

NUMERICAL MODELLING OF NANOSECOND LASER ABLATION AT ATMOSPHERIC SURROUNDINGS: COMPARISON OF HYDRODYNAMICS AND KINETICS APPROACHES



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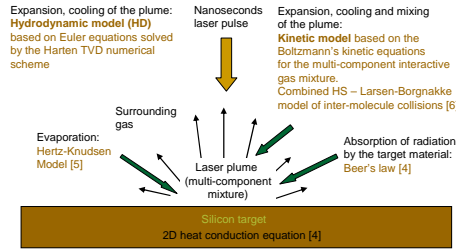
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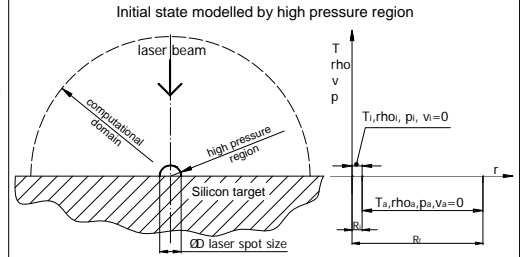
Introduction

- Two basic approaches are used for theoretical study of plume expansion induced by nanosecond laser irradiation, namely the macroscopic (hydrodynamic) (HD) approach [1,2] and the kinetic one [3]. Macroscopic models are used basically to study plume expansion at atmospheric pressure surroundings, where the mean free path of molecules is relatively small, while kinetic models are used in the case of ablation into vacuum or into ambient gas at low pressure. The applicability of macroscopic models is still questionable because of the large number of controversial assumptions which are necessary for real simulations.
- The purpose of this study is to compare computational results obtained in the same conditions with the help of macroscopic and kinetic models and to find when each model is appropriate.
- The macroscopic model is based on the Euler equations for the mixture of vapor and ambient gas which is treated as a perfect gas. Calculations were carried out by the Harten's TVD scheme. For kinetic calculations, the direct simulation Monte Carlo (DSMC) method based on the Bird's NTS scheme is used. Molecules are considered as hard spheres. Internal degrees of freedom of molecules are treated with the help of the Larsen-Borgnakke model.
- Computational results are obtained for two problems. In the first one, the initial state of the ablation plume is modelled by the half-sphere region of vapor with high pressure and temperature. This problem is one-dimensional and studied in detail. In the second problem, the absorption of laser radiation by the flat target and its evaporation is described by the 2D heat conduction equation coupled with the Hertz-Knudsen model.

Mathematical model and numerical algorithm



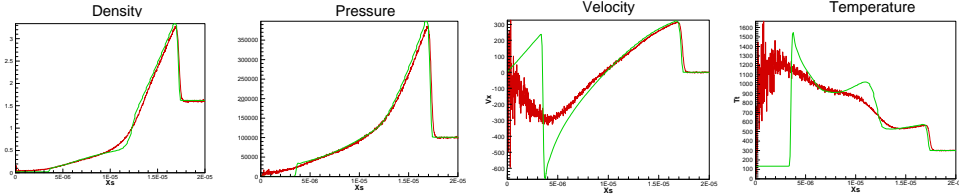
Problem is solved in 1D and 2D axisymmetric geometry
Two approaches for HD calc.:
1st - initial state modelled as a detonation of a high temperature and pressure region and ambient atmosphere,
2nd - initial and boundary condition are modelled with a help of Hertz-Knudsen model.



Initial conditions:
 T_i - temperature of evaporated metal (about 90% value of critical temperature)
 p_s - saturation pressure of silicon for above temperature T_i (Clausius-Clapeyron Equation)
 ρ_a - density of ambient gas calculated for above parameters (T_i and p_s)

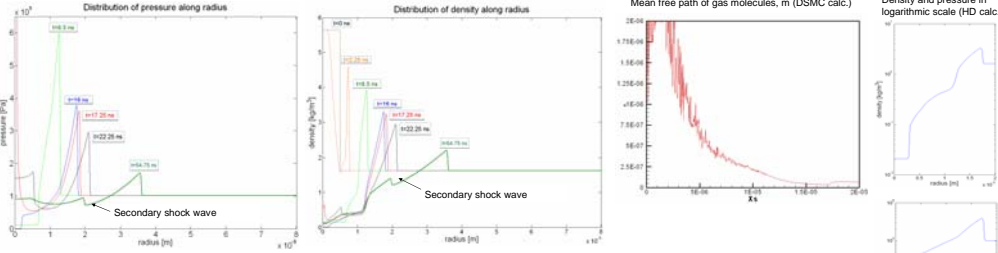
DSMC and HD solutions for the 1D plume expansion problem with spherical symmetry

1 component gas expansion (Argon); Time: 15 ns Red curves: DSMC simulation Green curves: HD simulation



Propagation of secondary shock wave

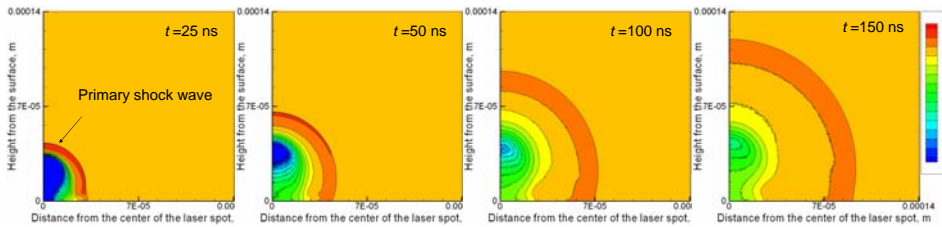
Gas rarefaction in the near-target region



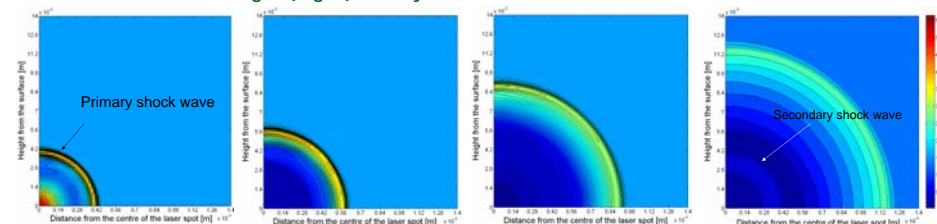
- Primary shock wave calculated by HD and DSMC have the same velocity for one-component case expansion.
- Regions of gas rarefaction in the near target region (where are low density, temperature and pressure) are not applicable for HD calculations. It is confirmed by calculations of mean free path of gas molecules (by DSMC) and Knudsen number, which is much greater than one.
- Presence of implosion and creation of secondary shock wave is observed in HD model simulations,

DSMC and HD solutions for the 2D plume expansion problem with cylindrical symmetry

DSMC solution (for Argon+Silicon) - Ambient gas (argon) concentration



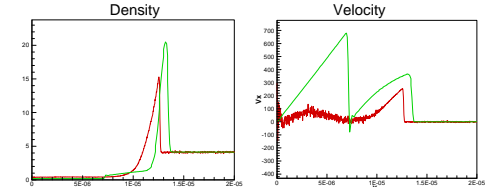
HD solution - Ambient gas (argon) density



- In 2D case, primary shock wave calculated by HD for Argon and DSMC (Argon + Silicon) have similar velocity of expansion.
- Presence of implosion and creation of secondary shock wave is also observed in 2D HD simulation
- Beginning of the macroscopic HD simulation differs from DSMC in the centre of expansion, due to different initial conditions.

Expansion of Mixtures (silicon+amb. gas)

Ambient gas: HFC Time: 15 ns
Red curves: DSMC for Silicon+HFC
Green curves: HD for HFC



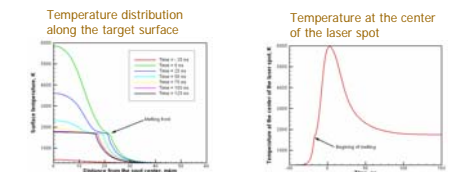
In many cases the consistency HD and DSMC models is dependent on the type of ambient gases used in the simulations.

In order to improve HD results, the boundary conditions have to be modelled in more realistic way (Hertz Knudsen model of evaporation).

HD models should be also improved by the multi fluid case.

Temperature of the target surface

Hertz Knudsen model have to be coupled with heat conduction equation.



Next stage of research will be introduction of improved boundary conditions

Conclusion

- Simulations of primary shock wave for one component fluid give the same results both macroscopic and kinetic models
- It was found that local, near-target region of rarefied flow is not applicable for macroscopic calculations.
- Presence of clear implosion and secondary shock wave was observed in HD model simulation for both 1D spherical and 2D cylindrical symmetry.
- In case of mixture plume expansion (silicon + ambient gas) Macroscopic model should be improved by boundary condition described by Hertz-Knudsen model and in the next stage by multi-component Hydrodynamic description.

Acknowledgments

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