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# Influence of pulse duration on $CO_2$ laser produced tin plasma by 1D plasma modeling

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## Introduction

A free 1-D radiation hydrodynamic code MULTI was introduced to simulate the $CO_2$ laser produced Sn plasma. influence of pulse duration, and target density on electron temperature was obtained. The optimal pulse duration is obtained by statistical analysis. It is found that long pulse duration is more availably with EUV emission.

## Theoretical details

The MULTI 1D code [1] combined with hydrodynamics and energy propagation. The hydrodynamics equation was used to describe the motion of plasma. The energy propagation included laser energy deposition, electron heat and radiation transfer. The Lagrangian hydrodynamics equations:

$$\partial_t \rho = -\rho^2 \partial_m v$$

$$\partial_t v = -\partial_m (P_{eq} + P_{vis})$$

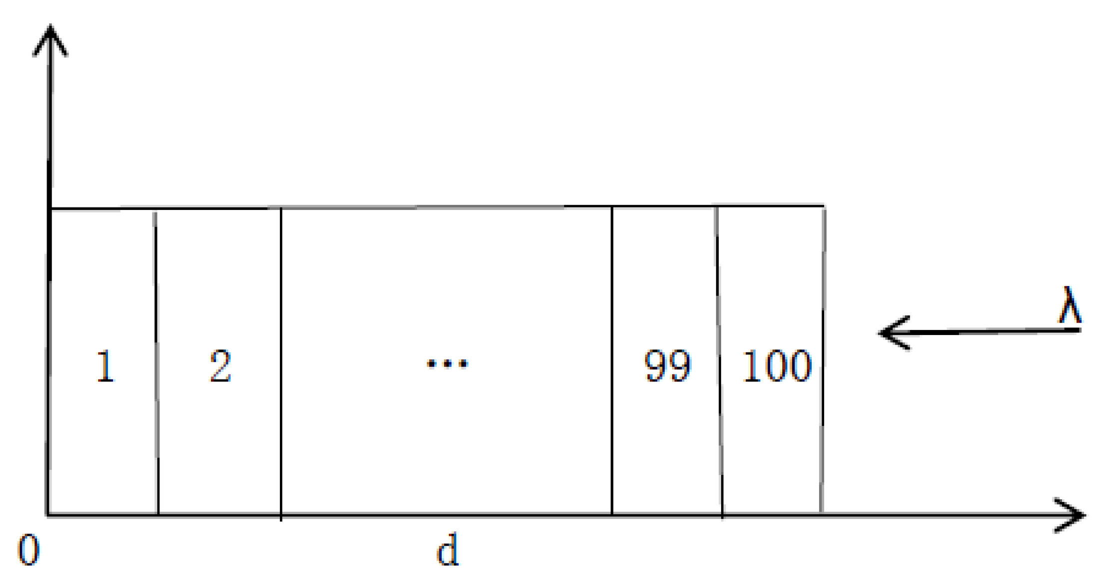
$$\partial_t \varepsilon = -(P_{eq} + P_{vis})\partial_m v - \partial_m q - \frac{Q}{\rho} + \frac{S}{\rho}$$

Laser energy deposition is modelled by inverse bremsstrahlung absorption and a dump at critical density.

$$\partial_x I - \alpha I = 0$$

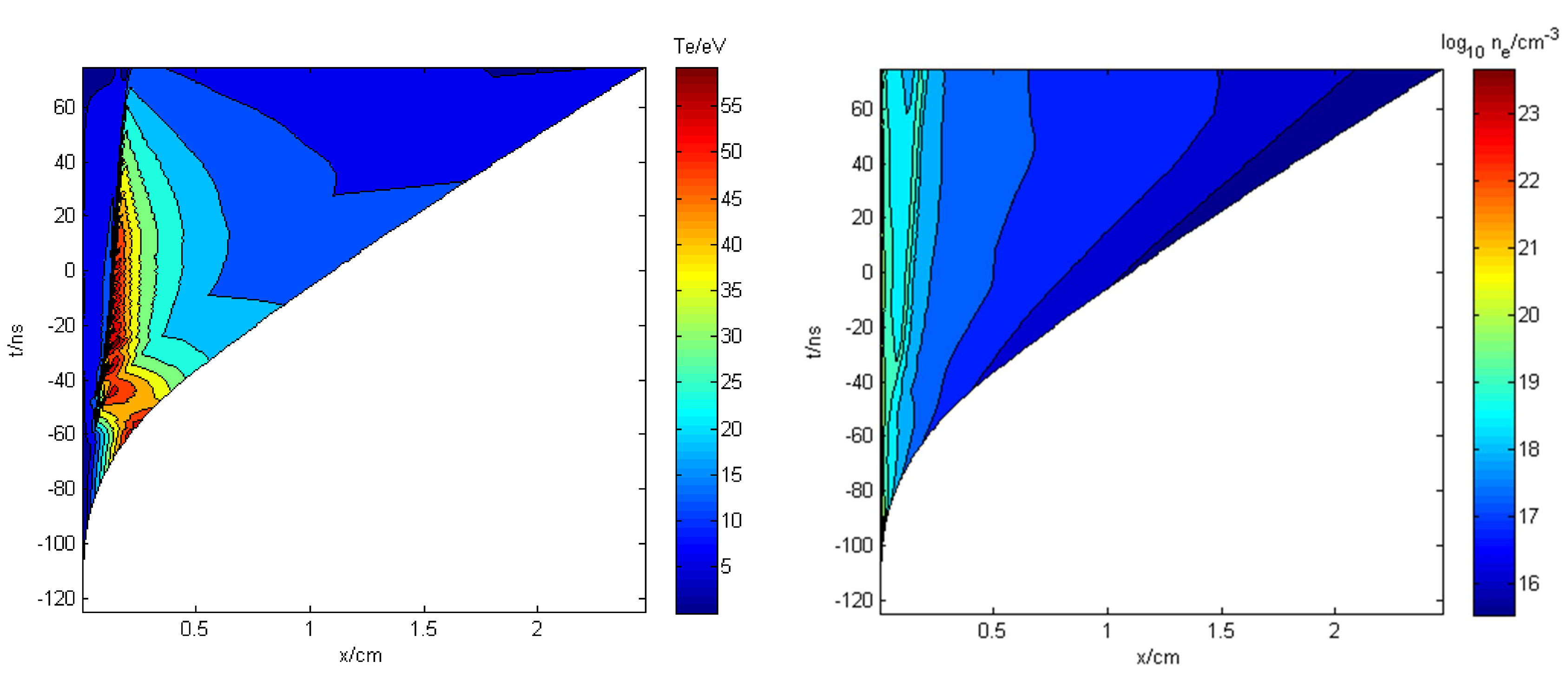
## Model details

The initial state of the Sn target was divided into 100 cells, laser was entered to the target from the right. The left side is rigid boundary, while the right is free boundary. The initial temperature is set to 300 K. The plasma expanded into vacuum.




## Results and discussion

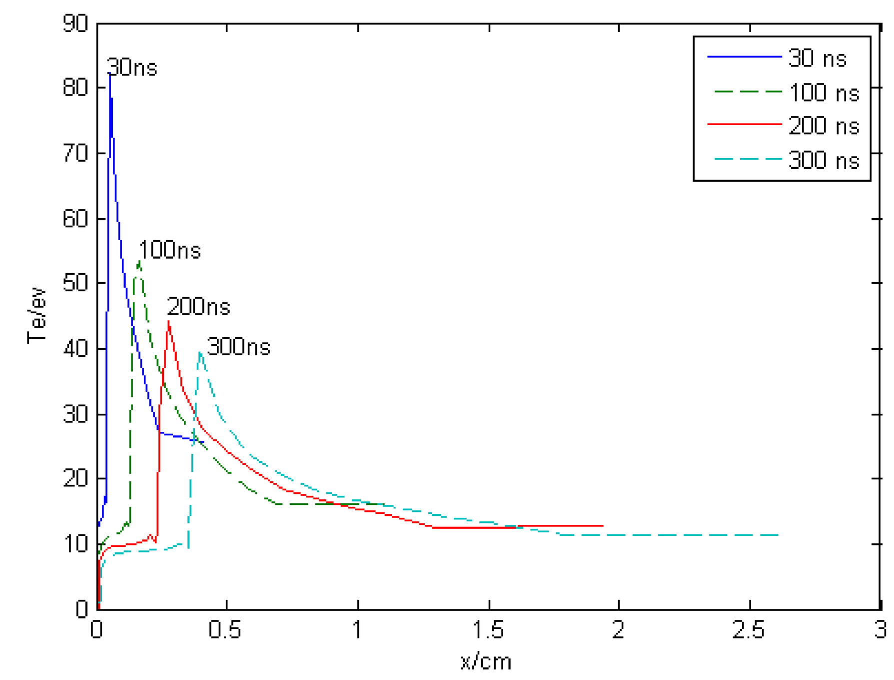
1. The spatial and temporal distribution of electron energy and density of laser produced Sn plasma.




Experimental and theoretically research have shown the optimal plasma Te is about 30 ~ 40 eV, so we pay most attention on the Te, and we statistically analysis the plasma Te at various laser pulse duration and target density.

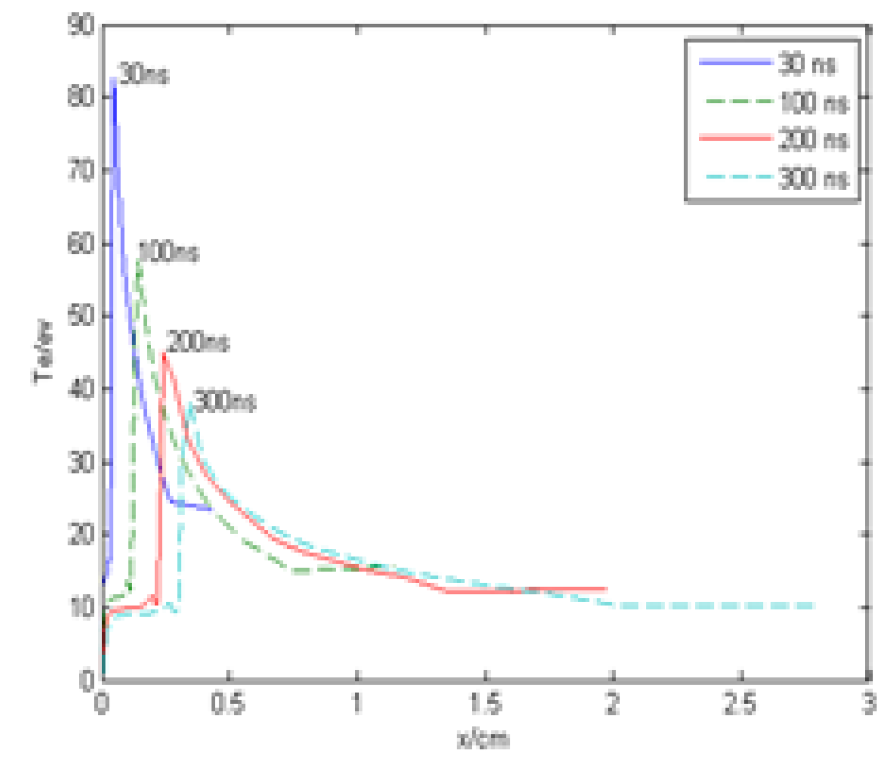
[1] Ramis R, 1988 *Comput. Phys. Commun.* 49 475.

## 2. Pulse duration




Spatial distribution of Te at pulse peak for various laser pulse duration with laser power density of $0.5\times10^{10}$ W/cm$^2$ and normal density target 7.28 g/cm$^3$.

## 3. Reduced target density




Spatial distribution of Te at pulse peak for various laser pulse duration with laser power density of $0.5\times10^{10}$ W/cm$^2$ and lower density target 0.728 g/cm$^3$.

No obvious relation of Te with target density was found.

## 4. Statistical analysis

| Pulse duration (ns) | Target density (g/cm$^3$) | | |
|---|---|---|---|
| | 0.728 | 0.0728 | 0.00728 |
| 30 | 4.7 | 4.4 | 4.8 |
| 100 | 18.7 | 21.6 | 23.8 |
| 200 | 102 | 97 | 94.3 |
| 300 | 185 | 193 | 175 |

The statistical persisted time of plasma Te between 30 ~ 40 eV at power density of $0.5\times10^{10}$ Wcm$^{-2}$.

## Conclusion

A free 1D radiation hydrodynamic code was introduced, we simulated the influence of pulse duration, peak power intensity and initial target density on spatial and temporal evolution of plasm electron temperature and. It is found that long pulse duration , for example, 100~200 ns, is more availably with EUV emission. Therefore, employing a long $CO_2$ pulse could make the EUV lithography system more efficient, simpler, and cheaper.

## Future work

1. 2D simulation will be developed soon;
2. Extension of the simulation to the high-Z elements.

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