Laser Propulsion and Ablation Profiles of Impurity Granules in NSTX-U

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Introduction and Main Goals

Impurity granules are effective at suppressing edge-localized modes (ELMs) in fusion devices like NSTX-U. Current techniques for granule injection have a limited range for granule velocity. Laser propulsion of impurity granules has the potential to provide greater control over injection velocity, which in turn provides control over the ablation profile of granules entering the confined plasma region. Models for propulsion and ablation were developed to aid the design of a laser injection device.

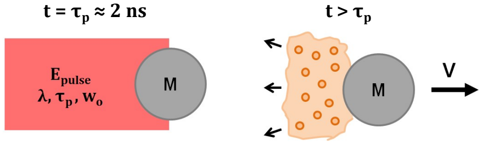

Fig. 1: Laser propulsion for a nanosecond pulse.

Method for Laser Injection

Modeling laser propulsion for micron-sized granules provides insight into the laser parameters required for an injection device. Pulse energies upwards of 500 mJ are required for large injection velocities. A laser wavelength of 532 nm and a pulse length of 2 ns are recommended.

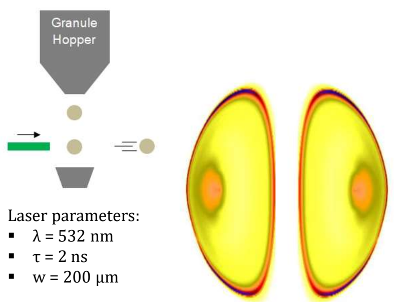

Fig. 2: Schematic of granule laser-injection device.

References

[1] C. R. Phipps et al. *J. of Applied Physics*. 1988, 64 (3), 1083.
[2] P. B. Parks et al. *Nucl. Fusion*. 1988, 28 (3), 477.

Laser Propulsion of Lithium Granules

$$V = \frac{B(\lambda, w)R}{\tau}\left[\frac{I\tau^3 - I_{min}\tau^3}{M}\right]^{\alpha}$$

Eqn. 1: Power law for injection velocity.

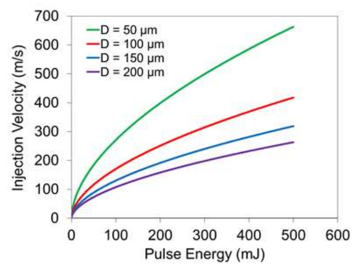

Fig. 3: Injection velocities for Li granules of various size.

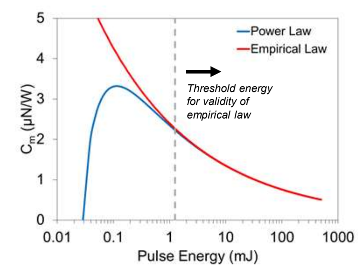

Fig. 4: Impulse coupling as predicted by power and empirical scaling laws [1].

Granule Ablation in NSTX-U

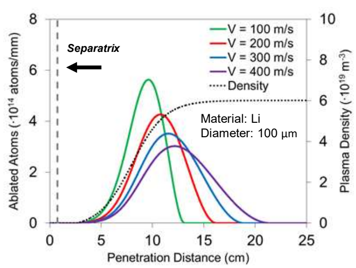

Fig. 5: Broadening of ablation profile for increased injection velocity.

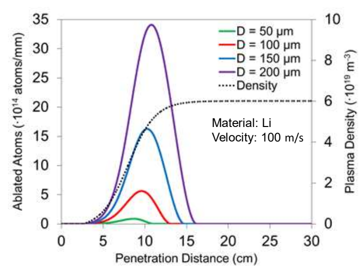

Fig. 6: Ablation profiles for granules of various size.

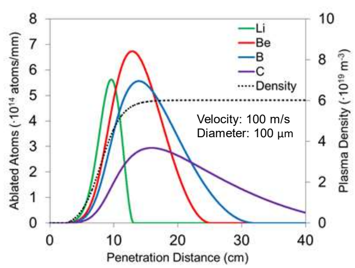

Fig. 7: Ablation profiles for common low-Z impurity granules.

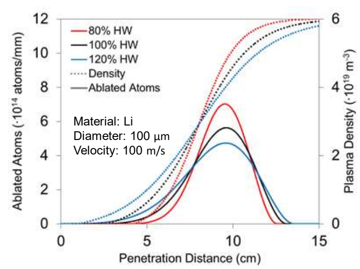

Fig. 8: Impact of pedestal half-width (HW) on ablation.

Relevant Terms and Definitions

- I ≡ peak intensity [W/m^2]
- E ≡ pulse energy [J]
- τ ≡ pulse length [s]
- w ≡ spot size [m]
- M, V, R ≡ granule mass, velocity & radius
- α, B ≡ dimensionless fitting parameters

$$C_m = \frac{MV}{E_{pulse}}$$

Impulse coupling coefficient

Pedestal Half-Width and Granule Ablation

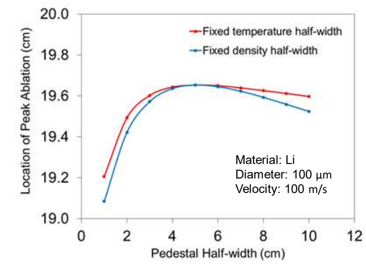

Fig. 9: Location of maximum ablation for different temperature or density pedestal half-widths.

Key Results

- Laser propulsion can achieve injection velocities as large as 250 to 660 m/s in a true vacuum for granule diameters from 200 to 50 μm.
- The power law equation for injection velocity correctly describes impulse coupling for low laser pulse energies, where traditional empirical laws fail.
- The ablation profiles of lithium granules (100 μm) injected into NSTX-U have profile widths that range from 8 to 17 cm for a density pedestal width of 6.5 cm.

Conclusions and Future Work

Laser injection of impurity granules allows for control over the granule ablation profile, relative to traditional injection methods. The profile width is more difficult to control and tends to increase in size with larger injection velocities. Experimental tests are required to verify the propulsion model [2].

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