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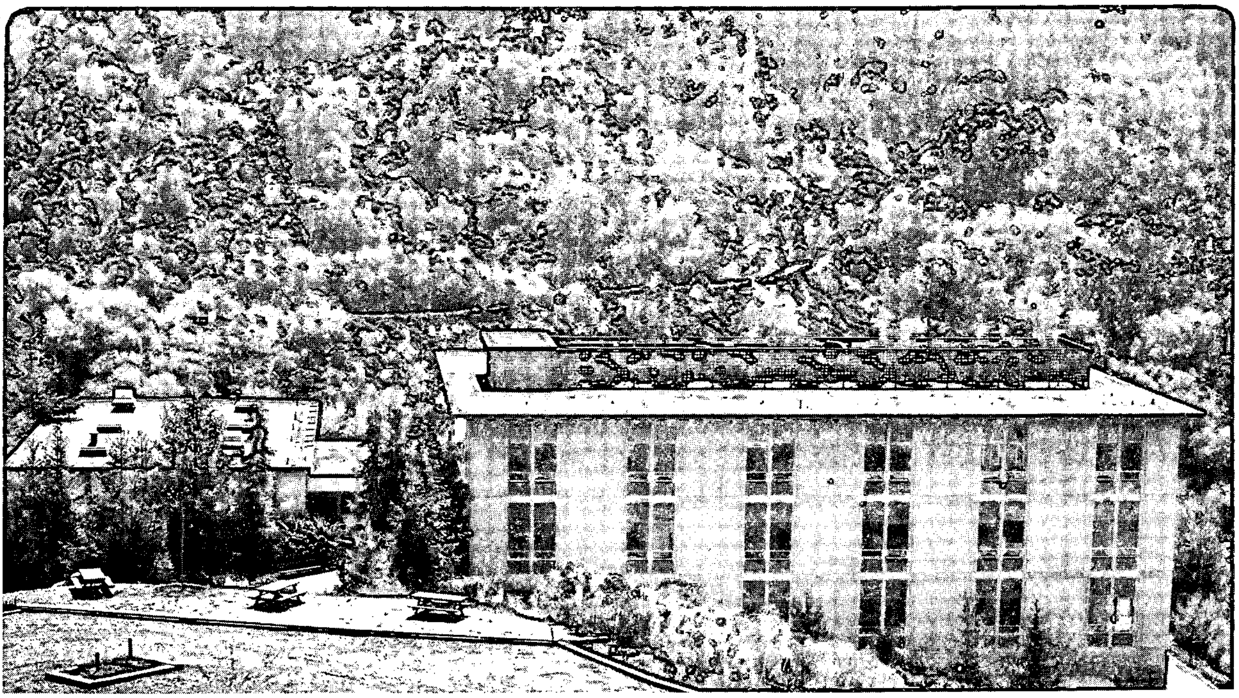

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TEMPORAL AND SPECTRAL INVESTIGATION OF MULTI-LANDAU LEVEL QUANTUM BEATS IN GaAs

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Abstract

By resolving temporally and spectrally transient four-wave-mixing, we observe multiple Landau level quantum beating in GaAs under 6T magnetic field. Excitation energy and density dependent quantum interference gives rise to non-periodic beats.

Temporal and Spectral Investigation of Multi-Landau Level Quantum Beats in GaAs

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In the parabolic band effective mass approximation model of a semiconductor, application of a magnetic field leads to the formation of equally spaced Landau levels. By application of a spectrally broad laser pulse, one would expect to observe in the coherent emission quantum beats with a periodic time dependence. In fact, in a transient (100fs) four-wave-mixing (FWM) experiments in GaAs, we observe ***non-periodic*** multiple beating between magnetoexcitons associated with different Landau levels. This results from complex density dependent quantum interferences between coupled states in the material. [1]

The linear absorption spectrum of the sample at B=6T is show in Fig.1. The light hole (lh) and the heavy hole (hh) magnetoexciton resonances are split due to strain, with the hh at higher energy [2]. The higher-order magnetoexcitons couple to the 1-D continuum with the wavevector parallel to B and form Fano resonances [3]. Here we concentrate on the dependence of the ultrafast nonlinear optical response vs excitation density and energy.

The temporal and spectral evidence for quantum interference is presented in Fig.2 (a), (b) and (c) for the three excitation energies of the laser pulses shown in Fig.1 (a), (b) and (c), respectively. The time-integrated (TI) FWM temporal profile vs time delay Δt clearly shows evidence for a complicated, non-periodic beating, which changes dramatically with excitation energy. As we tune the exciting laser pulse to higher energy, the magnetoexciton response time shortens by 3 orders of magnitude, finally becoming limited by the resolution of our laser pulses in (c). In Fig.2 (a), (b) several non-periodic beats are seen, whereas in Fig. 2(c) only a single beat node is apparent, near Δt=0. Importantly, the corresponding FWM spectra taken at Δt=0 contain information which is not readily discernable from either the temporal data or the linear absorption spectrum. In the emission power spectra (PS) we consistently observe several peaks, whose position does *not* necessarily correspond to a resonance in the linear absorption spectrum. Thus the FWM-PS indicate the nature of the quantum interference responsible for the temporal lineshape.

The excitation density dependence of the TI-FWM vs Δt, and FWM-PS at Δt=0 obtained for the excitation energy of Fig. 1(d) is shown in Fig.3. As a function of excitation density, the TI-FWM profile evolves from a camel back lineshape at low density, (a) $N \approx 3X10^{16} cm^{-3}$, to a double component peak, (b) $N \approx 10^{17} cm^{-3}$, and, finally, to a very narrow and asymmetric peak at high density, (c) $N \approx 3X10^{17} cm^{-3}$. This is not due to a simple density dependent relaxation but rather to an density dependent quantum interference, as shown by the corresponding FWM-PS. The spectral data reveal that the FWM emission originates from several components, whose linewidth and lineshape depends critically on the excitation density. The low density FWM-PS is comprised of two main contributions at the second (807nm) and third (796nm) hh-Fano resonances, and a smaller one at the second lh-Fano resonance (802nm). The shoulders seen superimposed on these peaks are not due to noise, since they evolve into beautiful interference patterns as the density increases, (b) and (c). The combination of temporal and spectral resolution thus demonstrates that the coupling of a discrete state with an underlying continuum, responsible for the Fano-interferences, is strongly affected by the presence of photocarriers.

In conclusion we have observed multiple level quantum beats between magnetoexcitons and demonstrated energy and density dependent quantum interferences.

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[1] C. Stafford, S. Schmitt-Rink, W. Schaefer, Phys. Rev. B 41, 10000 (1990)

[2] F. H. Pollak and M. Cardona, Phys. Rev. 172, 816 (1968)

[3] U. Fano, Phys. Rev. 124, 1866 (1961)

FIGURE CAPTIONS

Fig.1 Low-temperature linear absorption spectrum of the GaAs sample at B=6T. The dashed lines show the spectra of the exciting laser pulses used in the four-wave-mixing experiments.

Fig.2 Time-integrated four-wave-mixing signal vs time delay (left column) and four-wave-mixing power spectrum at zero time delay (right column) under the excitation conditions (a), (b) and (c) indicated in Fig.1.

Fig.3 Time-integrated four-wave-mixing intensity vs time delay (right column) and four-wave-mixing power spectrum at zero time delay (left column) for the excitation energy (d) of Fig.1 at different excitation densities: (a) $N \approx 3X10^{16}cm^{-3}$, (b) $N \approx 10^{17}cm^{-3}$ and (c) $N \approx 3X10^{17}cm^{-3}$.

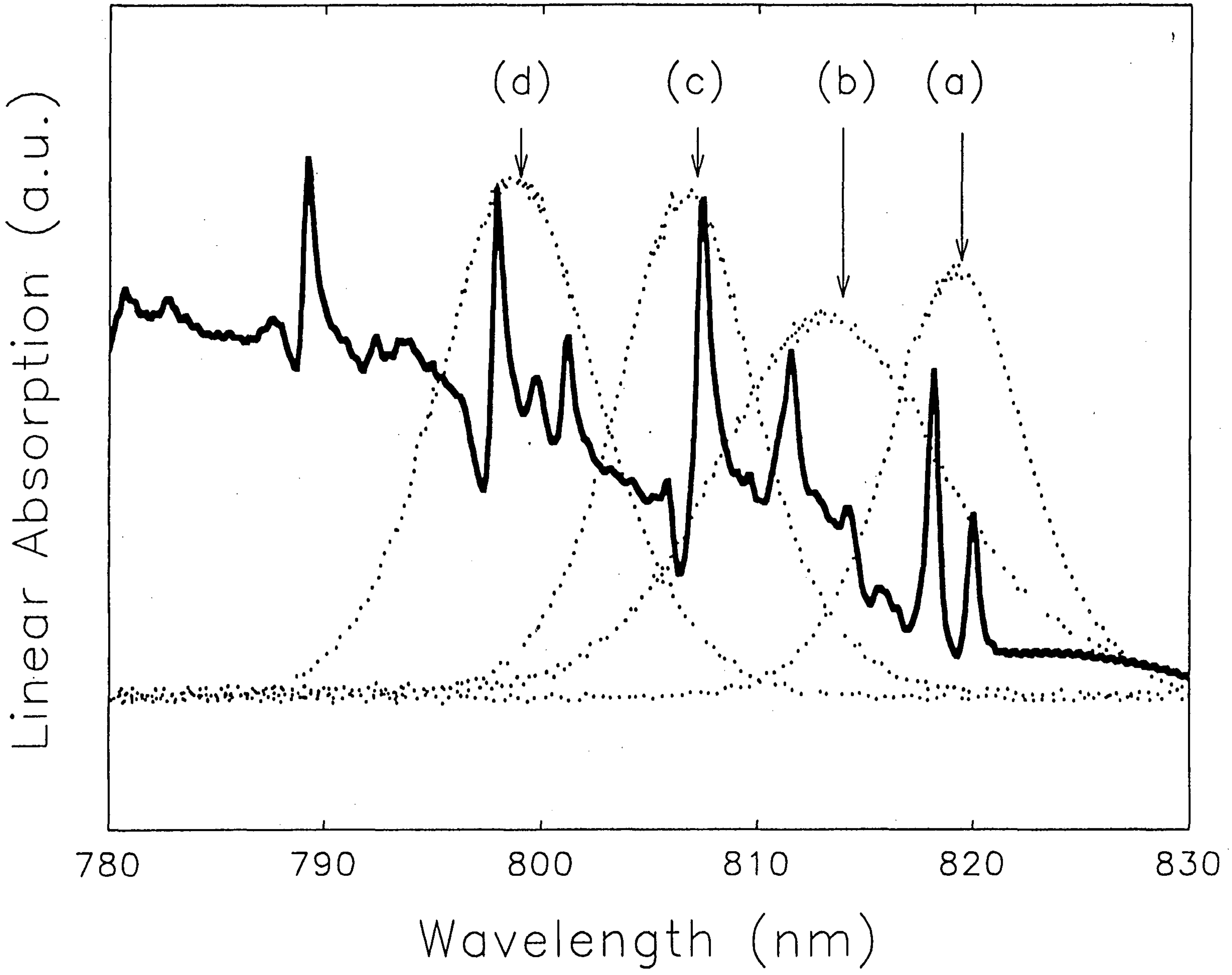

(d)
(c)
(b)
(a)
Linear Absorption (a.u.)
780
790
800
810
820
830
Wavelength (nm)

Fig 1

Fig. 2

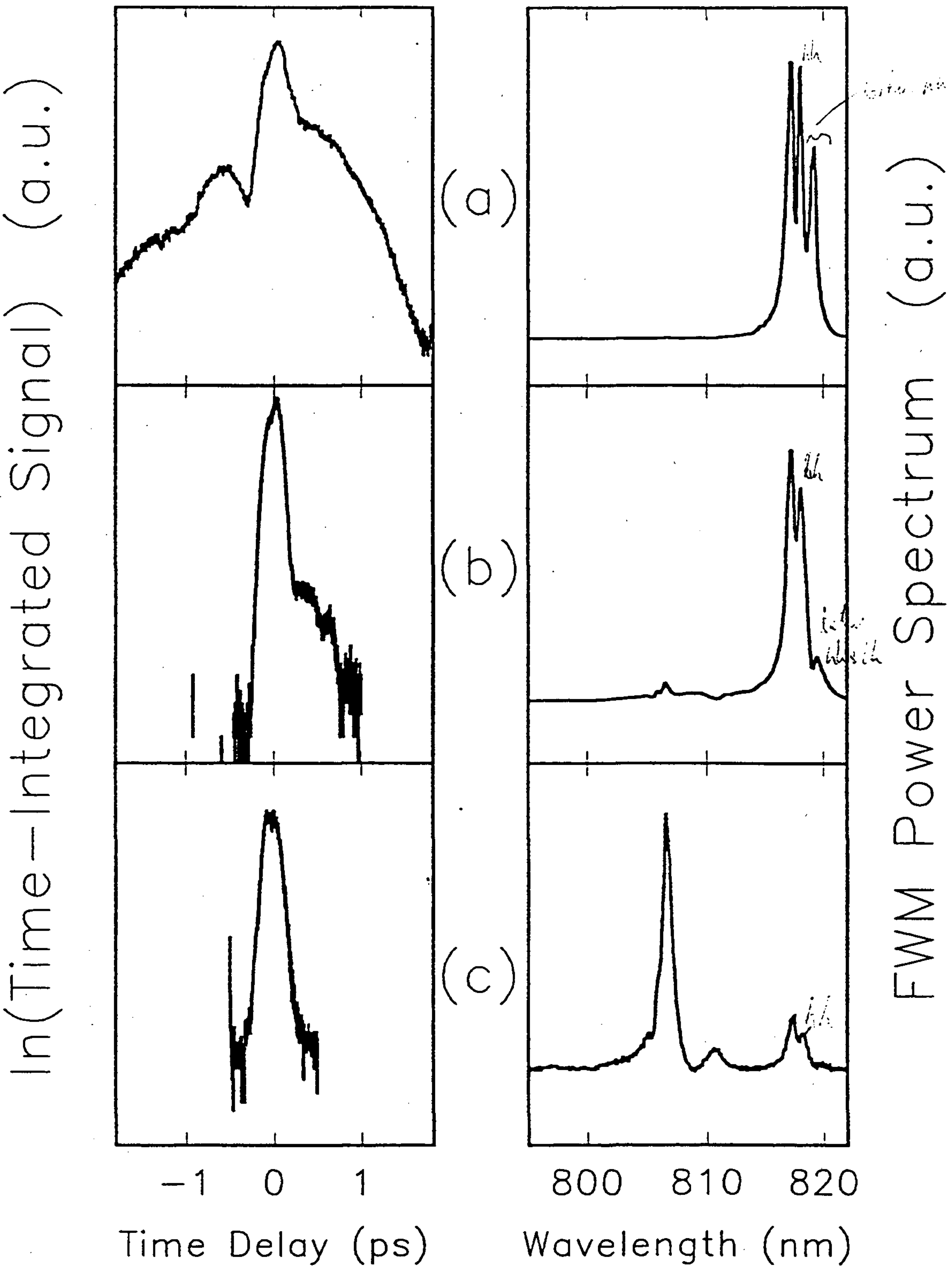
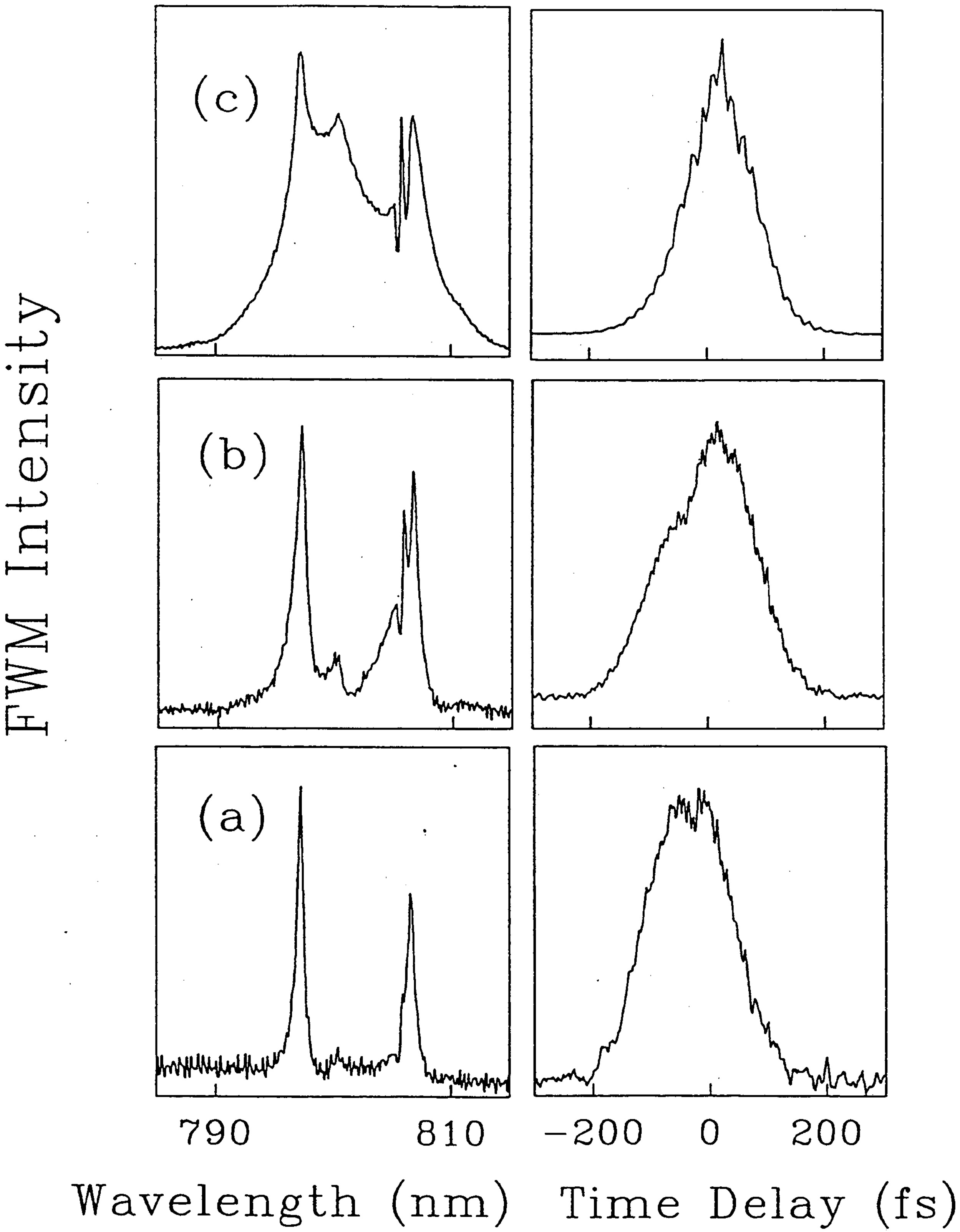

ln(Time-Integrated Signal) (a.u.)
(a)
(b)
(c)
FWM Power Spectrum (a.u.)
hh
hh
hh
−1
0
1
Time Delay (ps)
800
810
820
Wavelength (nm)

Fig. 3


(c)
(b)
(a)
FWM Intensity
790
810
−200
0
200
Wavelength (nm)
Time Delay (fs)