Colliding Laser-Produced Plasmas as Targets for Laser-Generated EUV Sources.

Thomas Cummins, Colm O'Gorman, Padraig Dunne, Emma Sokell, Gerry O'Sullivan & Paddy Hayden.

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T. Cummins,[1] C. O'Gorman,[1] P. Dunne,[1] E. Sokell,[1] G. O'Sullivan,[1] and P. Hayden[1,2,a)]
[1)] *School of Physics, University College Dublin, Belfield, Dublin 4, Ireland*
[2)] *National Centre for Plasma Science and Technology, Dublin City University, Glasnevin, Dublin 9, Ireland*

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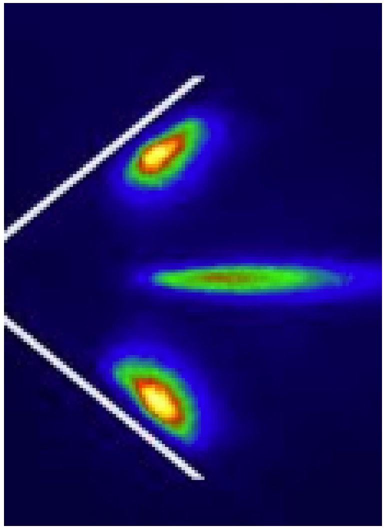
Motivation.

- Colliding Plasmas can create a Stagnation Layer, whose nature is determined by the collisionality parameter ς.

$$\zeta = \frac{D}{\lambda_{ii}}$$

Hough *et al* J. App. Phys **107** 024904 (2010)



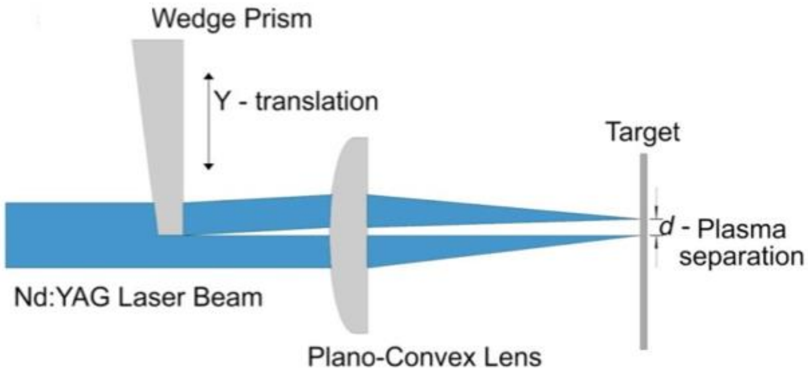
Where D is the ablation front separation & λ_{ii} is the ion-ion mean free path:

$$\lambda_{ii}(1 \to 2) = \frac{\left(m_1 v_{12}^2\right)^2}{4\pi e^4 Z^4 n_2 Ln(\Lambda_{12})}$$

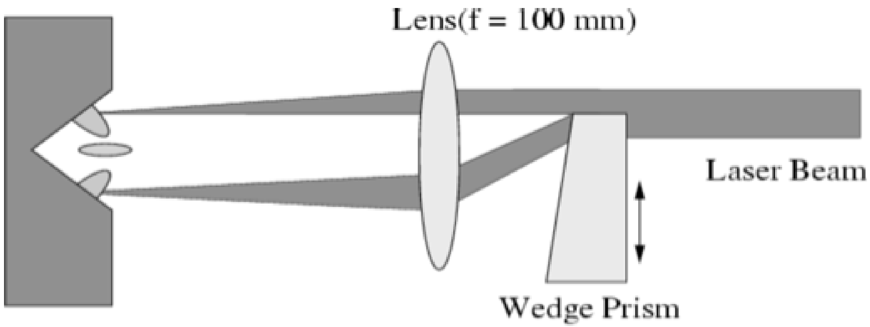
Rambo and Denavit, Phys. Plasmas **1** 4050 (1994)

Parameter Control:

- Initial plasma (ablation front) separation – D
- Laser intensity – relates to v_{12}
- Target wedge angle
- Laser wavelength – related to plasma density



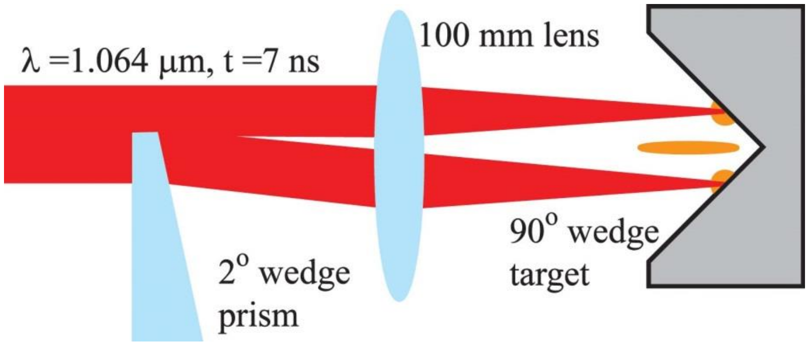
Planar target – lateral plasmas

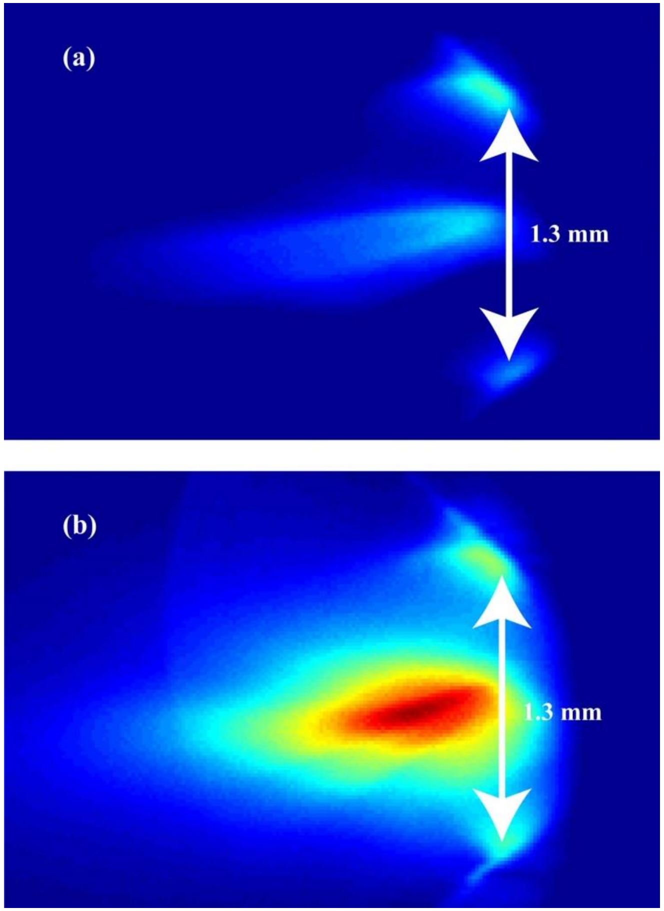


Wedge target – converging plasmas

The main idea:

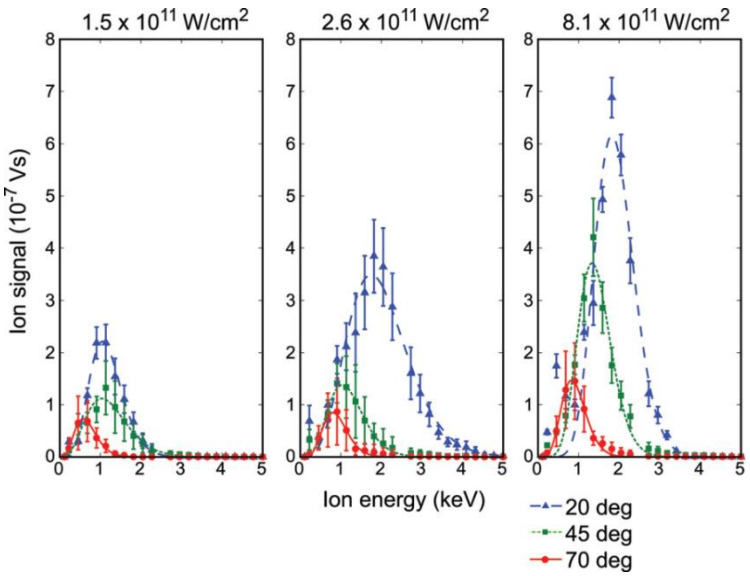
- Form stagnation layer
- Tailor plasma temperature, density & density gradient
- Irradiate with CO_2 laser to re-heat



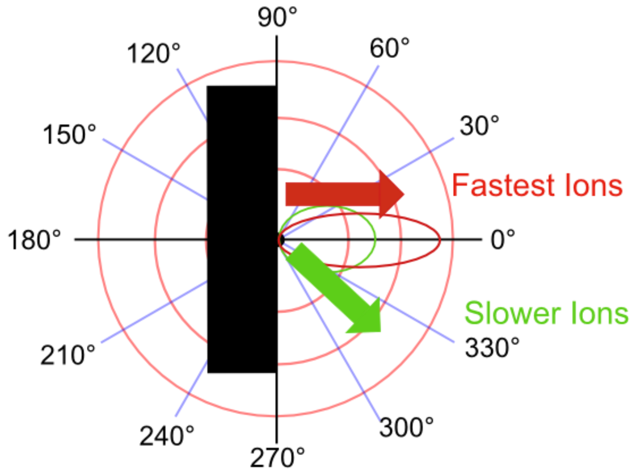


Images of the seed plasmas and stagnation layer in the 400–600 nm wavelength range for A) no reheating with the CO_2 laser and B) reheating at a time delay of 50 ns. The color scales in each image are the same.

Ion Behaviour:



Aodh O'Connor PhD Thesis UCD (2009)

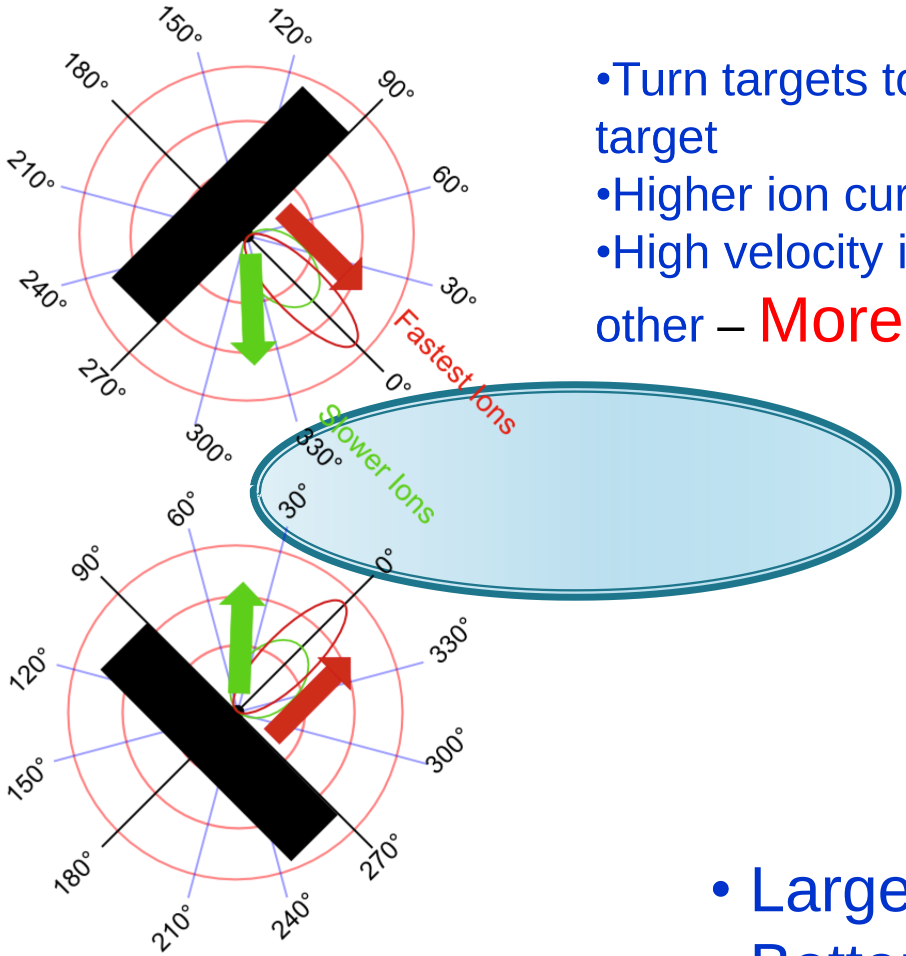


For normal laser incidence

- Highest ion current along *target normal*
- Highest ion KE along *target normal*
- Larger angles – Lower KE

- Stagnation layer results from the interaction between two plumes

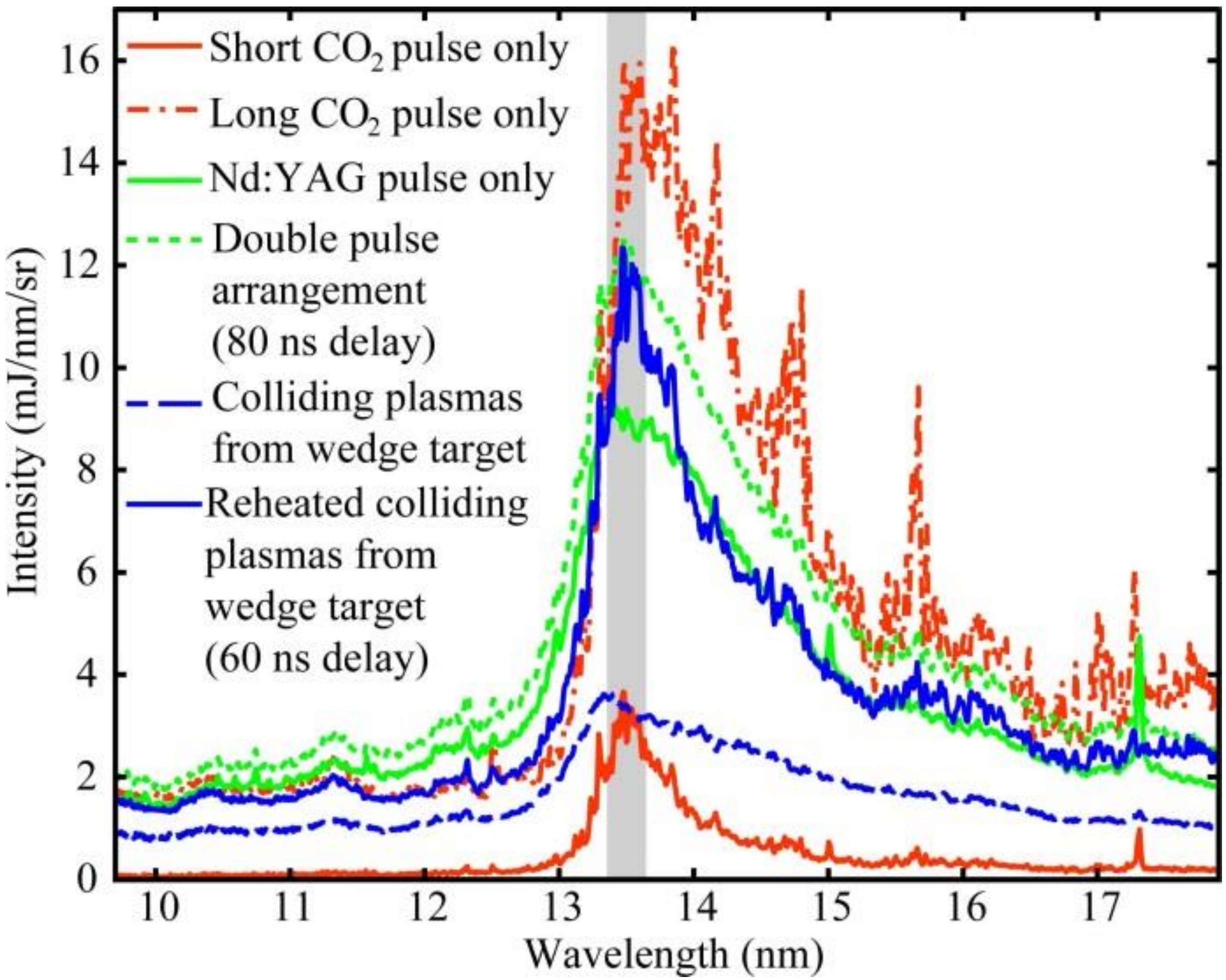
The Wedge Target



- Turn targets towards each other – Wedge target
- Higher ion current towards each other
- High velocity ions are travelling towards each other – More interpenetration

- Larger stagnation layer
- Better matching to CO_2

Comparison of Spectra:

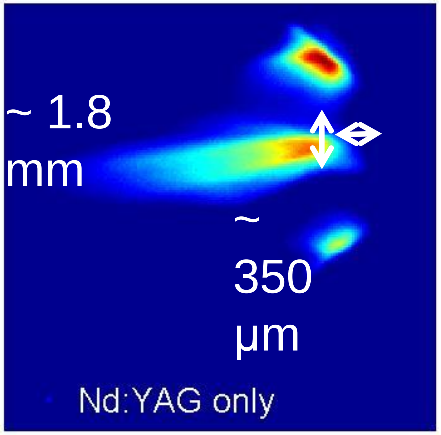


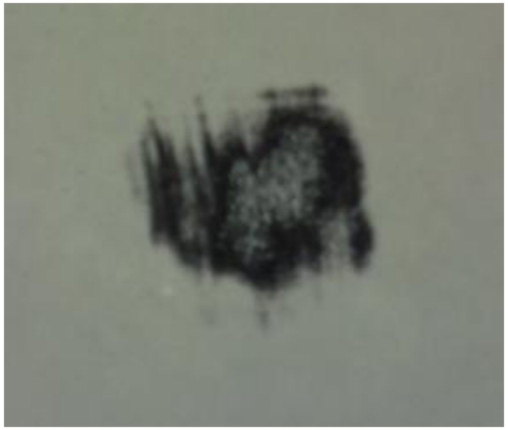
Quantitative results:

Experimental set-up	Total			CO_2 laser		
	Input laser energy (mJ)	In-band energy (mJ)	Conversion efficiency (%)	Input laser energy (mJ)	In-band energy (mJ)	Conversion efficiency (%)
Flat Target						
Long CO_2 pulse	1220.6 (±70)	23.6 (±1.3)	1.9 (±0.2)	1220.6 (±70)	23.6 (±1.3)	1.9 (±0.2)
Short CO_2 pulse	151.7 (±3)	5.0 (±0.2)	3.3 (±0.2)	151.7 (±3)	5.0(±0.2)	3.3 (±0.2)
Nd:YAG pulse only	636.6 (±8)	15.2 (±0.5)	2.4 (±0.1)	0	0	0
Double pulse (80 ns delay)	760.7 (±10)	20.2 (±0.7)	2.7 (±0.1)	124.1 (±2)	5.1 (±0.2)	4.1 (±0.2)
Colliding plasmas from flat target						
Nd:YAG pulse only	491.9 (±8)	11.2 (±0.5)	2.3 (±0.1)	0	0	0
Double pulse (40 ns delay)	627.5 (±17)	13.5 (±0.5)	2.2 (±0.1)	135.6 (±9)	2.4 (±0.5)	1.8 (±0.3)
Colliding plasmas from wedge target						
Nd:YAG pulse only	269.1 (±8)	5.7 (±0.5)	2.1 (±0.2)	0	0	0
Double pulse (60 ns delay)	522.6 (±16)	18.6 (±1.2)	3.6 (±0.2)	253.5 (±8)	13.0 (±0.1)	5.1 (±0.2)

The CE of 5.1% does not include either the energy used to form the seed plasmas or the EUV emitted from them.

CO_2 Laser Spatial Overlap:





The CO_2 beam has a diameter of 520 microns, while the stagnation layer has a 350 microns. Accounting for this factor points to a potential CE of ~ 7%.

Conclusions

- Colliding Plasmas can great the optimum conditions for coupling CO_2 laser radiation into plasmas.
- Grooved targets allow for improved stagnation layer
- Potentially high CE values obtainable
- Much parameter space remains to be probed.

Acknowledgements

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Thank You