Reply to "Comment on 'Model for transmission of ultrastrong laser pulses through thin foil targets'"

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(Received 9 July 1999)

The Comment of Macchi *et al.* [Phys. Rev. E **60**, 6234 (1999)] on our paper [Yu *et al.*, Phys. Rev. E **59**, 3583 (1999)] is considered. It is pointed out that our model was not intended to explain the experiments of Giulietti *et al.* [Phys. Rev. Lett. **79**, 3194 (1997)], as asserted by Macchi *et al.* The physics of the interaction of short-pulse superintense lasers of different polarizations with solid targets is discussed.
[S1063-651X(99)03411-X]

PACS number(s): 52.35.Ra, 52.35.Mw, 52.35.Qz

Macchi *et al.* [1] are correct in that our model and simulation [2] do not apply to the experimental results of Giulietti *et al.* [3]. We were fully aware of this and in fact no claim in this direction was made in our paper [2]. Our model describes a situation (the physical mechanism, angle of incidence, polarization, regimes of the physical parameters, etc.) that differs significantly from that of the experiment [3].

First of all, the physical mechanism in our model and simulation differs from that of the experiment. For circularly polarized light at normal incidence, as is in our analytical model and the simulation in Sec. V [2], the ponderomotive force, which is time independent, pushes back the target electrons. In addition to the electron compression, our model takes into account the relativistically induced transparency of the target. The relativistic effects, which are significant, were not taken into consideration in the simple estimation (second part of the second paragraph) of Macchi *et al.* [1]. In fact, we found that the (effective) skin depth is $\xi_s \sim \sqrt{\gamma/N}$ instead of the usual $\sqrt{1/N}$ ($=c/\omega_{pe}$ normalized by c/ω, where c is the speed of light and ω is the laser frequency). High transmission of laser light becomes possible if $\xi_d - \xi_b \lesssim \xi_s$, where ξ_d and ξ_b are the initial target and the positive layer (or electron displacement) thicknesses, respectively (see also Sec. III, Ref. [2]). For example, from Figs. 4 and 5 [2], we see that in the leading front ($t=0$, $\gamma=1$, and $N=50$), the effective skin depth is $\xi_s = 0.141 > \xi_d$ ($=0.1$, the initial thickness). At $t=10$, where $\gamma=3.162$ and $N=250$, we have $\xi_s = 0.112 \gg \xi_d - \xi_b$ (~ 0.03, the compressed target thickness). Note that such estimates can also explain the transmitted pulse shape, and may be useful in pulse shaping [2]. For near-total transmission this mechanism requires very high ($q\sim 10$) laser strength (see, for example, Fig. 3 of Ref. [2]), which to our knowledge is at present not available. On the other hand, as was also mentioned by Macchi *et al.* [1], high transmission can be achieved by using thinner targets.

For linearly polarized light at *normal* incidence, as in the simulation in our Discussion (Sec. VI) [2], the ponderomotive force consists of a time-independent component as well as a 2ω oscillating component (see [2] and the references therein, especially [27,28]). It turns out the main contribution is from the longitudinal (normal to the target) electron oscillations induced by the latter component. The oscillations can cause a large number of target electrons to be ejected into the front and back vacuum regions, and thus lead to a strong reduction of the electron density in the foil [2]. Therefore, under this mechanism the transmission (for the same initial target thickness) of a linearly polarized light is higher than that of a circular polarized one. Presumably, the simulation in Ref. [1] did include all these effects, leading to the agreement of the simulation results in Refs. [1] and [2] for similar parameter values.

The experiment of Giulietti *et al.* [3], on the other hand, involves the *oblique* incidence of a *linearly p-polarized* light. In this case the target electrons are driven directly by the longitudinal electric-field component of the light, and the resulting very large-amplitude oscillations of the particles can lead to new nonlinear phenomena. It is difficult to model such a complex situation unless the underlying physical mechanisms are better identified, say from specially designed simulations or experiments.

Thus, the polarization and the angle of incidence of the laser are crucial in determining the physics of light transmission. There are several other factors, such as that in the Discussion of Ref. [2] and the comments in Ref. [1], that can enter the interaction of high-intensity short-pulse lasers with solid-density targets. Furthermore, experimentally the laser light is concentrated in a very small region of the target, so that the three-dimensional nature of the plasma dynamics in the interaction region is unavoidable, as lateral movement (clearly important for the present problem) of the target particles can occur. In our simple one-dimensional model these factors are precluded [2]. Thus, any attempt to compare in detail our results with that of Ref. [3] would not be physically meaningful.

Finally, we have indeed left out the factor 2π when mentioning the foil thickness in the Introduction of Ref. [2]. The actual value of the normalized thickness ξ_d $(=0.1)$ used in our simulations was correctly stated at the beginning of Sec. V [2].

This work was supported by the Sonderforschungsbereich 191 Niedertemperatur Plasmen. One of the authors (W.Y.) would like to thank the K. C. Wong Education Foundation, the Deutscher Akademischer Austauschdienst, the National High-Technology Program of China, and the Shanghai Center of Applied Physics for financial support.

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