
LSD前方での電子生成の ガス種依存性のCFD調査 (予定含む)

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第3回「高エネルギー電磁ビームに誘起される放電とその工学的応用」研究会
／ 第5回マイクロ波ロケット研究会

目的

LSDを維持するための電子生成機構の解明

1. 方法

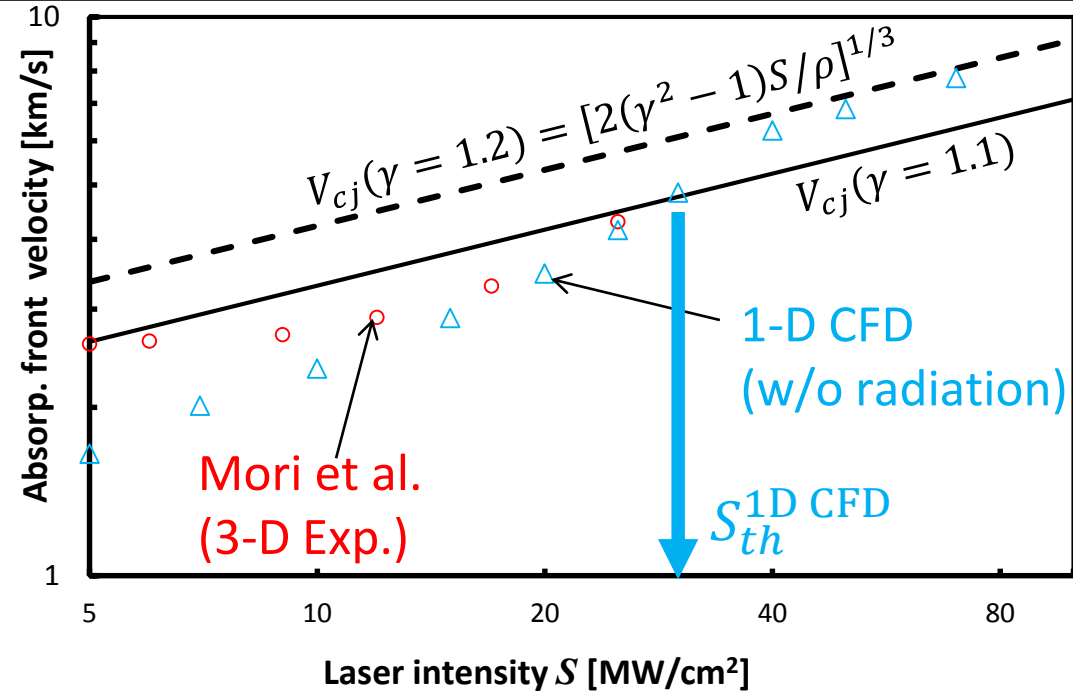
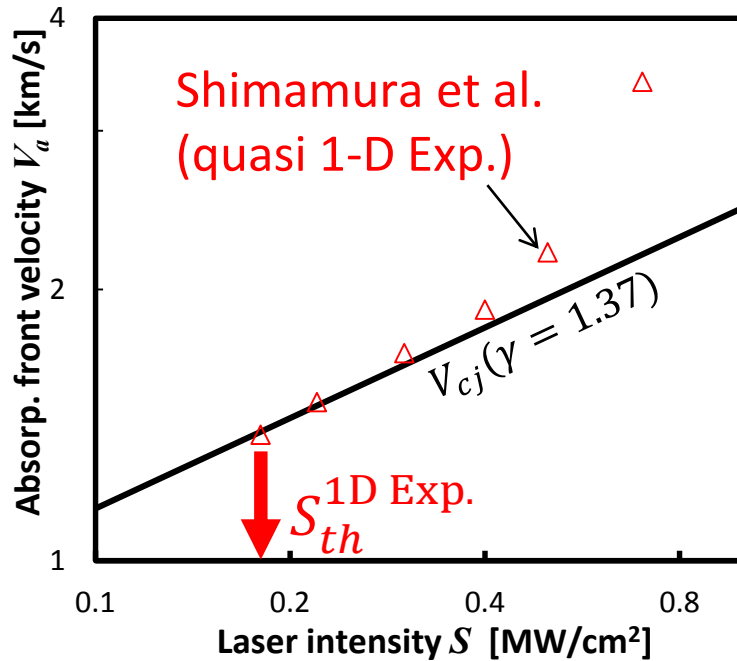
- 1次元の流体計算 (CFD)
 - 多温度熱化学非平衡
- 先行輻射電子生成
 - レーザー吸収帯を輻射平衡と仮定し、吸収帯前面からプランク放射

2. これまでの研究の紹介

- 空気のLSD

3. ガス種依存性の調査の進捗紹介

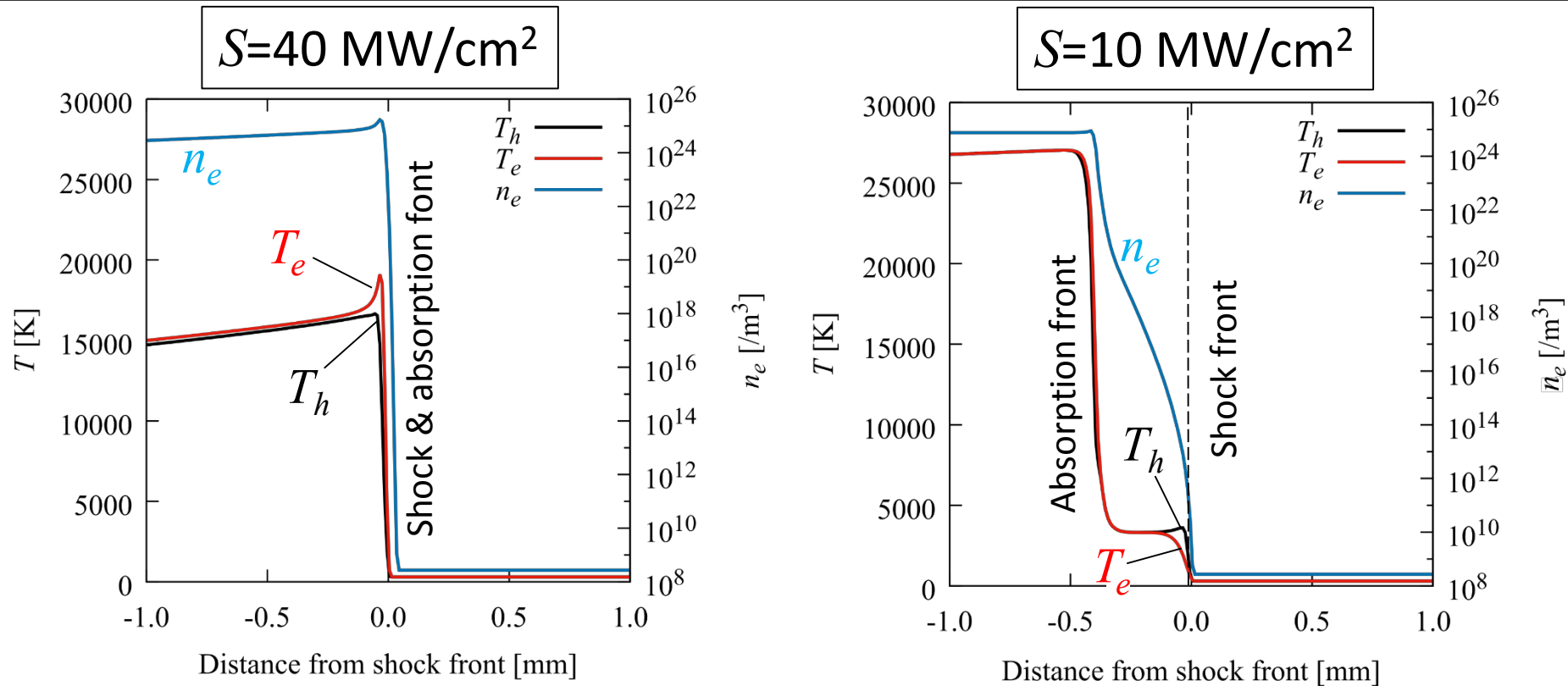
- アルゴンのLSD
- ヘリウムのLSD (取組中)・酸素のLSD (予定)



- C-J velocity V_{cj} is the theoretical detonation velocity.
 - LSD is not maintainable when the laser absorption front velocity V_a is smaller than V_{cj} .
- Measured V_a agree with V_{cj} in $S > 0.2 \text{ MW/cm}^2 = S_{th}^{1D \text{ Exp.}}$.
- Computed V_a becomes slower than V_{cj} in $S < 30 \text{ MW/cm}^2 = S_{th}^{1D \text{ CFD}}$.

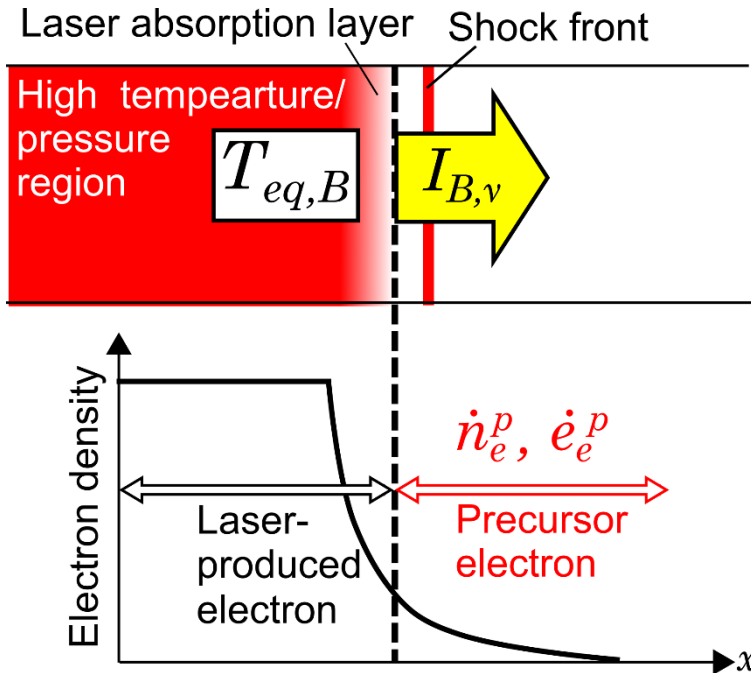
The CFD w/o radiation cannot reproduce the experimental S_{th} .

LSD Structure in CFD w/o Radiation



- In $S=40 \text{ MW/cm}^2$ (Complete LSD)
 - Laser absorption front touches the shock front.
 - LSD is maintainable because the two waves propagate together.
- In $S=10 \text{ MW/cm}^2$ (Incomplete LSD)
 - Absorption front is away from the shock front
 - LSD is not maintainable because the distance becomes large with time.

Simple Black Body Emitter Model



- Laser absorption front can be assumed to be a black body emitter of $T_{eq, B}$.
- Precursor electrons are produced by integrating the radiative transfer from the laser absorption front.

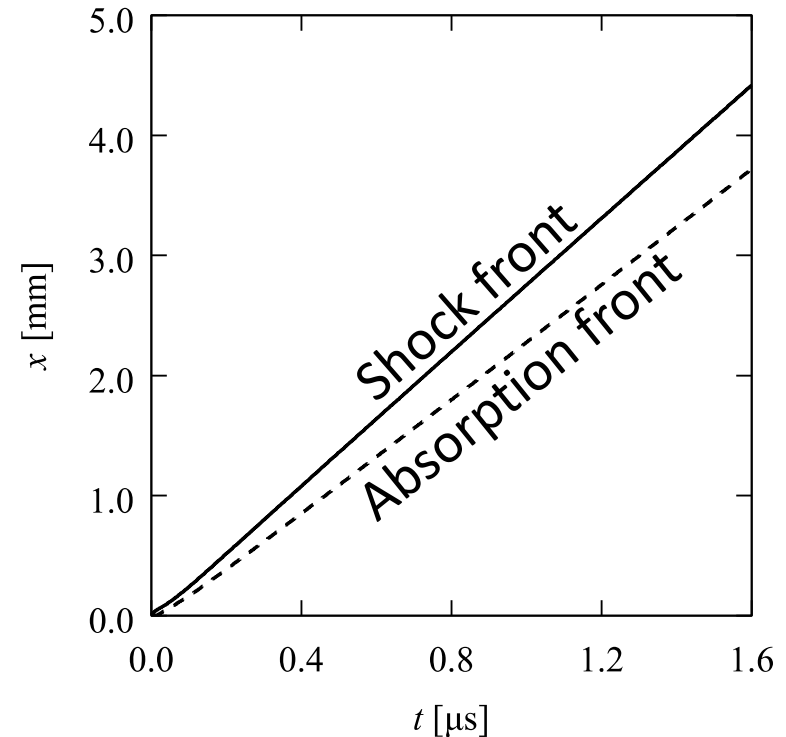
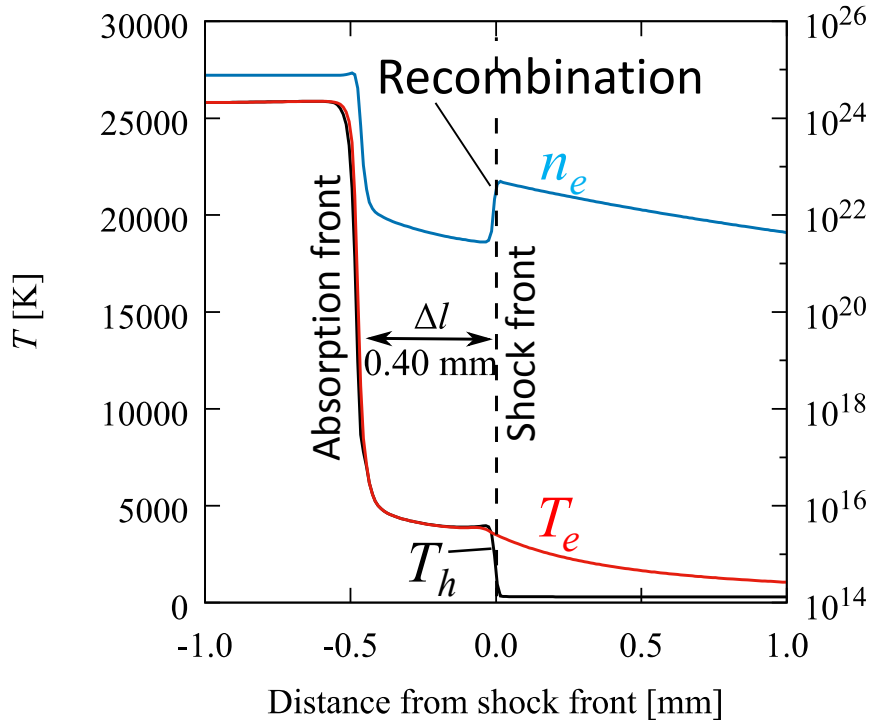
$$\frac{dI_{s,\nu}}{dl} = -\kappa_{s,\nu}I_{s,\nu} \text{ from } I_{s,\nu} = I_{B,\nu}$$

($\kappa_{s,\nu}$: photoionization absorption coef. of neutral s species at freq. ν)

At a distance l from the laser absorption front

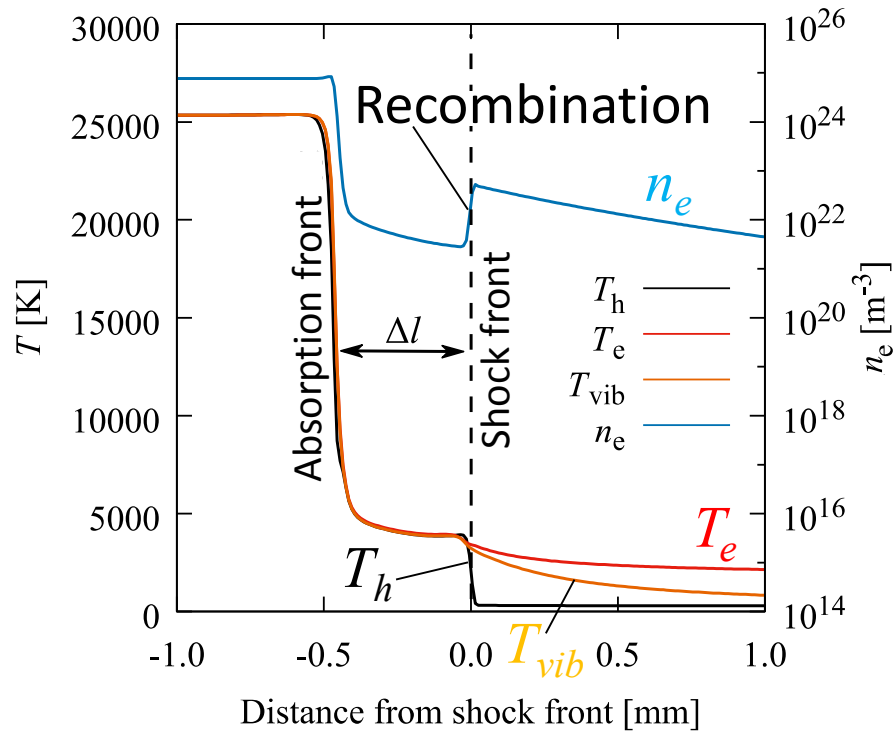
- **Precursor electron production rate:**
 - $\dot{n}_e^p = \sum_s \iint_{\nu_{s,i}}^{\infty} \kappa_{s,\nu} I_{s,\nu} d\nu dl$, ($\nu_{s,i}$: ionization freq. of s species)
- **Radiative electron heating rate** (Fujita et al. AIAA 2001-2765):
 - $\dot{e}_e^p = \sum_s k_B \dot{n}_{e,s}^p T_{p,s}$, ($T_{p,s} = \frac{1+4\gamma_s+6\gamma_s^2}{1+2\gamma_s+2\gamma_s^2} T_{eq,B}$, $\gamma_s = k_B T_{eq,B} / h\nu_{s,i}$)

Impact of Radiation on LSD

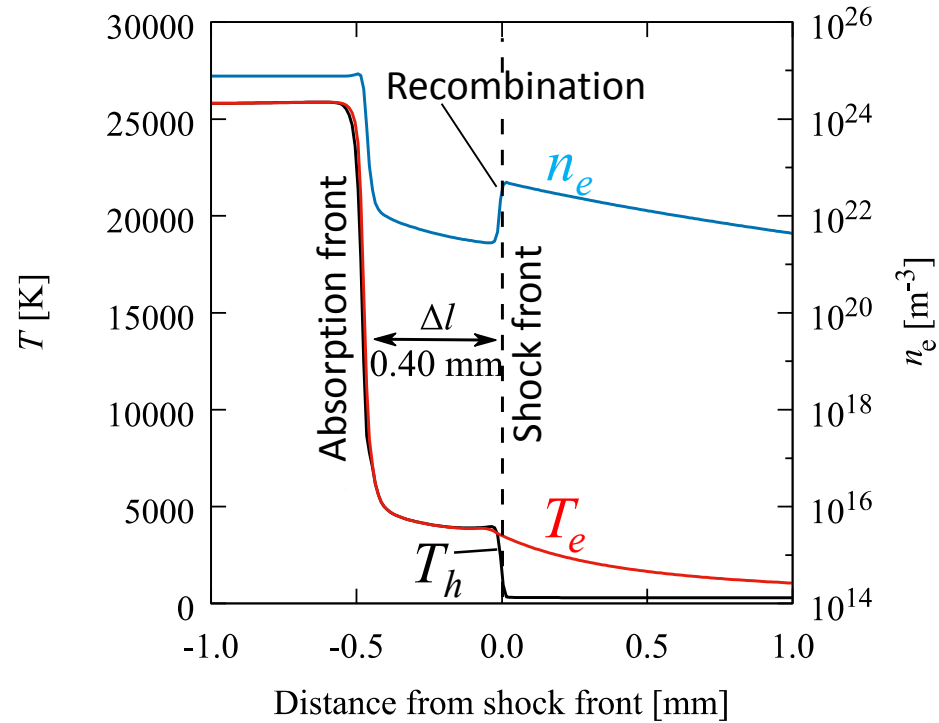


- Radiation produces a lot of electrons in the precursor region.
 - $n_e = 10^{23}$ m⁻³ and $T_e = 3,000$ K at the shock front.
- LSD is still incomplete
 - Absorption front separates from the shock front.
 - Precursor electrons are lost by active recombination behind the shock front.
 - The active recombination may result from an underestimation of T_e (3,000 K) at the shock front.

Comparison between 2 and 3 Temp. Model ^{7/12}



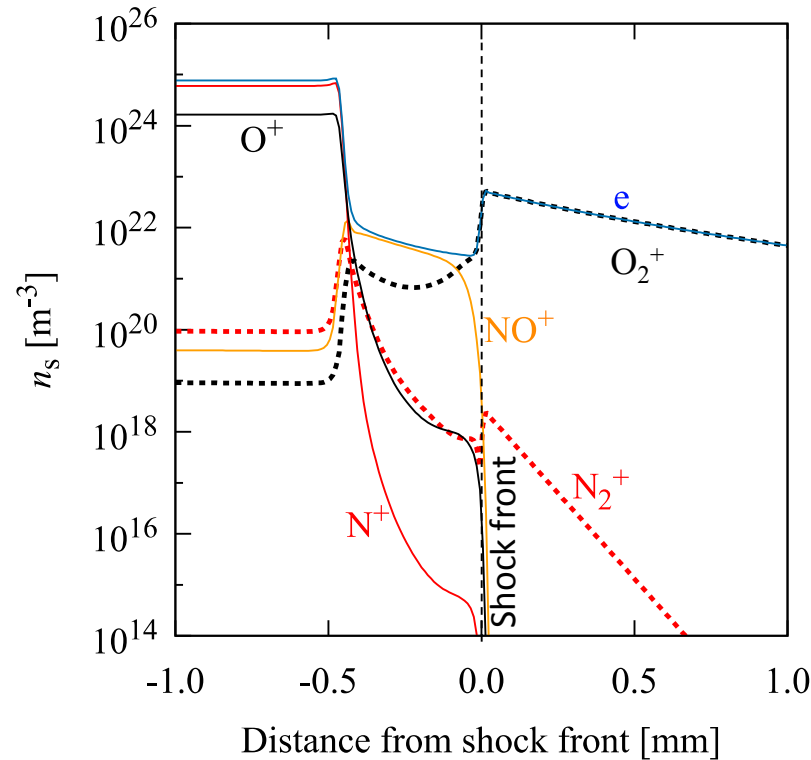
3 temp. model



2 temp. model

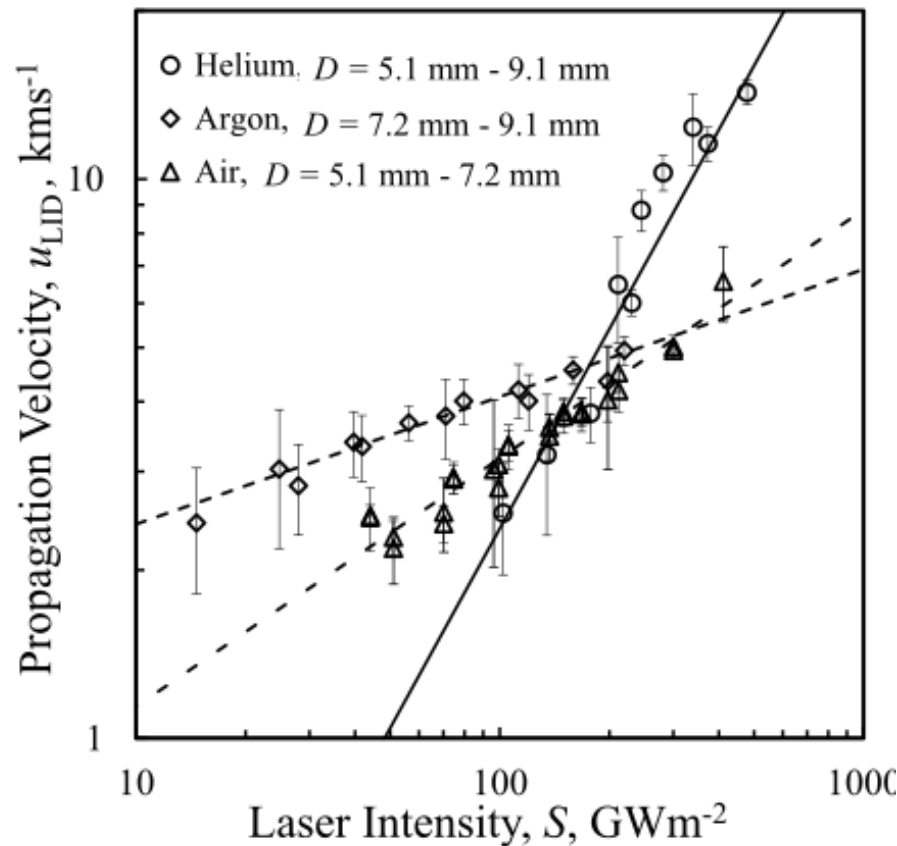
- T_e of 3. temp model in the precursor region becomes larger than that of 2 temp. model.
- The increase of T_e is only 1,000-2,000 K
- n_e distribution and its recombination behind the shock front remain unchanged.
- **LSD is still incomplete: the present CFD cannot reproduce the LSD threshold.**

先行領域の電子生成源



Densities of ion species and electron
(computation with radiation)

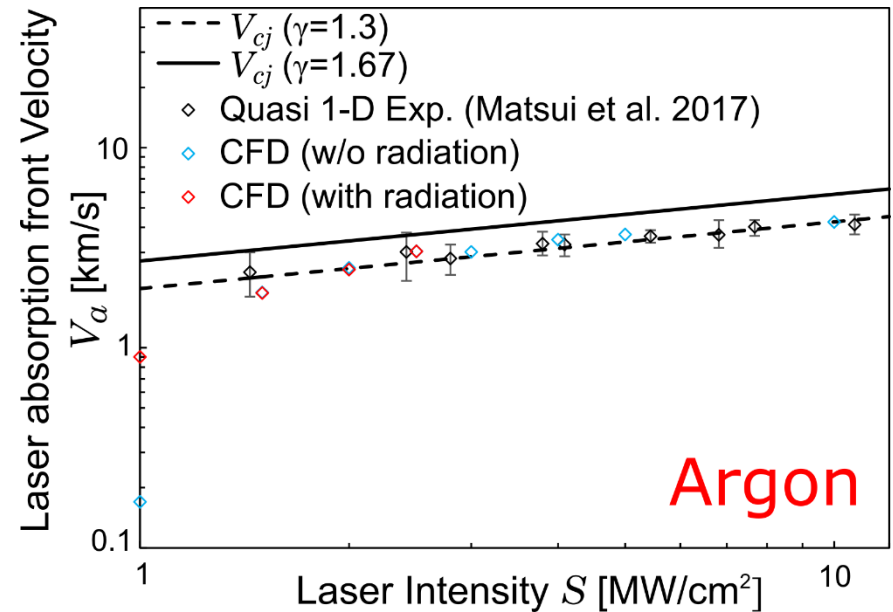
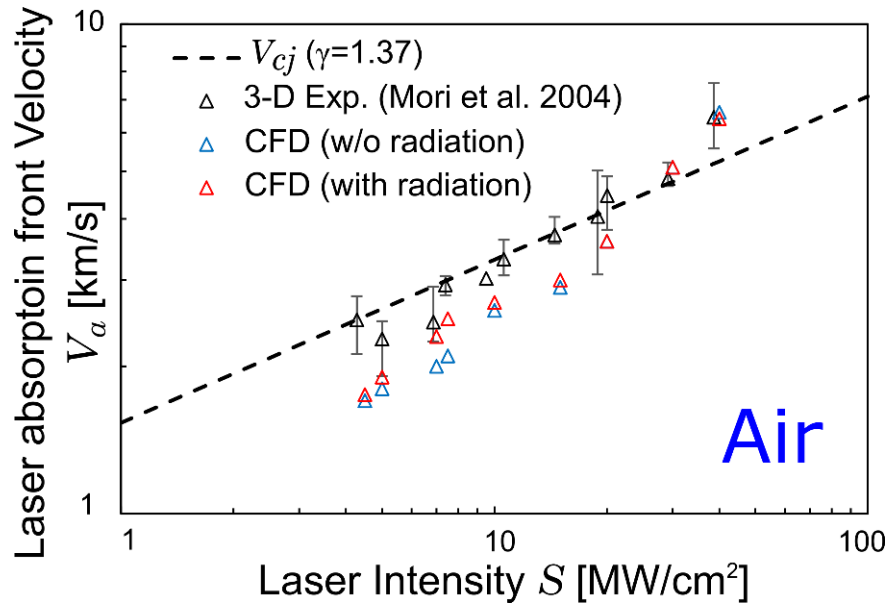
- 先行電子の生成源は酸素分子
- 化学種により先行輻射の電子生成は違う
 - LSD閾値のガス依存性は大きいかも



Shimano et al. Trans. JSASS 2017

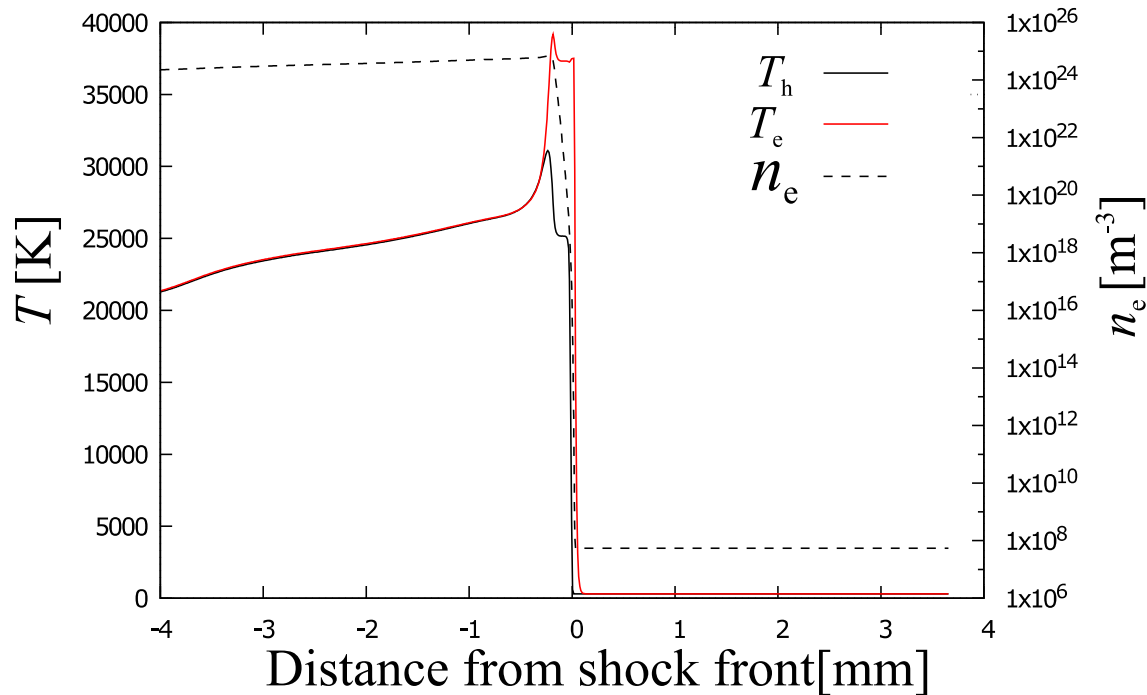
- このグラフには載っていないが、純窒素・純酸素の場合は、空気とほぼ同じだったはず

AirとArgonの計算



- 空気: CFDの $V_a < \text{実験の } V_a \text{ と } V_{cj}$ (特にLSD閾値付近で)
- アルゴン: CFDと実験値の V_a は V_{cj} とよく合う
- 今後の予定
 - ガス種で傾きに違いがでる理由を詳しく調べる
 - AirではLSD閾値付近がCFDで再現出来ない理由

他のガス種について(取組中)



輻射なしHe LSD (まだ怪しいが)

- He (取組中) や O₂ (予定) の LSD を調べる予定

まとめ

- 1Dの流体CFD＋簡単な輻射モデルで、LSD速度 V_a のレーザー強度 S の依存性を調べた
 - 空気
 - S が小さい時は、CFDの V_a は実験値より小さい
 - S が大きい時は、CFDと実験値の V_a は一致する
 - アルゴン
 - CFDと実験値の V_a は一致する
 - ヘリウム、純酸素、純窒素 → 取組中
- 今後
 - データを解析し、メカニズムの解明