Temporal modification of laser source term in TTM calculations

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1. Introduction

In simulating femtosecond laser pulses, we always represent the pulse shape to be a Gaussian function [1], be it spatial or temporal. While this assumption is valid spatially and supported by many studies, the other forms of temporal shape has not given much concern. Because femtosecond laser pulses find applications in many different fields, accurate depiction of its nature is important, especially when modelling different laser-matter interactions.

In this study, we examine the effect of different temporal profiles of a single-shot femtosecond laser pulse in simulating pulsed laser ablation of a metal target using two-temperature model (TTM) simulations on copper.

2. Theoretical framework

Two-temperature model describes the interaction of laser pulses with metallic materials. The evolution of electron, T_e and lattice temperature, T_l after the laser energy is absorbed by the material is described using two coupled heat conduction equations [2]. The laser source is an important parameter in the TTM equation represented by $Q(r,t) = S(r,z)\cdot T(t)$ where $S(r,z)$ describes the spatial part and $T(t)$ describes the temporal part which can have different possible mathematical representation.

Standard functions

There are many different possible mathematical represantation to describe a laser pulse. We used Gaussian (E_G), Lorentzian (E_l), and hyperbolic secant (E_h) [3] as the standard forms.

Temporal pulse shape from experimental data

Given the spectral signal of the laser pulse $F(\omega)$, we can obtain the temporal counterpart, $f(t)$ through its inverse Fourier transform [4]. Since laser pulses are assumed to be Gaussian, we intuitively fit a Gaussian function to the experimental data to get the parameters we want. We can think of the pulse shape as a convolution of different Gaussian functions and each term can easily be inverse Fourier transformed to get the temporal function of the laser pulse.

3. Numerical results

Compared with Gaussian profile, Lorentzian and hyperbolic secant pulses have stronger "wings" and lower peak power implying that Lorentzian and hyperbolic secant laser profiles deliver laser energy at earlier time than Gaussian pulse as shown in Figure 1A, which can affect the heat diffusion in the material. The temporal profile from experimental data (Figure 1B) have a small pulses before (prepulse) and after (postpulse) the main pulse having pulse duration of 96 fs (Figure 1C). We presume the prepulses, in the context of laser ablation, can initially heat the surface of material prior to the arrival of main pulse.

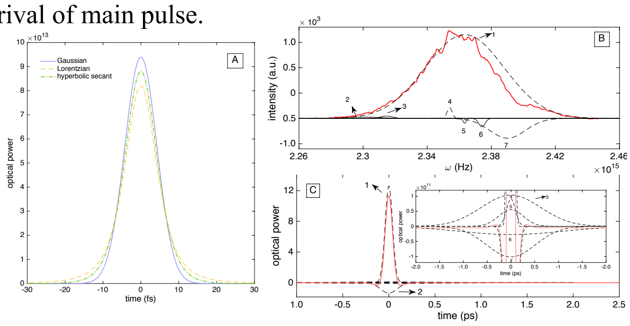

Figure 1. Generated standard temporal profiles all having the same FWHM equal to t_p =10 fs centered at $t = 0$ fs and generated temporal profile (C) from experimental data (B).

Calculation of temporal evolution of T_e and T_l shows no difference in the temperatures achieved between the different temporal profiles as shown in Figure 2A implying that temporal pulse form has no effect in the dynamics of temperature diffusion in the ablation of metals justifying the assumption of a Gaussian temporal profile. A closer look on the maximum electron temperature in Figure 2B shows that the temporal pulse from experimental data achieved a few thousands of temperature higher than the standard pulsed laser forms. With multi-pulsed laser ablation, we might see an appreciable variation in the temperature evolution which will be addressed in our future works [5].

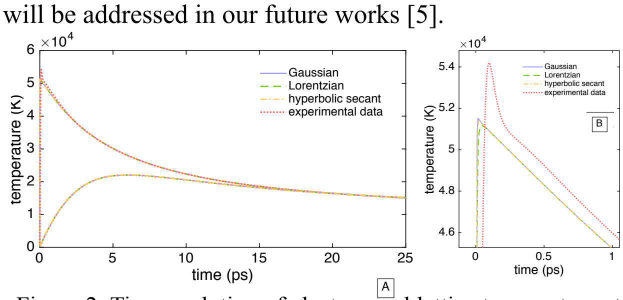

Figure 2. Time evolution of electron and lattice temperature at copper surface. Electron temperature rises drastically while lattice temperature evolves more slowly.

References

[1] Rulliere, C., [Femtosecond laser pulses], Springer Science+ Business Media, Incorporated, 28-32 (2005).
[2] Rethfeld, B., Ivanov, D. S., Garcia, M. E., & Anisimov, S. I., "Modelling ultrafast laser ablation," J. Phys. D 50(19), 193001 (2017).
[3] Diels, J. C., & Rudolph, W., [Ultrashort laser pulse phenomena] Elsevier, 10 (2006).
[4] J. W. Goodman, Introduction to Fourier optics (Roberts and Company Publishers, 2005).
[5] Sagisi, J., Garcia, W., Dasallas, L. *Manuscript in preparation*