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Kner, P.

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EFFECT OF MAGNETIC CONFINEMENT ON MANYBODY NONLINEARITIES OF LORENTZIAN EXCITONS

Peter Kner, Shimshon Bar-Ad, Maria V. Marquezini, and Daniel S. Chemla

Department of Physics
University of California
Berkeley, CA 94720
and
Materials Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

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Peter Kner, Shimshon Bar-Ad, Maria V. Marquezini and Daniel S. Chemla

Department of Physics, University of California at Berkeley
Materials Sciences Division, Lawrence Berkeley National Laboratory
MS 2-300, 1 Cyclotron Rd, Berkeley CA 94720
Phone: (510)-486-7475 *Fax: (510)-486-5530*

Abstract

100fs time and frequency resolved four wave mixing in GaAs at T=1.6K under magnetic field, $0 \le \vec{B} \le 12T$, is used for investigating how magnetic confinement modifies the processes that govern the manybody nonlinearities of the Lorentzian excitons.

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Peter Kner, Shimshon Bar-Ad, Maria V. Marquezini and Daniel S. Chemla

Department of Physics, University of California at Berkeley
Materials Sciences Division, Lawrence Berkeley National Laboratory
MS 2-300, 1 Cyclotron Rd, Berkeley CA 94720
Phone: (510)-486-7475 Fax: (510)-486-5530 email: kner@ux5.lbl.gov

When a magnetic field, $\vec{B}$, is applied to a bulk semiconductor the lowest energy excitons retain Lorentzian lineshapes[1]. The magnetic confinement strongly modifies almost all the processes that govern the manybody nonlinearities of Lorentzian excitons (LX). Screening and carrier scattering depend strongly on whether carriers are in Landau levels or in bands. The LX internal structure experiences a contraction $\propto|\vec{B}|^{1/2}$ perpendicular to $\vec{B}$, and $\propto \ln(|\vec{B}|)$, along $\vec{B}$ affecting the relative motion wave function, $\psi(r)$, and the oscillator strength $\propto|\psi(0)|^2$. The nonlinear optical response of semiconductors results from a delicate balance between Pauli Blocking (PB), Coulomb Correlation (CC) and dephasing,[2] whose relative strengths are normally fixed by the material parameters. Application of a magnetic field, which strongly affects this balance, thus provides a perfect laboratory for studying the fundamental process that govern semiconductor nonlinearities.

We explore these processes in an optically thin, 0.25μm, bulk GaAs sample at T=1.6K and for $0 \le \vec{B} \le 12T$, by time integrated (TI), time resolved (TR) and frequency resolved (FR) σ^- / σ^- Four Wave Mixing (FWM) for 100fs excitation resonant with the LX and generating $N_{eh} \approx 5X10^{16} cm^{-3}$ eh-pairs.

Figure (1) displays the evolution of TI-FWM for $\vec{B} = 0T, 6T \& 10T$. The maximum of the signal for $\vec{B} = 6T \& 10T$ is respectively 7 and 13.5 times larger than for $\vec{B} = 0$. For $\vec{B} = 6T \& 10T$ one sees at $\Delta t \ge 0$ oscillations superimposed on a background with an exponential decay constant $2T_2(6T) = 2ps$ and $2T_2(10T) = 1.25ps$. The clear $\Delta t < 0$ signal has a decay constant $4T_2(\vec{B})$, as expected,[3] and much less pronounced oscillations. In contrast for $\vec{B} = 0$ the $\Delta t < 0$ signal is almost

absent and the oscillations are just visible. Figure 2 presents FR-FWM at $\vec{B} = 6T$ vs. Δt ,and at $\Delta t = 0$ vs. $\vec{B} = 0T, 6T \& 10T$. Two sharp contributions are seen at the light-hole (lh) and the heavy-hole (hh) LX, whose degeneracy has been lifted by stress in the sample, suggesting that the TI-FWM oscillations are Quantum Beats. This is confirmed by the $\vec{B} = 10T$ TR-FWM presented in Figure 3 for six values of Δt .[4]

The magnetic length l_B at $\vec{B} = 6T \& 10T$ is respectively ~105Å and 81Å, significantly smaller than the exciton radius a_o~140Å. Thus the strong enhancement of the signals magnitude at large fields reflects the tighter confinement of the exciton wavefunction. As for the time dependence, we note that the TI-FWM signal for $\Delta t < 0$ originates exclusively from CC and is more affected by dephasing, $\propto e^{4\Delta t/T_2}$, than the $\Delta t \geq 0$ signal, $\propto e^{-2\Delta t/T_2}$,which originates from both PB and CC.[3] The dependence vs. $\vec{B}$ of the lh-LX and hh-LX spectral linewidth corresponds nicely to the slope of the TI-FWM, confirming that dephasing is strongly affected by $\vec{B}$. Since the $\Delta t < 0$ TI-FWM signal is almost suppressed for $\vec{B} = 0$, this suggest that the main effects of $\vec{B}$ on the signal come from its influence on carrier-carrier scattering and screening. The experiments also reveal a number of issues that remain to be clarified: i) the very different lineshape of the TI-FWM for $\Delta t < 0$ and $\Delta t \geq 0$, ii) the origin of the variation of the relative spectral weights of lh-LX and hh-LX with Δt , at fixed $\vec{B}$.

In conclusion we have demonstrated that application of a magnetic field is a powerful tool to investigate the interplay between the fundamental processes governing the nonlinear optical response of excitons.

References:

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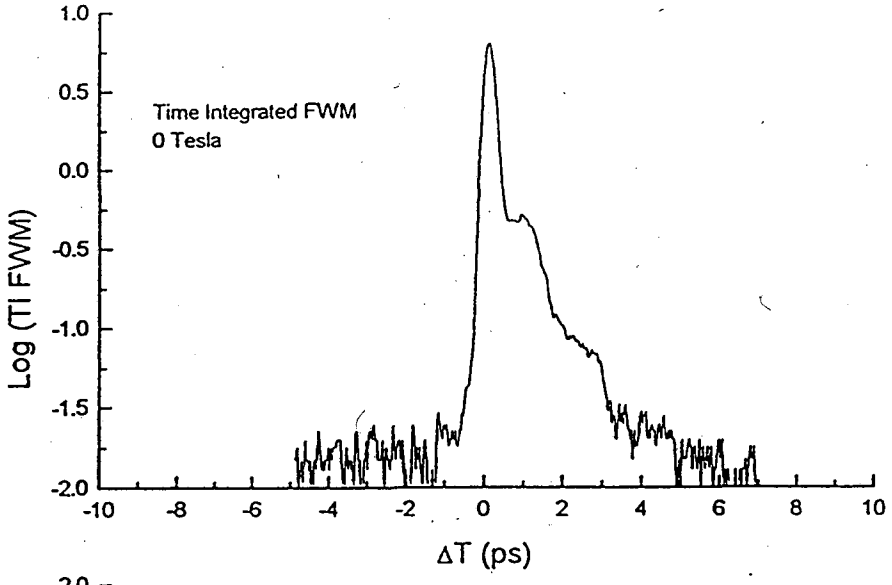
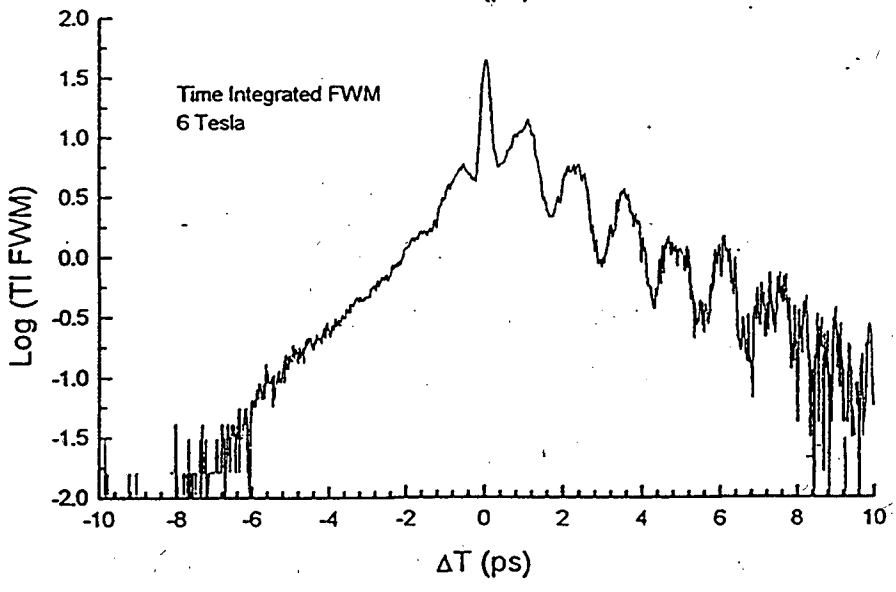
Figure Captions:

Figure 1: Time integrated Four Wave Mixing signal vs time delay Δt, generated in a 0.25μm, bulk GaAs sample at T=1.6K by 100fs excitation resonant with the lowest excitons, for magnetic fields $\vec{B} = 0T, 6T \& 10T$.

Figure 2: Power spectrum of the Four Wave Mixing signal: 1) vertical series, for $\vec{B} = 6T$ vs. Δt, $-0.5ps \leq \Delta t \leq 1.1ps$, 2) horizontal series, at $\Delta t = 0$ for $\vec{B} = 0T, 6T \& 10T$.
The two sharp peaks originate from the light-hole and heavy-hole excitons.

Figure 3: Time resolved Four Wave Mixing signal vs. "absolute time" t, for six fixed time delays $-1.34ps \leq \Delta t \leq 1.67ps$, obtained by up conversion with a reference laser pulse. The GaAs sample is at T=1.6K and $\vec{B} = 10T$. The oscillations in absolute time are Quantum Beats between the light-hole and heavy-hole exciton resonances.


Time Integrated FWM
0 Tesla
Log (TI FWM)
ΔT (ps)


Time Integrated FWM
6 Tesla
Log (TI FWM)
ΔT (ps)

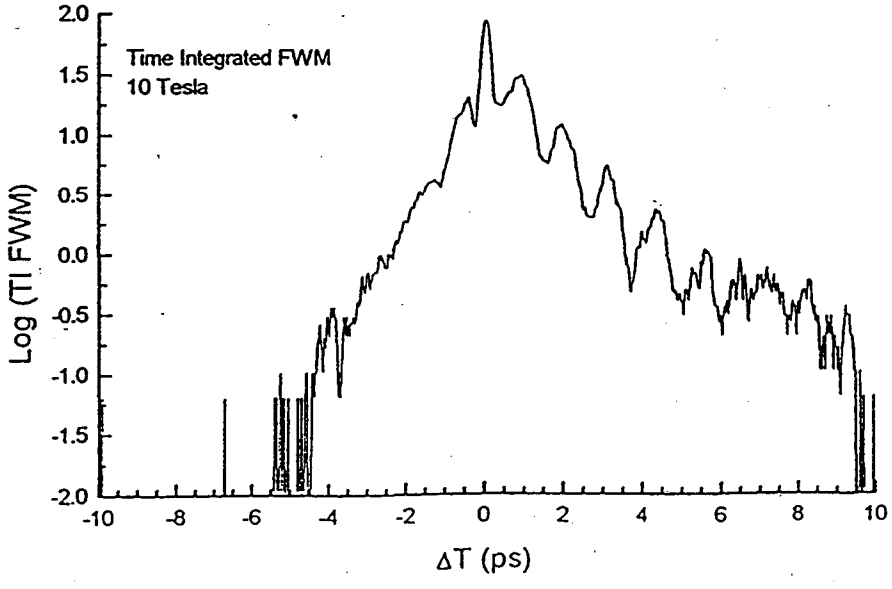

Time Integrated FWM
10 Tesla
Log (TI FWM)
ΔT (ps)

Figure 1

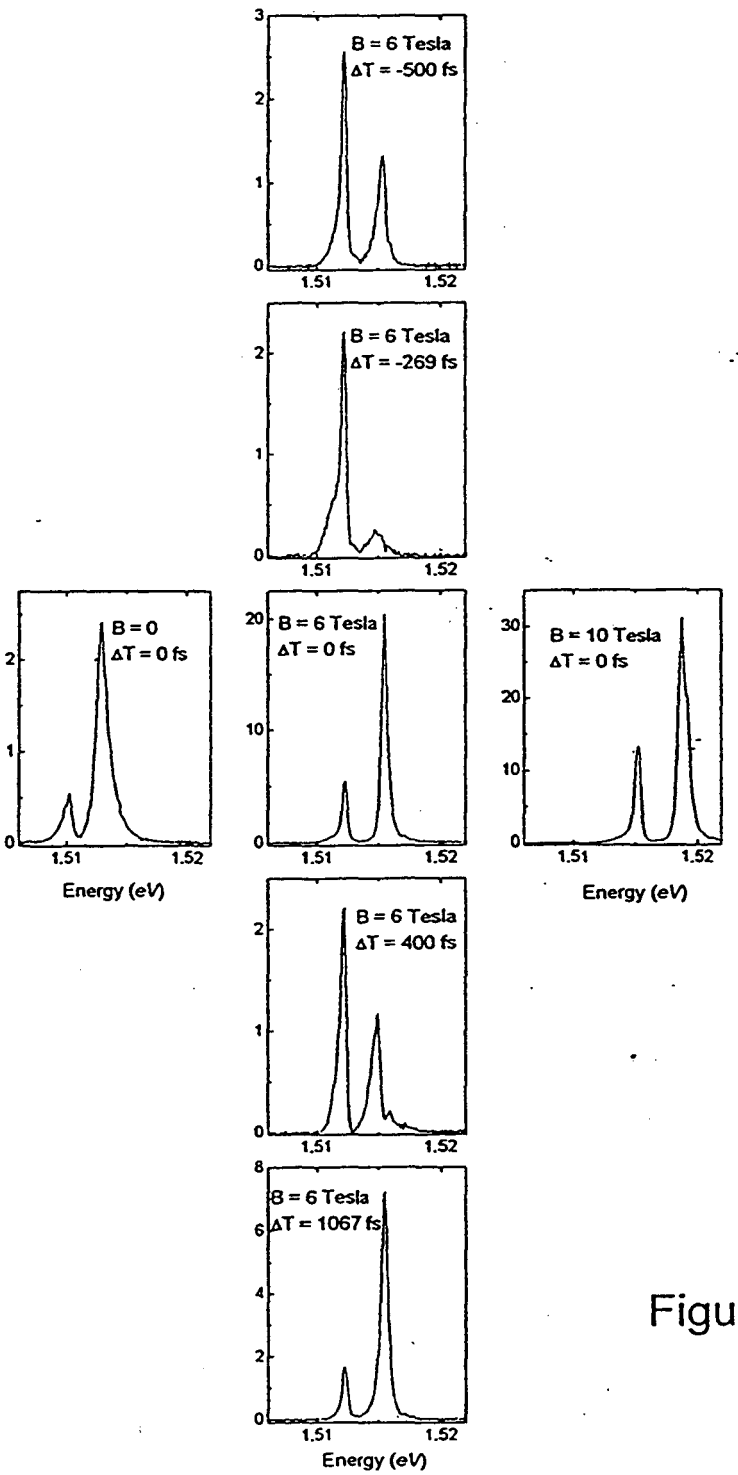

B = 6 Tesla
ΔT = -500 fs
B = 6 Tesla
ΔT = -269 fs
B = 0
ΔT = 0 fs
B = 6 Tesla
ΔT = 0 fs
B = 10 Tesla
ΔT = 0 fs
B = 6 Tesla
ΔT = 400 fs
B = 6 Tesla
ΔT = 1067 fs
1.51
1.52
Energy (eV)

Figure 2

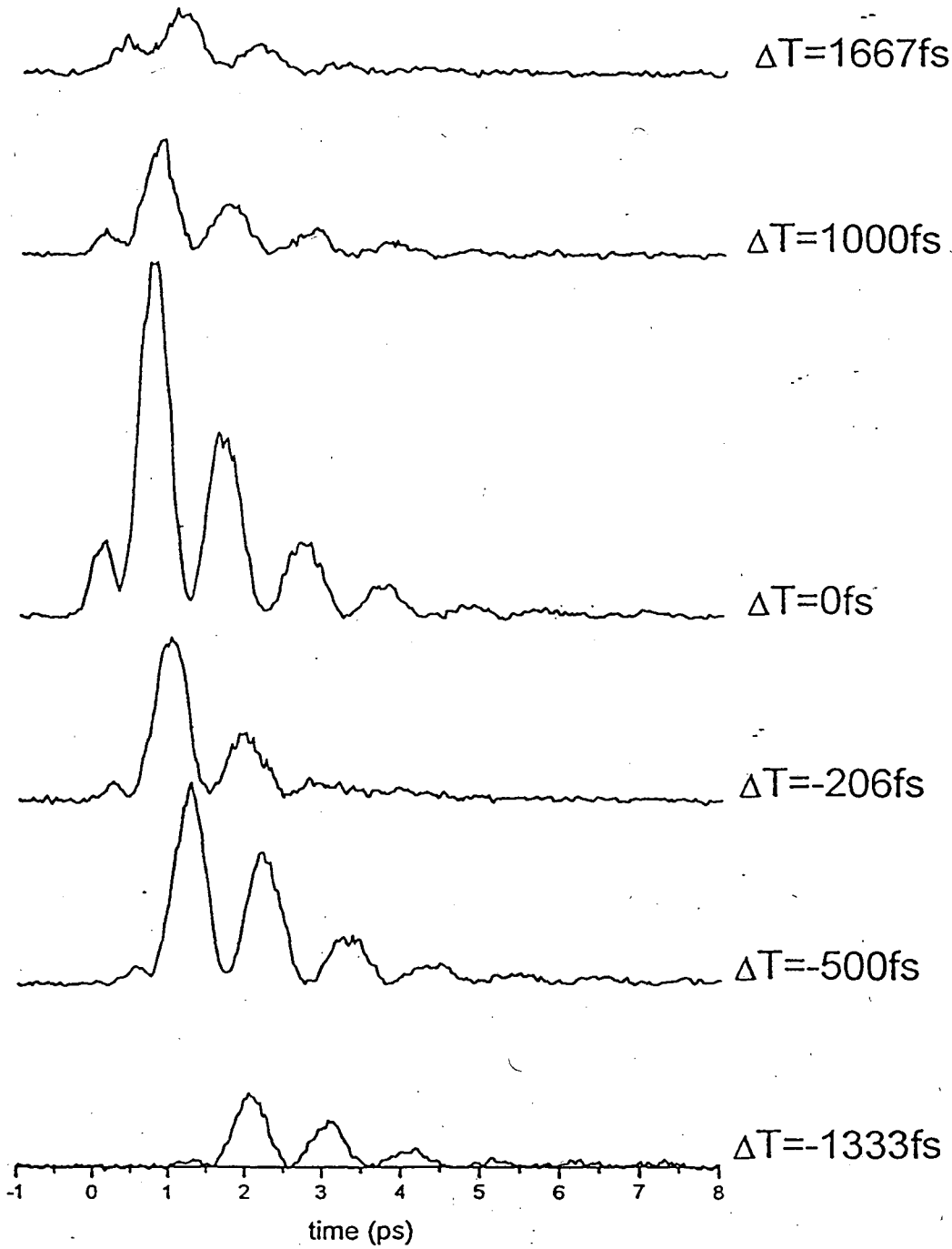

ΔT=1667fs
ΔT=1000fs
ΔT=0fs
ΔT=-206fs
ΔT=-500fs
ΔT=-1333fs
-1
0
1
2
3
4
5
6
7
8
time (ps)

Figure 3

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UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720