The Theory of Temporal Compression of Intense Laser Pulses In a Metal Vapor

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Abstract

We examine compression of near-resonant pulses in metal vapor in the nonlinear regime. Our calculations examine nonlinear effects on compression of optimally-chirped pulses of various fluences. In addition, we compare model predictions with experimental results for compression of 4 nsec Nd:YAG pumped dye pulses.

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We wish to utilize atomic group velocity dispersion to compress energetic copper vapor laser pumped dye laser pulses from 40 nsec to approximately 300 psec. This talk focuses on numerical results which illustrate coherent atomic effects on the process. Traditionally, analysis has been based upon linear dispersion theory (LDT). This model represents the atoms as a static susceptibility. This susceptibility gives rise to the differential group delay required for compression of frequency swept pulses. However, LDT is inadequate in analyzing compression in a regime in which the coherent transition rate (Rabi frequency) is comparable to the laser detuning. Here, population transfer becomes significant, thus invalidating the concept of a steady-state dipole. An adequate representation of the atomic system requires solution of the coupled Maxwell-Bloch equations. We have developed a code to model near-resonant coherent propagation through inhomogeneously-broadened two-level atoms.

We begin by examining nonlinear effects on the compression of 10 nsec gaussian pulses whose frequency chirp identically matches the differential delay curve of the 689 nm $5\ ^1S_0 \rightarrow 5\ ^3P_1$ transition in strontium (oscillator strength = $1.e^{-3}$). The compression point for this system is designed to be at 3000 optical depths. Figure 1 shows the compression of a weak (10^{-5} mj/cm^2), near-resonant (Δ = 3.0 GHz) pulse as it propagates through the medium. The gaussian shape is retained as the pulse narrows to approximately 300 psec at peak compression. Correspondingly, the peak intensity increases by a factor of 30. As we increase fluence, the peak Rabi frequency becomes comparable to the detuning leading to a deviation from LDT. Here, the output pulse begins to acquire spiking in its trailing end corresponding to the absorption and reemission of photons by the atoms as they undergo a complete population oscillation. Further increases in energy lead to additional atom cycling which, in turn, lead to additional structure in the

output pulses (Figure 2). This eventually inhibits the compression process for highly energetic pulses.

As a first step in developing a large scale system for compressing copper vapor laser pumped dye laser pulses, we performed a set of experiments using a smaller Nd:YAG pumped dye laser. One goal of these tests was to verify predictions for the onset and nature of nonlinear effects. Our laser was sinusoidally modulated and the carrier frequency was detuned 3.5 GHz from the stronium transition. The modulation format was 40 radians at a frequency of 24 MHz. We measured a density of $1.1e^{15}$ cm^{-3} and a Doppler width of 1.05 GHz . The pulse propagated 95 cm, which corresponds to approximately 2500 optical depths. Figure 3 shows the measured output pulses for fluences of 0.01, 0.1, 0.22, 0.5 and 3.5 mj/cm2 (bold lines) and the corresponding theoretical calculations (thin lines) . Qualitatively, we see good agreement. The onset of nonlinearities occur at approximately the same energy and additional spiking occurs with increases in fluences in accordance with theory. Defocusing of the high fluence (3.5 mj/cm2) pulse reduces the significance of a comparison to our plane-wave model.

Figure Captions

Figure 1 - Propagation of optimally-chirped, weak pulse through stronium vapor. Peak compression occurs near 1.1 meters, or 3000 optical depths.

Figure 2 - Output pulses (z = 1.1 meters) versus time for various input fluences [10^{-5}, 0.05, 0.10, 0.125, 0.50 and 1.00 mj/cm^2].

Figure 3 - Comparison of measured (thick lines) and predicted (thin) pulse shapes at the output of the cell for various input fluences [a–e) : 0.016, 0.10, 0.22, 0.55 and 3.50 mj/cm^2]

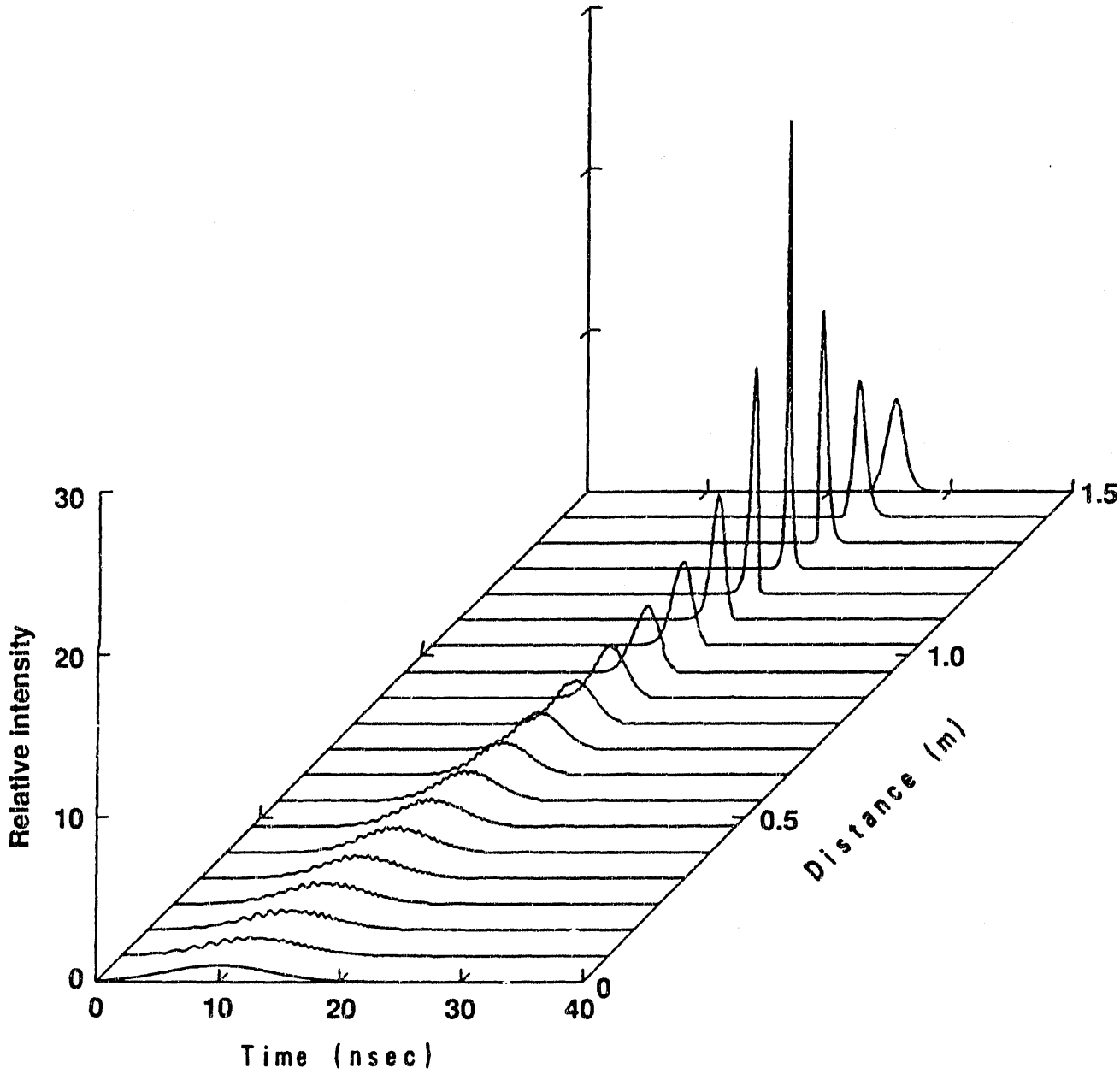
Relative intensity
30
20
10
0
0
10
20
30
40
Time (nsec)
0
0.5
1.0
1.5
Distance (m)

Fig. 1.

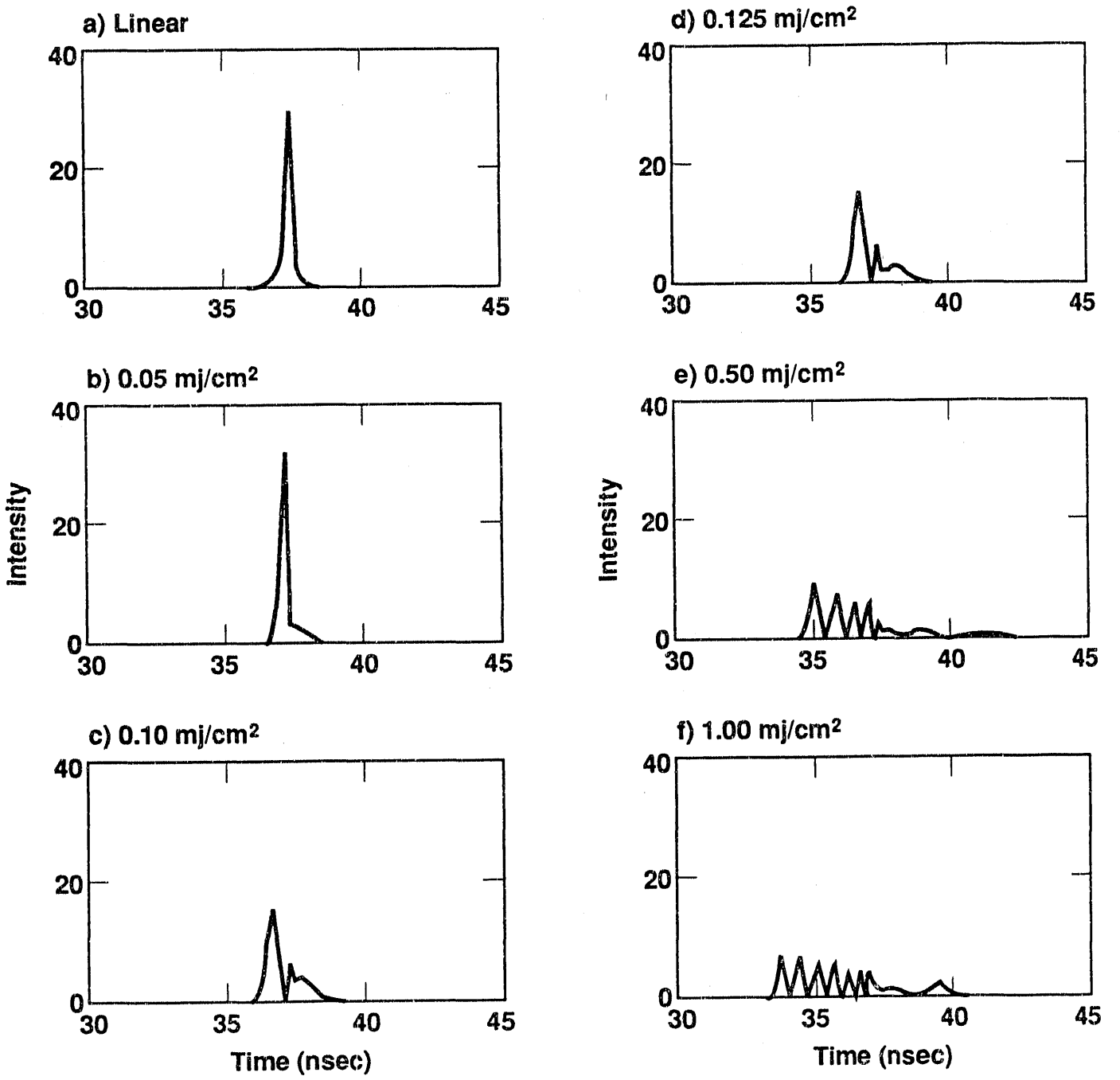
a) Linear
b) 0.05 mj/cm2
c) 0.10 mj/cm2
d) 0.125 mj/cm2
e) 0.50 mj/cm2
f) 1.00 mj/cm2
Intensity
Time (nsec)
0
20
40
30
35
40
45

Fig. 2.

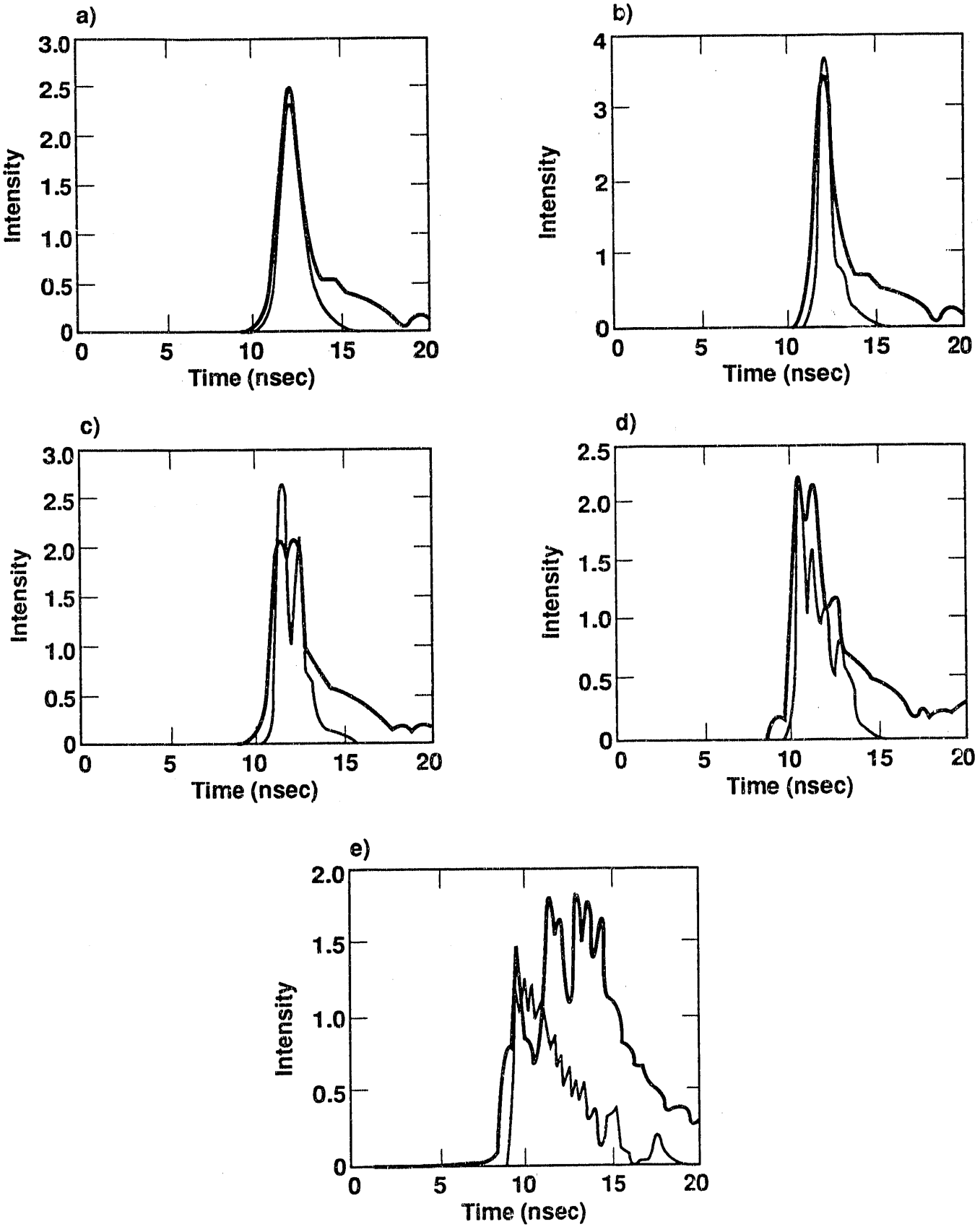
a)
Intensity
Time (nsec)
b)
Intensity
Time (nsec)
c)
Intensity
Time (nsec)
d)
Intensity
Time (nsec)
e)
Intensity
Time (nsec)

Fig. 3.

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