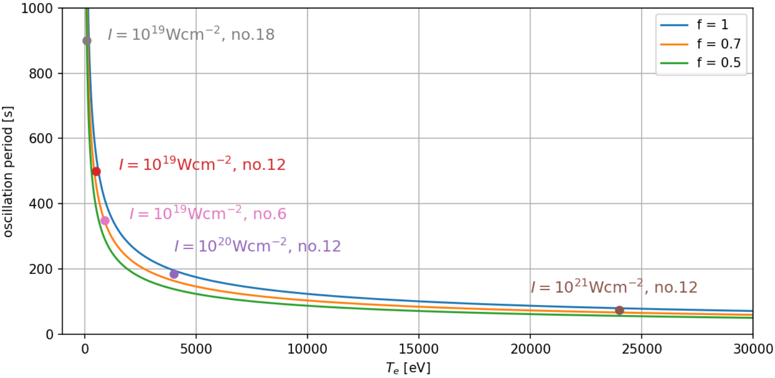
Density Oscillation - Intensity Scan

height of the middle tantalum layer over time

$\rightarrow$ measure the oscillation period



Density Oscillation - Comparison Model and Simulation



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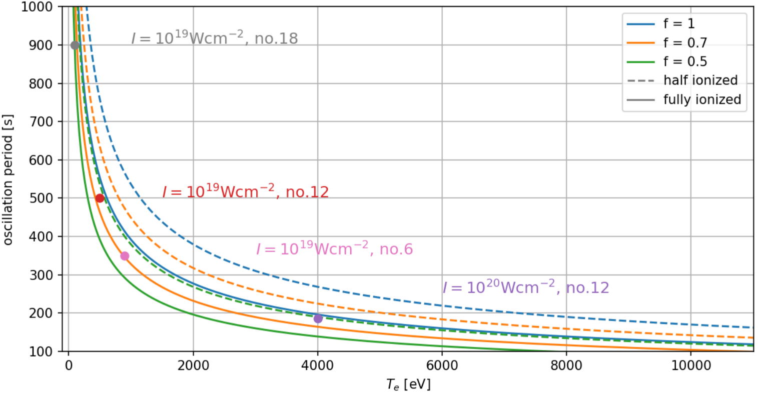
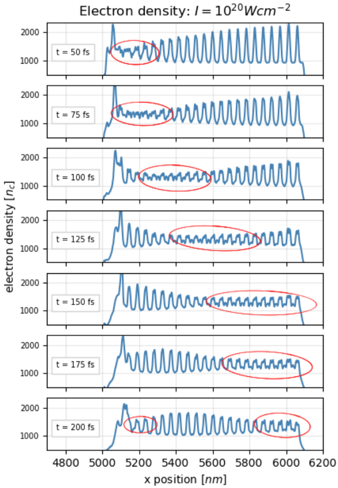


Density Oscillation - GISAXS feasibility



- electron density dominated by tantalum → oscillation period for tantalum layers

- can not follow single layer oscillation
- can follow density alteration over time
- GISAXS: Is the layer structure intact or not?

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Thesis Questions

1. **Is GISAXS feasible for high intensities?**
   Yes!

2. **What should a target look like?**
   layer thickness similar to the simulation setup, more layer for higher intensities ($>$12), layers survive 100 fs to several ps

3. **What time resolution do we need?**
   50 - 100 fs

4. **What dynamics can we observe?**
   compression, layer expansion front and back, density oscillation

5. **What parameters can we extract?**
   electron temperature T_e based on the density oscillation frequency

Outlook

- create scattering pattern with **BornAgain** to confirm GISAXS feasibility
- model damping and diffusion to erase free parameter f
- recommend GISAXS **experiments for high intensities**, support with simulations