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Plasma as a Fast Optical Switch

Laser uses relativistic effects to turn otherwise opaque plasma transparent, creating an ultra-fast optical switch useful in next-generation particle accelerators

CHICAGO—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 a 200 terawatt power pulse (roughly 400 times the average electrical consumption of the United States) in half a trillionth of a second (picosecond) time. As shown in Fig. 1, when the laser power reaches a threshold limit, relativistic transparency in plasma turns the initially opaque plasma transparent in less than a tenth of a picosecond.

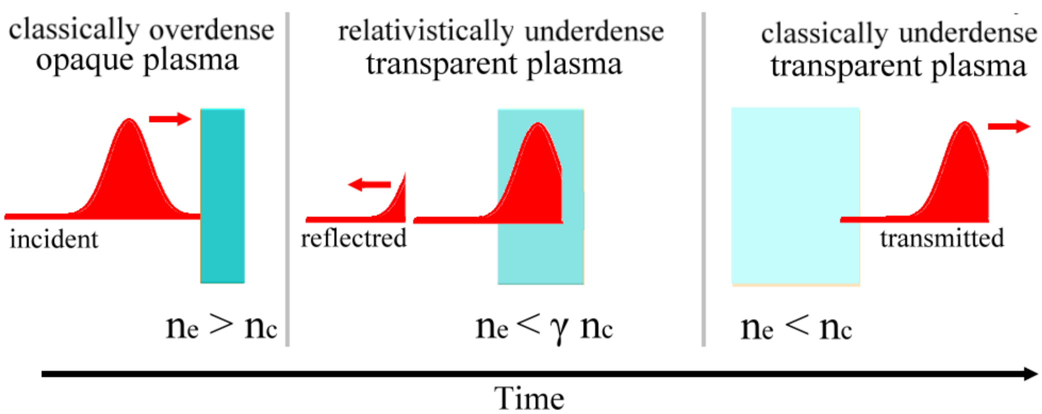

Figure 1: At sufficient laser power, the opaque plasma becomes transparent to the laser light due to relativistic transparency; n_e – electron density, n_c – critical density, and γ – laser relativistic factor.

Powerful lasers are used to drive plasmas in next-generation particle accelerators and x-ray beams. One shortcoming of these beams is that they typically have a range of energy, caused by the gradual rise of laser power from zero to its maximum level, as shown in Fig. 1. Using an optical switch, this ramp up time can be reduced to less than a tenth of a picosecond, delivering peak laser power to the plasma on a faster time scale.

So, how does this relativistic transparency happen inside plasma? When a laser beam is incident on (or strikes) plasma, electrons in the plasma react to the laser to cancel its presence inside the plasma. But when the laser is powerful enough to accelerate electrons close to the speed of light, the mass of the electrons increases, making them "heavier." These heavier electrons cannot react quickly enough; hence the laser beam propagates through the plasma.

Now, for the first time, scientists at Los Alamos National Laboratory and Ludwig-Maximilian Universität (LMU) in Germany have been able to make a direct observation of relativistic transparency in thin plasmas using a Frequency-Resolved Optical Gating (FROG) device. The discovery was made possible by two key capabilities: the ability to fabricate carbon foils a few nanometers thick to produce thin plasma, and the elimination of optical noise preceding the Trident laser pulse on a few picosecond timescale.

Initially, the researchers observed pulse shortening due to relativistic transparency and consistent spectral broadening. Later, they 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 the duration of the incident laser pulse, with a transparency turn on time around a fifth of a picosecond. The experimental results are well consistent with that of computer simulation, except the loss of fast turn-on time due to propagation effects arising from diffraction. Efforts are currently underway to eliminate diffraction limitations to observe the true turn-on time.

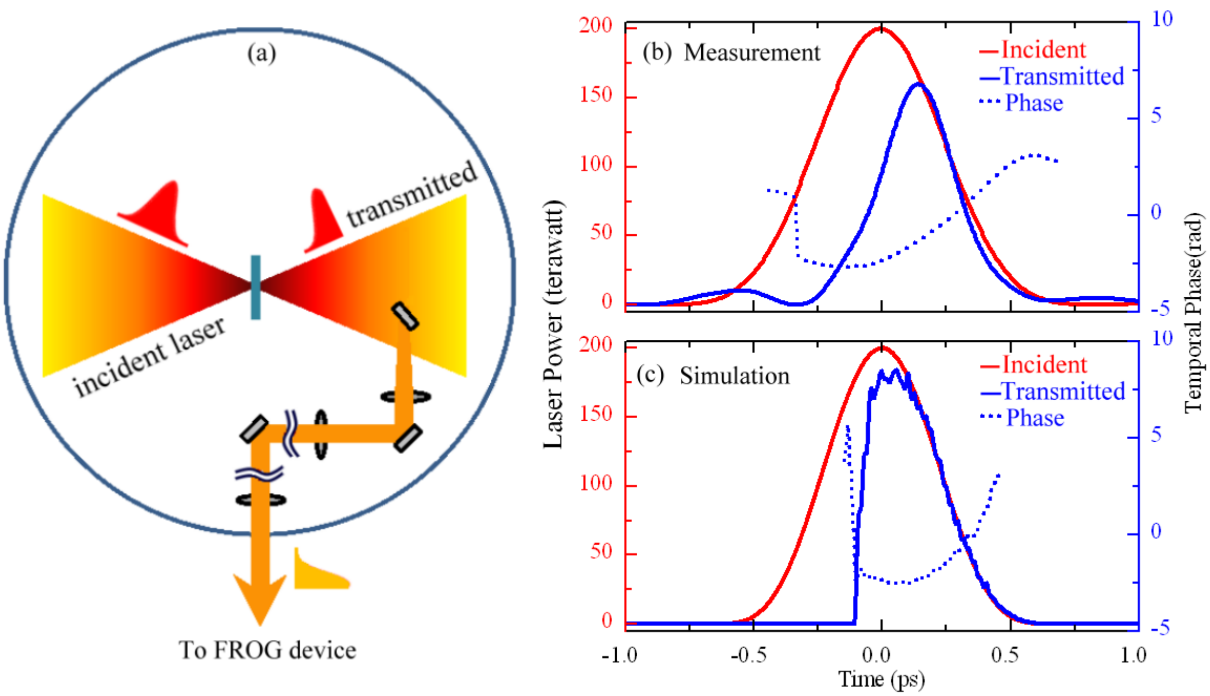

Figure 2: simple schematic of experimental setup (a), Incident Vs transmitted laser pulse thorough plasma due to relativistic transparency, measured (b) and computer simulated (c). The sharp turn on time in measured transmitted pulse is lost due to propagation effects.

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Abstracts:

XO6.00011 **Pulse shortening via Relativistic Transparency of Nanometer Foils**
Session **XO6: Ultraintense Lasers and Particle Generation**, Columbus GH, Friday, November 12, 2010, 11:30AM–11:42AM

XO6.00012 **Laser pulse shaping due to self-induced relativistic transparency in laser-nanofoil interactions**
Session **XO6: Ultraintense Lasers and Particle Generation**, Columbus GH, Friday, November 12, 2010, 11:420AM–11:54AM

UO5.00004 **Fast Ignition with Laser-Driven Ion Beams**
Session **XO6: Ultraintense Lasers and Particle Generation**, Columbus GH, Friday, November 12, 2010, 2:36PM–2:48AM

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)