Laser Damage Measurements

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Workshop "Laser plasma generation for particle acceleration"
at Wigner Research Center for Physics, Budapest, Hungary

Outline

1. Conception of Laser Beam Dumps
2. Ablation Studies
3. Comparison with results of Wynne/Stuart
4. Conclusion
5. Next steps

Conception of Laser Beam Dumps

→ in total three laser beam dumps:

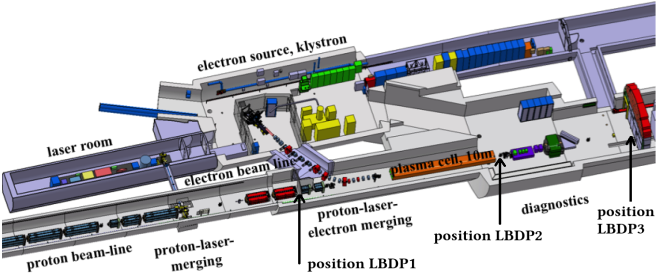


Figure taken from AWAKE status report, October 2014 and adapted

Purpose of LBDP2:

protection of sensitive CTR and OTR diagnostic foils located downstream against intense laser radiation

Purpose of LBDP3:

dumping the laser beam before the downstream vacuum window

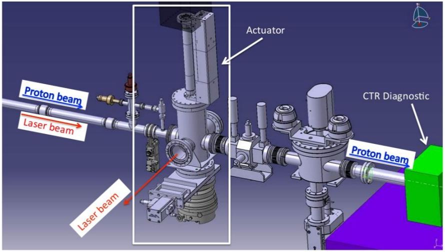
Conception of Laser Beam Dumps

Realization: Use thin metal foil as beam dump

→ blocking the laser beam (foil should be as thick as possible)

→ no effect on proton beam in order to test downstream diagnostics

→ minimize creation of hard radiation when passed by proton beam (foil should be as thin as possible)



Schematic of the integration of the laser beam dump located immediately after the vapor source. The second beam dump is identical.
Figure taken from AWAKE status report October 2015

Fluence on Target

Peak fluence on beam dump:

Laser parameters:

- pulse energy: $E \approx 450$ mJ
- pulse length: $\tau \approx 100$ fs
- beam waste: $w_0 \approx 1$ mm
- Rayleigh length: $z_R \approx 4$ m

→ maximum AWAKE fluence:

$$\boxed{F_{max} = 14 \ \frac{\mathrm{J}}{\mathrm{cm}^2}}$$

→ expected peak laser fluence at LBDP2:

$$\boxed{F\ (5\ \mathrm{m}) \approx 6.4 \ \frac{\mathrm{J}}{\mathrm{cm}^2}}$$

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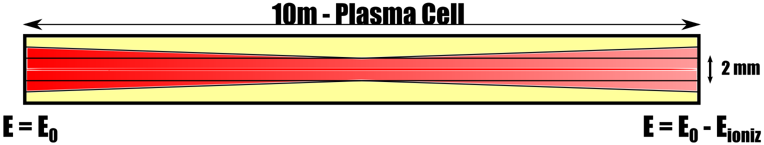
Fluence above ablation thereshold of most metals!

Fluence Losses by Ionisation

→ but: fluence losses by ionisation of Rb within the 10 m source sufficient to come below the ablation threshold?



Energy to ionize all 1st Rb-electrons in the plasma cell:

$$E_{ioniz} = n_0 \phi_{Rb} \pi R_P^2 L \approx 25 \text{ mJ}$$

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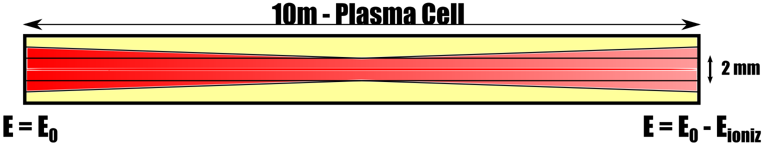

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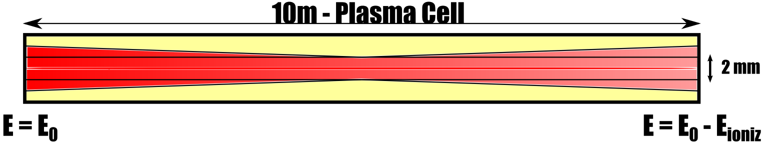

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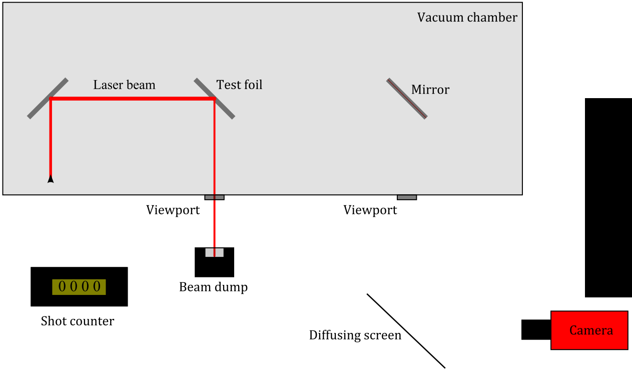
→ Studies for Ablation Rates necessary – Foil has to be shifted after several shots!

Ablation Studies performed at MPP

- before relocation of the laser to CERN
- shots on 25 mm × 25 mm Al-foils
  - 4 different thicknesses: 200 µm, 380 µm, 400 µm, 1000 µm
  - 3 different alloys: Al 99% purity, Al 7075, Al 6082
  - 3 different tempers: hard, half-hard, T6

25 mm × 25 mm Al-foils (200 µm thickness) before and after laser ablation

Setup



no light on camera!

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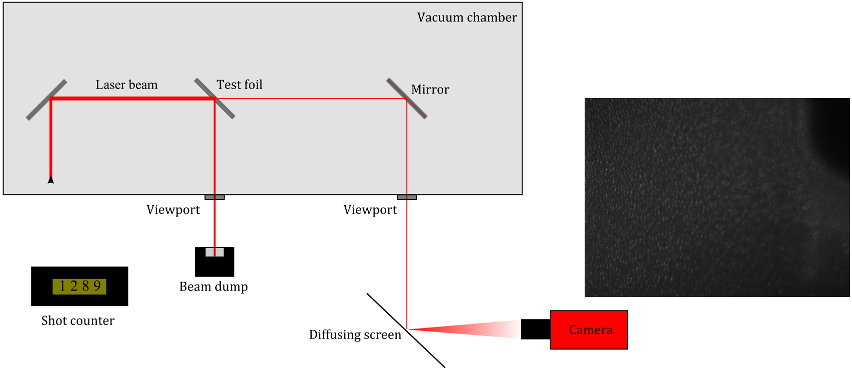
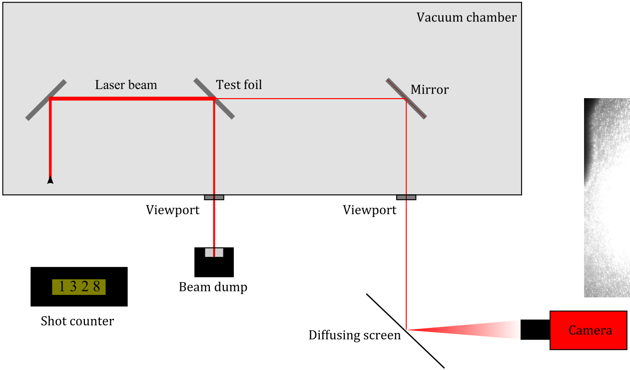
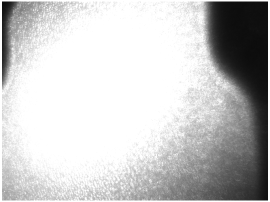


first light: first appearance of light on camera

Setup





breakthrough: light saturated on camera!

Ablation Studies performed at MPP

Laser parameters of MPP experiment:

pulse length:	$\tau = 120$ fs
repetition rate:	$\nu =$ max. 10 Hz
wavelength:	$\lambda = 780$ nm
pulse energy:	$E = (7.20 \pm 0.16)$ mJ
beam diameter:	$d = (530 \pm 45)$ µm
pointing stability:	$\gamma = 110$ µm
vacuum pressure:	$p = 10^{-5}$ mbar

→ fluence on target:

$$\boxed{F = \frac{E}{A} = 6.6 \pm 2.2\ \frac{\mathrm{J}}{\mathrm{cm}^2}}$$

$\left(\text{cf. expected AWAKE value: } F\ (5\ \mathrm{m}) = 6.4\ \frac{\mathrm{J}}{\mathrm{cm}^2}\right)$

Results

Summary of Results:

foil	thickness	runs	$\overline{N} \pm \Delta N$	AAR [nm/pulse]
Al 99% hard	200 µm	9	1283 ± 139	157 ± 19
Al 99% half-hard	380 µm	9	1749 ± 177	211 ± 21
Al 7075 T6	400 µm	13	1713 ± 398	256 ± 15
Al 99% half-hard	1000 µm	10	9645 ± 1022	98 ± 8
Al 6082 T6	1000 µm	3	7324 ± 1288	94 ± 9

- $\bar{N}$: average shot number for breakthrough
- Average Ablation Ratio (AAR):

$$AAR = \frac{1}{N} \sum_{i=1}^{N} \varepsilon_i$$

  - ε: depth ablated at the i-th shot

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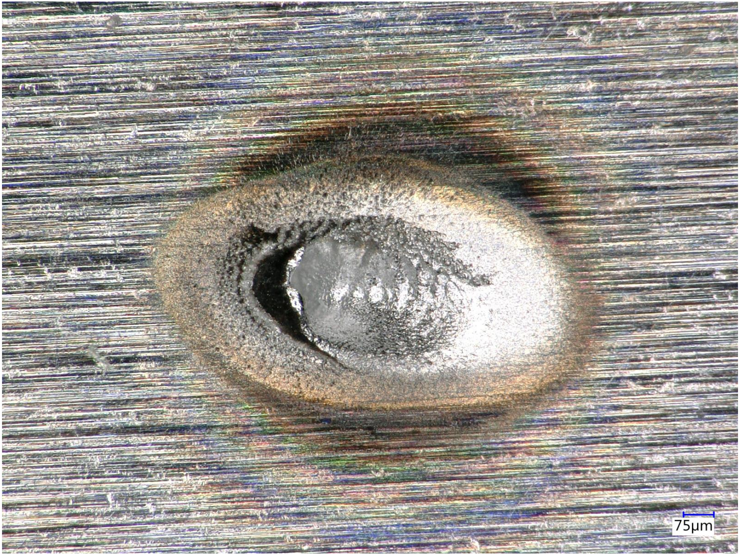
Microscope images



Hole after 1289 shots on 200 µm thick Al foil (temper hard)

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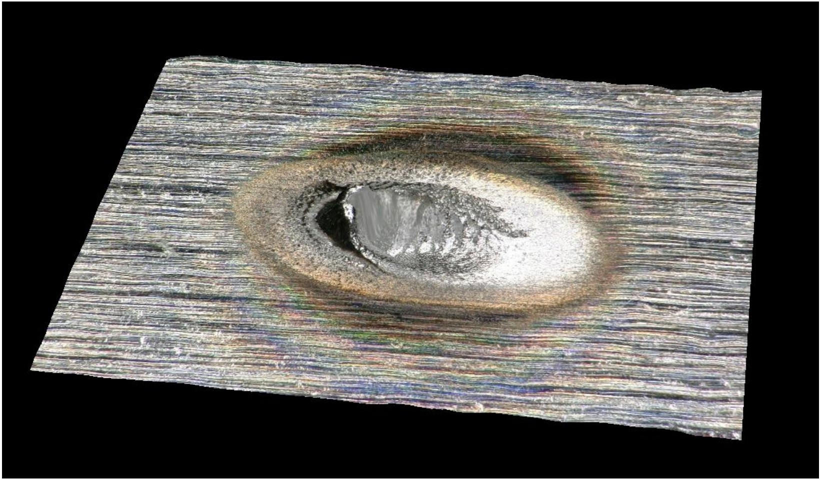

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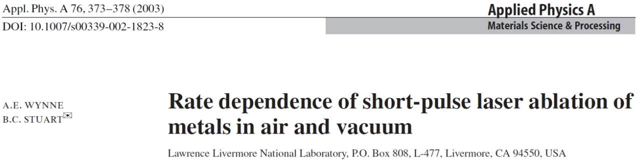
Comparison with results of Wynne/Stuart



Appl. Phys. A 76, 373–378 (2003)
DOI: 10.1007/s00339-002-1823-8

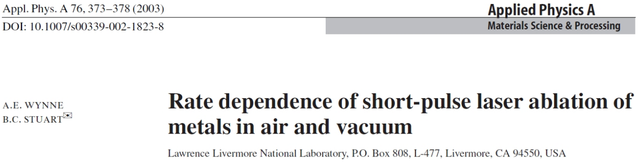
Applied Physics A
Materials Science & Processing

A.E. WYNNE
B.C. STUART✉

Rate dependence of short-pulse laser ablation of metals in air and vacuum

Lawrence Livermore National Laboratory, P.O. Box 808, L-477, Livermore, CA 94550, USA

Comparison with results of Wynne/Stuart



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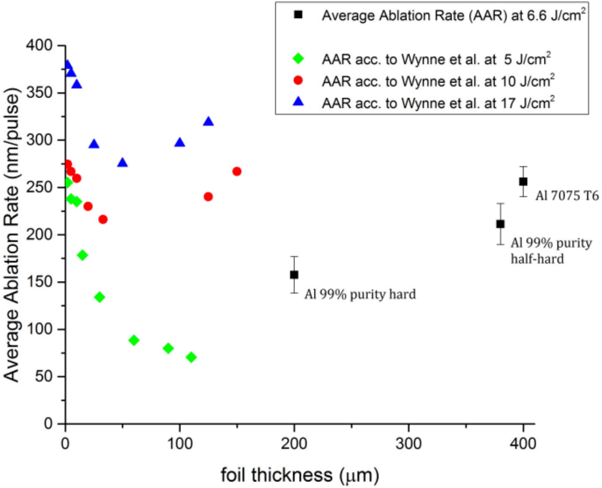
- laser with almost equal wavelength and pulse length
- only for Al alloy 7075
- foil thickness 1000 µm, but no depth greater than 150 µm measured

	MPP	Wynne/Stuart
pulse energy [mJ]	7.20 ± 0.16	max. 1.5
beam diameter [µm]	530 ± 45	150
fluence on target [J/cm^2]	6.6 ± 2.2	0.2 – 17

Comparison with results of Wynne/Stuart



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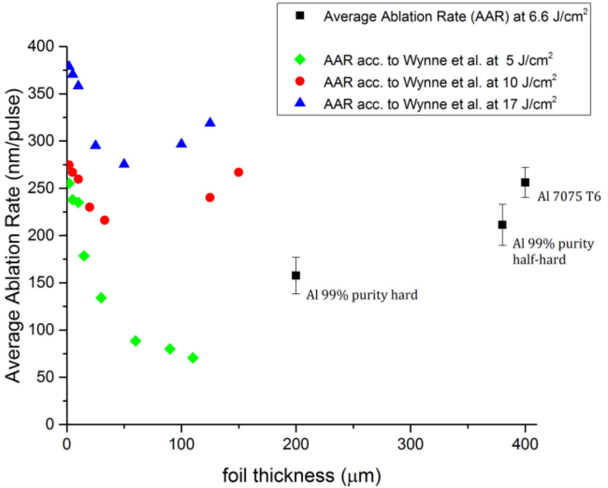

Ablation rates comparable with the results of Wynne/Stuart

Conclusion

- pure Al seems to have slightly lower ablation rates than alloys
- "hard" seems to be best temper

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suggestion for a reasonable foil selection:

→ Al 99% hard

→ 200 µm thickness

→ limitaion to 600 shots (50% safety margin)

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suggestion for a reasonable foil selection:

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→ 200 µm thickness

→ limitaion to 600 shots (50% safety margin)

- repetition rate: $\frac{1}{30}$ Hz
- effective actuator travelling range: 140 mm

60 foil positions, assuming 10 h of laser operation per day:

→ foil has to be shifted every 5 h of constant laser operation

→ foil has to be replaced roughly every month of laser operation

Next steps

before comissioning:

- vacuum testing and installation of beam dump chambers
- ordering the foil holders

during commissioning-phase:

- verification of final foil-selection at CERN
- programming of a shot counter and a stepper motor program
- implementation in control system

Degradation by the proton beam

Degradation of the Al foils by the proton beam?

- 300 µm Al-foils for BTV's in HiRadMat-Beam (Marlene Turner, CERN)

HiRadMat
High-Radiation to Materials

- no degradation of Al visible, but data analysis still ongoing!

→ perhaps we can profit from these measurements???

Thank you for your attention!