Enhanced Performance for Ultrafast Lasers in Heavy Scattering Medium, Experimental Evidence for Theoretical Predictions

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Abstract: Researchers present data indicating reduced scattering losses for femtosecond lasers, which a previously published theory explains. The theory is used to predict performance with a lab-based fog at several pulsewidths, which experimental data then validates.

In recent years, several research groups have reported ultrafast lasers seeing markedly different losses in various media than classical theory would predict[3,4,5,6]. Researchers at the Stevens Institute of Technology, along with Attochron LLC and the Georgia Institute of Technology, have taken several measurements indicating an advantage of Femtosecond pulses over CW pulses at the same wavelength. A number of pulsed scattering measurements are presented in this study, all of which indicate a power savings. Further testing has shown that the amount of scattered light from the ultrafast laser is less than the amount scattered by a continuous wave beam. (Figure 1)[2]

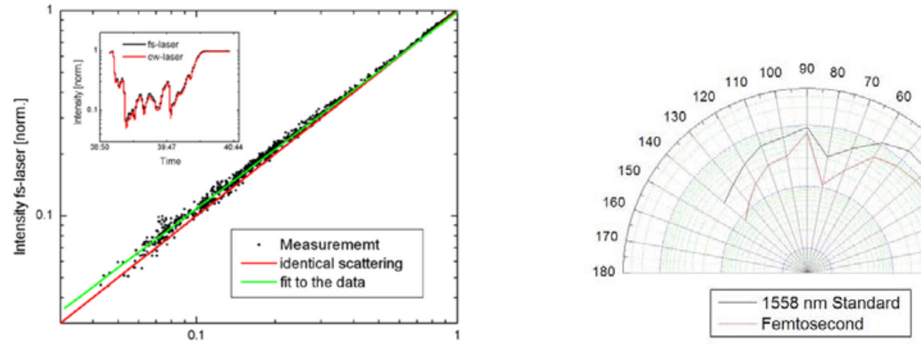
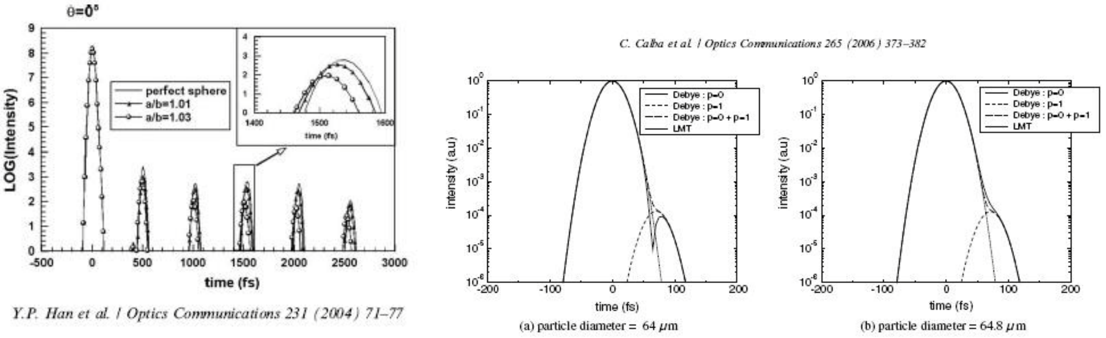


Figure 1. Results of Experiments performed at the Stevens Institute of Technology[2]

In the above images, a commercially available 1558 nm diode laser is compared to a commercially available Femtosecond (fs) laser system (IMRA femtolite B-60), operating at center wavelength of 1560nm with 90fs short pulses. The bandwidth of the femtosecond pulse (the full width at the half-power maximum) covered approximately 10 nm, and encompassed the 1558 nm diode laser used for comparison. Detection was conducted via Lock-In Amplifiers to suppress background effect and to achieve dynamical range of >3 order of magnitudes (estimated ~0.05% error on data in Figure 1).

Given the power gains seemed to come from a decrease in the total energy scattered, the researchers investigated generalized Lorenz-Mie theorems (GLMT) that had been developed (~350 references) to predict scatter from atoms, but found only a handful study the interaction of low-power ultra-short pulses with atmospheric particles.



Y.P. Han et al. / Optics Communications 231 (2004) 71–77

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(a) particle diameter = 64 μm

(b) particle diameter = 64.8 μm

Figure 2. Results of the scattering thoery from the published paper[1]

In short, each mode generated in the light-particle interaction (reflection, refraction, diffraction) may be resolved separately, and each process has a characteristic time corresponding to how long the mode spends in the particle. When the pulse is short enough in time these modes no longer interfere together in space, eliminating destructive losses. This theory has been investigated extensively by a French group who constructed a full time resolved Mie program, the results of which are shown in Figure 2 (for a 50fs pulse and a 40-micron particle).

The solution to each mode may be found using a Debye series[1] and formatting the scattering coefficients as

$$\begin{bmatrix} a_n \\ b_n \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 1 - R^{22}_{n,a} - \sum_{p=1}^{\infty} T^{21}_{n,a}(R^{11}_{n,a})^{p-1}T^{12}_{n,a} \\ 1 - R^{22}_{n,b} - \sum_{p=1}^{\infty} T^{21}_{n,b}(R^{11}_{n,b})^{p-1}T^{12}_{n,b} \end{bmatrix} = \begin{bmatrix} \sum_{p=0}^{\infty} a_n{}^{(p)} \\ \sum_{p=0}^{\infty} b_n{}^{(p)} \end{bmatrix} \qquad \textbf{(1)}$$

Here the particle is medium *1*, *2* is the surrounding medium, R^{22} terms are reflection coefficients from outside (*a*) and inside (*b*) the particle and again T^{21} are the transmission coefficients inside (*a*) and outside (*b*) the particle. The *p*-mode nomenclature follows that of VanderHulst. The scattered fields may then be solved as before. Two major criteria which must be violated in order to observe such behavior are

$$c\Delta t >> d_p \qquad c\Delta t >> \lambda_0 \qquad (2)$$

These correspond to the length of the pulse in space (Δt, pulse duration) traversing the diameter of the particle in space (d_p).

The research team has taken this basic frame work, and recalculated for the conditions used in the actual experiments (a 2 micron particle diameter size, and pulsewidths of 100 fs, 220 fs, and 440 fs). The expected savings are then compared to lab-based measurements (Figure 3). The pulsewidths were measured with a Newport 15-100 GRENOUILLE (built by Swamp Optics). The fog chamber was a 10 m long tube, filled with an artificial water/oil-based fog. The average particle size was 2 microns, based on calculations from several multiwavelength measurements, which all yielded this particle size. This represents the first published confirmation of the theoretical models of Han et al.[1]

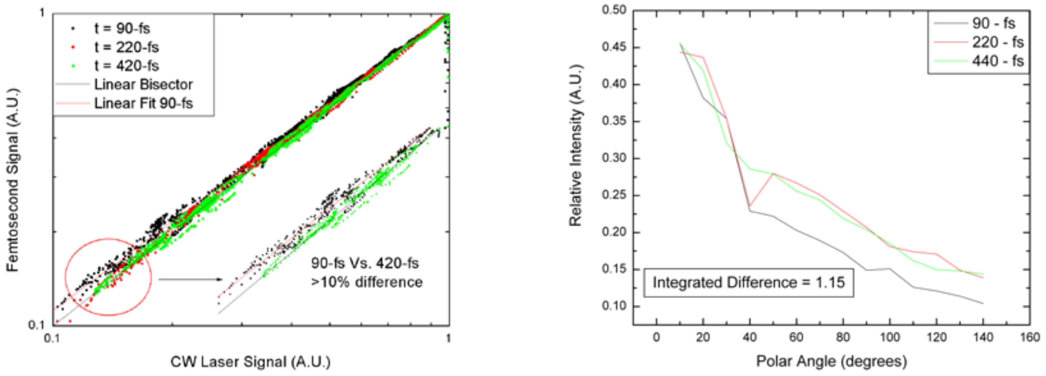

Figure 3. Experimental Results of 100 fs, 220 fs, and 440 fs pulses passing thorugh a fog chamber with particles of 2 microns in diameter.

References

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