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Measurement of Ultrashort Pulses with a Non-instantaneous Nonlinearity

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Abstract

We show how non-instantaneous nonlinearities can be used to characterize an ultrashort pulse in an extension of the Frequency-Resolved Optical Gating technique. We demonstrate this principle using the Raman effect in fused silica.

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We extend the technique of Frequency-Resolved Optical Gating (FROG) [1, 2] to include the use of non-instantaneously responding optical nonlinearities. Most pulse characterization schemes, such as second-harmonic generation autocorrelation, rely on the use of a nonlinearity that responds on a much faster time scale than the pulse temporal width. Because slowly-responding nonlinearities are generally stronger than quasi-instantaneous ones, the use of a more slowly responding nonlinearity would enable the measurement of weaker intensity pulses.

Using the Raman ringing effect [3] in fused silica that inevitably accompanies the electronic Kerr effect in polarization-gate (PG) FROG, we demonstrate the effect of slowly responding nonlinearities in FROG. We use the formalism of Hellwarth [4] to derive the form of the nonlinear polarization in the presence of Raman effects in PG FROG. The effect of the Raman ringing is to distort the resulting FROG trace, and when this distorted trace is input into the FROG pulse-retrieval algorithm, a distorted pulse is retrieved. Figure 1 shows the distortion in the retrieved pulse for a 25 fs pulse, where the retrieved pulse is 8% longer than the actual pulse. We see therefore that the Raman effect causes an error in our pulse width measurement. The amount of pulse distortion is dependent upon the initial pulse width. Figure 2 shows the amount of pulse lengthening produced by the Raman ringing effect in fused silica as a function of pulse length. The effect is small for long pulses, where the Raman ringing appears as a fast response, and is also small for short pulses, where the ratio of intensity to energy is large, thus emphasizing the effect of nearly-instantaneous processes.

We have modified the FROG pulse retrieval algorithm to include the Raman effect. Based on the method of generalized projections [5], we find that we can retrieve pulses exactly from their Raman-distorted FROG traces. We have used this modified algorithm on experimental data. The inset of Figure 3 shows a PG FROG trace generated by a pulse from an optical parametric generator. Using the modified algorithm, we achieve a pulse width of 42.4 fs, 3.5% shorter than the pulse retrieved with the standard FROG algorithm. Figure 3 shows the pulses retrieved by both the normal FROG algorithm and the modified algorithm that includes Raman effects. The residual error between the experimental trace and the trace of the retrieved field was 15% lower with the use of the modified algorithm, indicating better convergence.

In principle, this method can be extended to any form of nonlinearity, paving the way for the use of slowly-responding materials in the measurement of ultrashort laser pulses.

References

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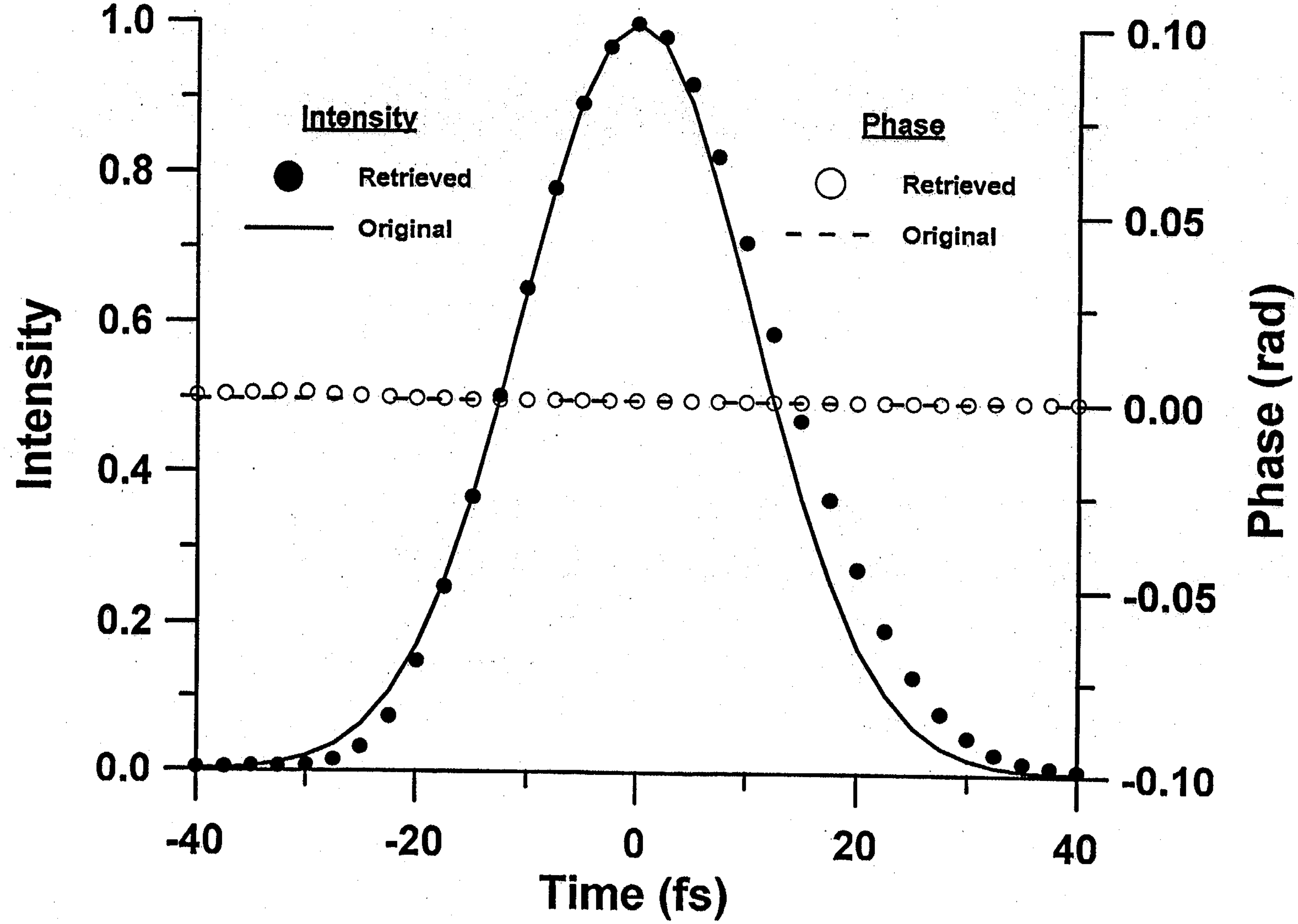
Figure Captions

Figure 1. The pulses retrieved by both the normal FROG algorithm when the FROG trace has been distorted by Raman effects. The material response used here is that of fused silica for a 25 fs pulse. The retrieved pulse is wider than the original pulse, and has acquired some spectral cubic phase (not shown).

Figure 2. The amount of pulse broadening for pulses retrieved from Raman-distorted FROG traces when the normal FROG algorithm is used. The effect is maximal at pulse widths of 25 fs, where the retrieved pulse is lengthened by 8% over the correct value.

Figure 3: Inset: The PG FROG trace of a pulse measured using fused silica. The figure shows the intensity of the retrieved pulse for both the normal and the modified FROG algorithms. The algorithm that incorporates Raman effects retrieves a narrower pulse, and achieves a lower error (better convergence).



Intensity
Retrieved
Original
Phase
Retrieved
Original
1.0
0.8
0.6
0.4
0.2
0.0
Intensity
0.10
0.05
0.00
-0.05
-0.10
Phase (rad)
-40
-20
0
20
40
Time (fs)

Fig. 1

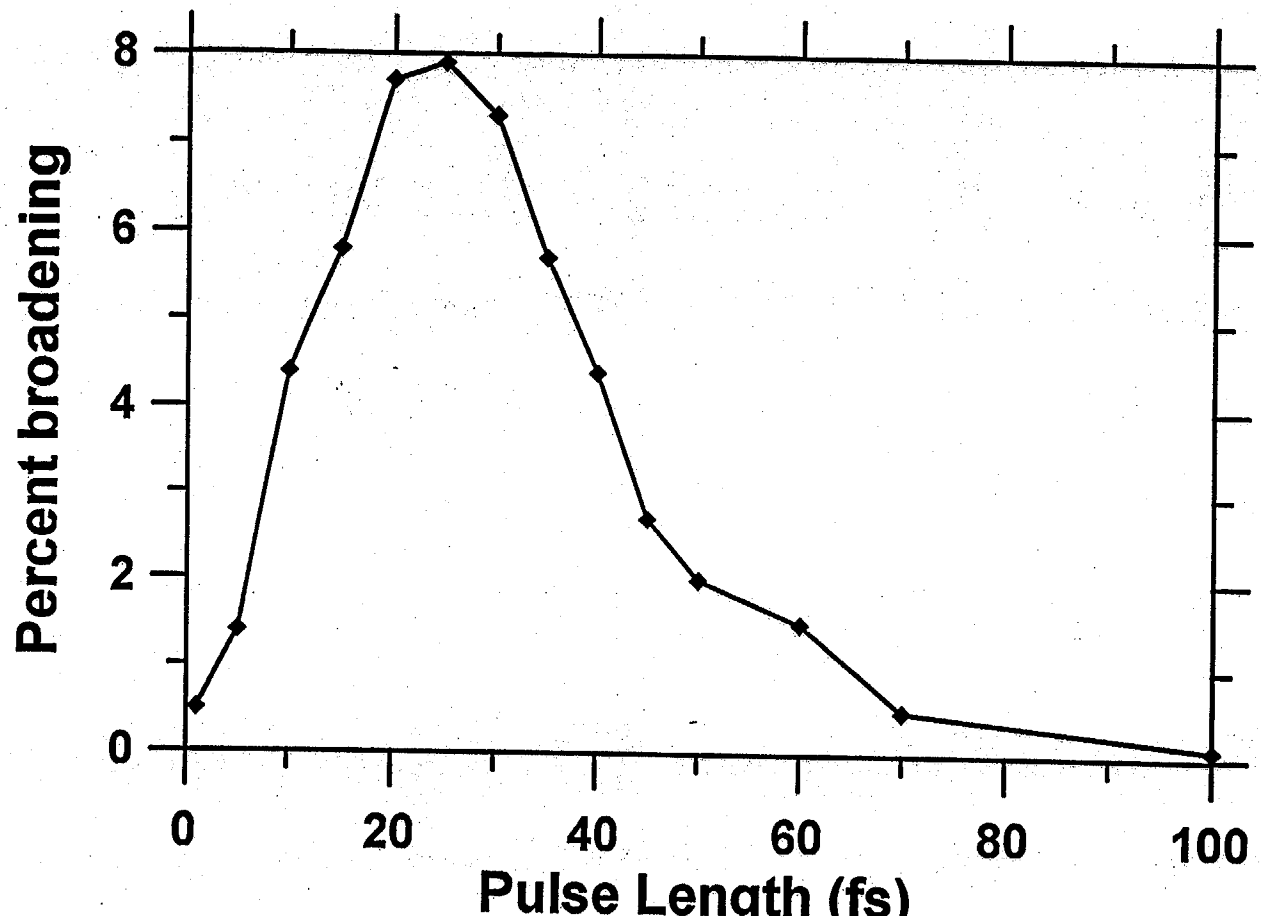
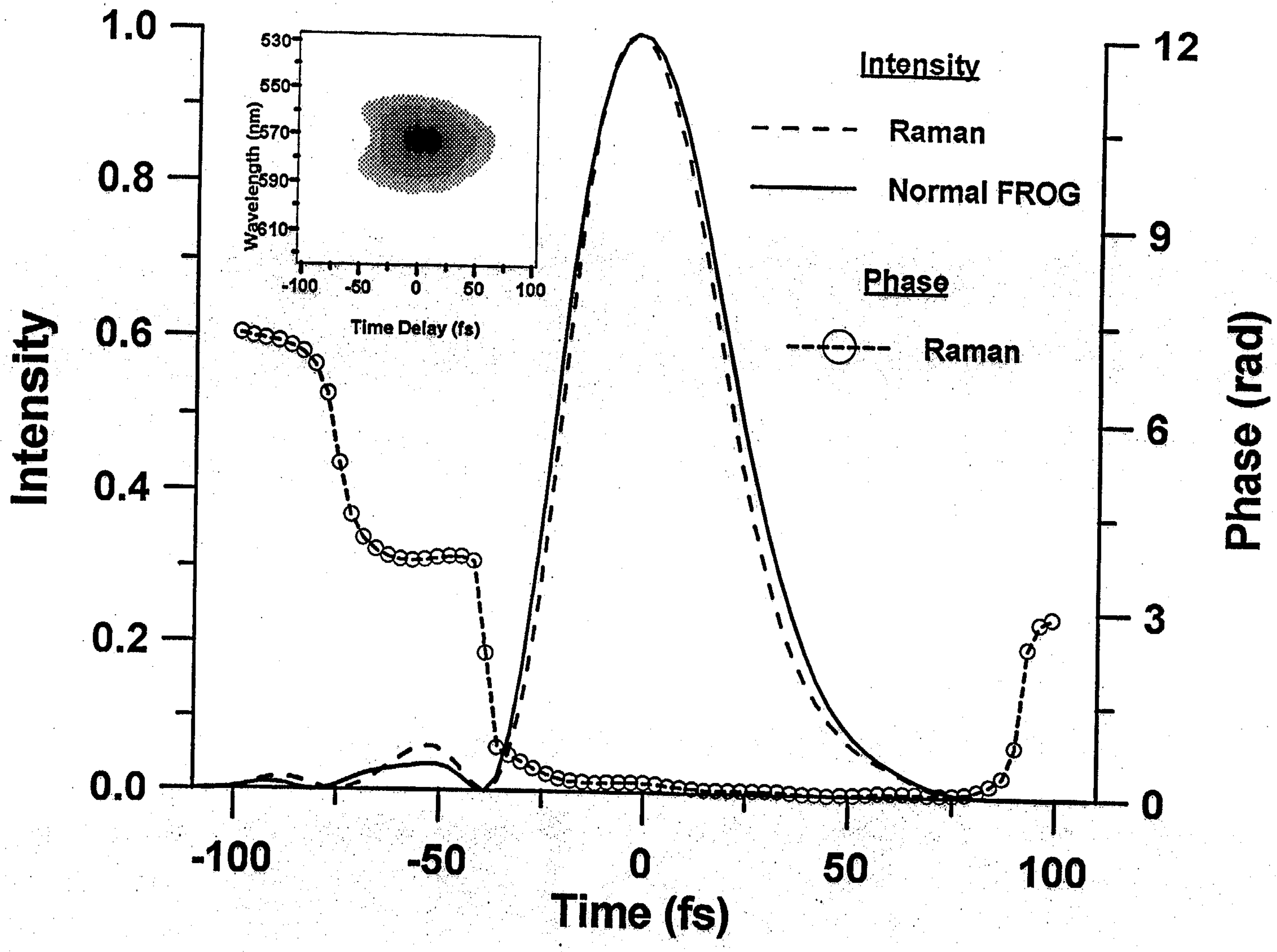


Fig. 2



1.0
0.8
0.6
0.4
0.2
0.0
Intensity
-100
-50
0
50
100
Time (fs)
12
9
6
3
0
Phase (rad)
Intensity
Raman
Normal FROG
Phase
Raman
530
550
570
590
610
Wavelength (nm)
-100
-50
0
50
100
Time Delay (fs)

Fig. 3

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