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Through Metal Vapor: Refractive Intensity Limits
and Spectral Effects**

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**Propagation of Intense, Ultrashort Laser Pulses
Through Metal Vapor: Refractive Intensity Limits
and Spectral Effects**

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Fundamental understanding of high intensity ultrashort laser pulse propagation through media is critical to applications such as harmonic generation and development of recombination type, xuv/x-ray lasers driven by optical field ionization. At relativistic intensities self-induced channeling or waveguiding effects have been predicted for cases of nonionizing or preformed plasma media¹. For many single pulse propagation experiments optical field ionization rapidly forms an ionization front at the leading edge of the pulse envelope traveling at relativistic speeds. It is important to understand formation mechanisms of this front and its effects on propagation of intense laser pulses. Strong field ionization can occur at rates exceeding the laser frequency. Such abrupt alteration of the propagation constant results in significant reduction of transmitted pulse energy on axis and in predominantly 'blue biased' shifts in the incident pulse spectrum².

We have examined these two effects on axis using 140 femtosecond pulses produced by an energetic Ti:S laser system at 800 nm. Incident pulse energies up to 42 mJ were focussed onto an aluminum vapor target representing incident vacuum intensities of 5×10^{17} W/cm². Focussing and collection optics of F/4 were used. Laser-induced ablation of metal films precoated onto glass slides produces high density vapor targets. Ablation pulse energies of duration 10 nsec and 60 - 80 mJ at 1064 nm provided by a Nd:YAG laser were focussed to the 10^9 W/cm² level onto the back surface of the aluminum coating. The 1 mm spotsize sets the propagation depth through the vapor target for the ultrashort Ti:S heater pulse. L_z can be independent of incident laser intensity, well defined and controlled. Typically the vapor plume expands into the vacuum highly directed with an edge velocity near 10^6 cm/sec. By focussing the Ti:S pulse energy about 550 microns above the coated slide surface target densities in the range 10^{19} - 10^{20} cm⁻³ are achieved if the arrival of this heater pulse is delayed by hundreds of nanoseconds relative to the ablation pulse. Independent reduction of the propagation length, L_z facilitates delivery of higher intensity on target.

The fraction of incident heater pulse energy transmitted on axis is plotted in fig.1 for aluminum vapor and laboratory air targets. In all cases transmission is a diminishing function of the incident energy. For the

aluminum vapor the original coating thickness on glass is 1.0 microns and the propagation length is 1.1 mm. The variation of heater pulse delay (relative to the ablation pulse) from 171 nsec to 571 nsec brackets transmission through air. In the 171 nsec case transmission is observed to drop to the 1 percent level for incident energies near 10 mJ and above. For each target type fig. 1 shows a single power fit to the data. Increasing the delay time from 171 nsec to 571 nsec for aluminum vapor increases the exponent from -0.47 to -0.10, with that of laboratory air being -0.17. Most of this energy loss is attributed to ionization induced refraction outside the collection solid angle. Even single ionization of the aluminum can raise the electron density to within less than two orders of magnitude of critical density, $1.8 \times 10^{21} \text{ cm}^{-3}$. With the aluminum vapor (171 nsec delay) an incident energy of 42 mJ results in a transmitted energy of only 0.4 mJ. Diluting the target density (by about 15 times) by increasing the delay to 571 nsec would increase the transmitted energy in this case to about 33 mJ. For a given target type and heater pulse delay the transmission is significantly increased when the propagation length is reduced. Transmission above 60 percent has been observed through similar aluminum vapors (with a small mixture of carbon) and timing using a reduced propagation length of 250 microns.

The transmitted portion of the laser pulse experiences significant spectral alteration. Time integrated transmission spectra were recorded for the same laser shots used in obtaining fig. 1. A portion of the transmitted energy was directed to an EG&G spectrometer containing a 150 groove per millimeter grating. Two dimensional spectral images were recorded showing wavelength variation horizontally and spatial structure vertically. Fig. 2 shows a typical lineout spectrum for 42 mJ energy incident on aluminum vapor with 171 nsec heater pulse delay. Significant structure is apparent across the entire spectrum. Much of this complexity is attributed to multiple optical field ionization. Spectral features are observed for wavelengths as low as 680 nm representing a 15 % effect. Features have been seen at wavelengths as low as 650 nm (19 % effect). We note that the low wavelength spectral limit decreases with increasing incident pulse energy up to about 10 mJ beyond which it appears to saturate near 650 nm. The figures illustrate refractive intensity limiting above 10 mJ incident energy. Field ionization and consequent scattering dynamics determine the level of 'sneakthrough' energy and its spectral content. By contrast with the 571 nsec delay time altered spectral features for all energies studied remain within a wavelength range equal to the incident spectral bandwidth.

This information about control of the transmitted waveform is essential to the design of traveling wave, optical field ionization pumped, recombination xuv/x-ray lasers. We will also extend these examinations of intense ultrashort pulse propagation to preionized vapor targets and to investigations of plasma channeling at relativistic intensities.

Fig.1 Incident energy dependence of on-axis transmission for 140 fsec laser pulse for aluminum vapor (171 and 571 nsec delay) and laboratory air.

Fig. 2 Transmitted spectrum for 42 mJ , 140 fsec laser pulse incident on aluminum vapor (171 nsec delay). Dotted line is incident spectrum.

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