Plasma as a Fast Optical Switch

"Laser turns otherwise opaque plasma to become transparent"

Los Alamos, New Mexico – Just like an electrical switch allows the flow of electricity into electrical circuits, relativistic transparency in plasma can act like a fast optical switch allowing the flow of light through otherwise opaque plasma. Modern day lasers, such as the Trident laser in Los Alamos National Laboratory delivers 200 terawatt power pulse (roughly 400 times the average electrical consumption of US) in half a Trillionth of a second (picosecond) time. As shown in figure 1, when the laser power reaches a threshold limit, relativistic transparency in plasma turns the initially opaque plasma to become transparent in less than a tenth of a picosecond.

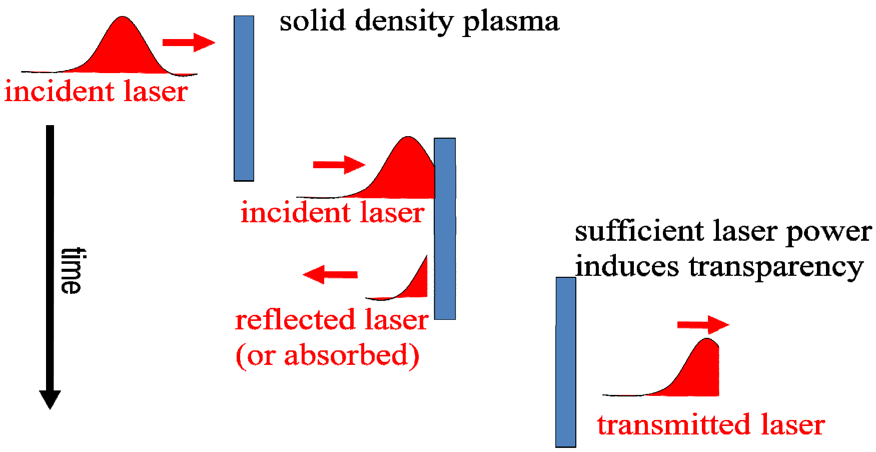

Figure 1: At sufficient laser power, the opaque plasma becomes transparent to the laser light due to relativistic transparency

Powerful lasers are used to drive plasmas into next-generation particle accelerators and x-ray beams. One of the shortcomings with these beams is that they typically have a range of energy spread in them, arising from gradual rise of laser power from zero to maximum as shown in figure 1. Using an optical switch, this ramp up time can be reduced to less than a tenth of a picosecond, enabling the peak of the laser power to be deposited into the plasma at a faster time scale.

So, how does this relativistic transparency happen inside plasma? Normally when a laser is incident on plasma, the electrons inside the plasma react to the laser to cancel its presence inside the plasma. But when the laser is powerful enough to move the electrons close to the speed of light, the mass of the electron increases, making it heavier than normal. These heavier electrons cannot react to the incident light quick enough to cancel the presence of laser inside the plasma; hence the laser beam propagates through the plasma leading to more mono-energetic particle and x-ray beams.

Even though this effect is known to the scientists since 1970, earlier attempts more than a decade ago showed high transmittivity through solid-density-plasmas. Only now the scientists at Los Alamos National Laboratory and their collaborators from Ludwig-Maximilian Universität (LMU) from Germany were able to make a direct observation of relativistic transparency in thin plasmas for the first time using a home built single shot "FROG" device. The discovery was made possible by two key capabilities. The ability to fabricate a few nanometer thick carbon foil to produce thin plasma and eliminating the optical noise preceding the Trident laser pulse on a few picosecond timescale. Initially they observed pulse shortening due to relativistic transparency and consistent spectral broadening. Later, they have also measured the shape of the laser pulses incident on and transmitted through the plasma to directly observe the transparency as shown in figure 2. The transmitted laser pulse is roughly half shorter than the incident laser pulse, with a transparency turn on time around a fifth of a picosecond. Researchers believe that the true turn-on time of this effect is faster than what they could measure currently, due to diffraction effects. Efforts are currently underway to eliminate diffraction limitations to observe the true turn-on time.

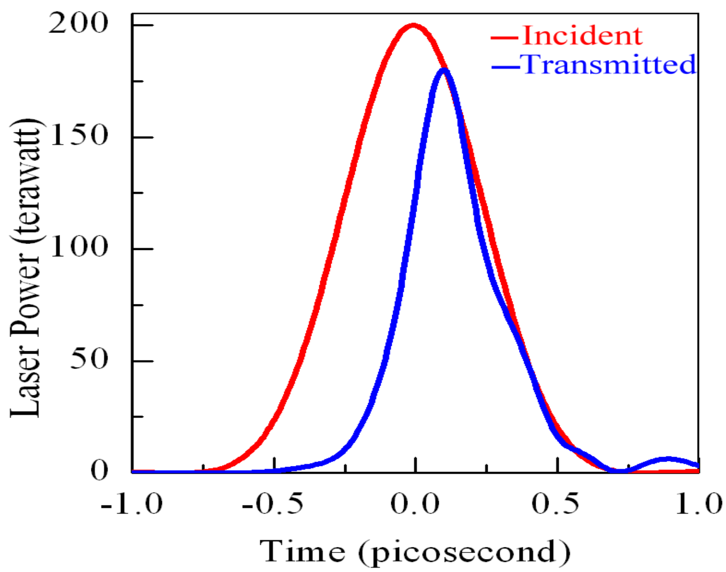

Figure 2: Incident Vs transmitted laser pulse thorough plasma due to relativistic transparency. The sharp turn on time is lost due to diffraction effects.

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Abstract:
XO6.00011 Pulse shortening via Relativistic Transparency of Nanometer Foils
XO6.00012 Laser pulse shaping due to self-induced relativistic transparency in laser-nanofoil interactions
UO5.00004 Fast Ignition with Laser-Driven Ion Beams

Further Information:

J. Fuchs, et al. Transmission through highly overdense plasma slabs with a sub-picosecond relativistic laser pulse. Phys. Rev. Lett. **80**, 2326 (1998)
B. M. Hegelich, et al. Laser acceleration of quasi-monoenergetic Mev ion beams, *Nature* **439**, 441(2006)
R. C. Shah, et al. Pulse shortening via Relativistic Transparency of Nanometer Foils. (In preparation)

S. Palaniyappan, et al. Laser pulse shaping due to self-induced relativistic transparency in laser-nanofoil interactions. (In preparation)