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J.-Y. Bigot, M.-A. Mycek, S. Weiss, and D.S. Chemla

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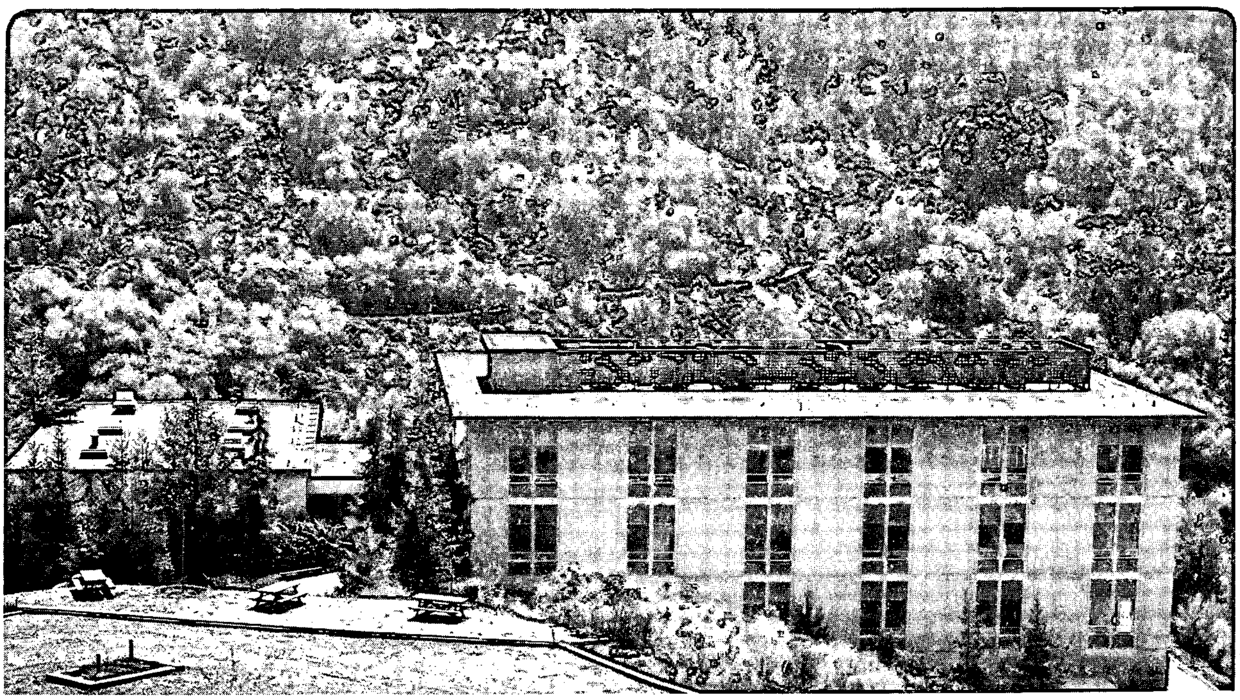

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PHASE DYNAMICS OF NON-EQUILIBRIUM DISTRIBUTIONS OF FREE ELECTRON-HOLE PAIRS IN GaAs QUANTUM WELLS

J.-Y. Bigot

Institut de Physique et Chimie des Matériaux de Strasbourg
5 rue de l'Université, 67084 Strasbourg
Cedex, France

M.-A. Mycek, S. Weiss, and D. S. Chemla

Department of Physics
University of California
Berkeley, CA 94720

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

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J.-Y. Bigot[(a)], M.-A. Mycek, S. Weiss, and D.S. Chemla.

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

(Corresponding author: M-A Mycek, Tel: (510)-486-5265, Fax: (510)-486-5530

Abstract:

We resolve the phase and amplitude of the coherent emission of a non-equilibrium Fermi-sea in four wave mixing experiments. It exhibits an ultrafast dynamical *blue shift*, due to Fermi-edge many-body effects.

(a) Permanent address: Institut de Physique et Chimie des Matériaux de Strasbourg, 5 rue de l'Université, 67084 Strasbourg Cedex, France.

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J.-Y. Bigot[(a)], M.-A. Mycek, S. Weiss, and D.S. Chemla.

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

(Corresponding author: M-A Mycek, Tel: (510)-486-5265, Fax: (510)-486-5530

The elementary excitations of semiconductors are governed by quantum statistics and Coulomb correlation. Both the amplitude and the phase of their nonlinear optical polarization displays a complex temporal behavior. This was experimentally demonstrated by the observation of nonlinear dynamics of the instantaneous-frequency of coherent wave mixing resonant with excitons [1]. However, the continuum-states, well above the band gap, are much more difficult to study because of the ultrafast relaxation of electrons and holes (e-h) [2,3]. In this paper we address for the first time the question of the phase dynamics in the continuum of states of quasi-free e-h. We show that the temporal evolution of Four-Wave-Mixing (FWM) power spectra (PS) reveals important information on the complex dynamical behavior of the Fermi surface of non equilibrium e-h distributions.

The experiments are performed on a GaAs/GaAlAs quantum well structure, in the self-diffracted FWM configuration using unchirped transform limited 100fs pulses. For each delay ΔT between the two pulses, the PS of the FWM signal S_{FWM}, observed in the direction $k_s=2k_2-k_1$, is recorded with an OMA detector. The laser frequency is tuned 44meV above the lowest exciton, in the two-dimensional continuum of quasi-free e-h states. The dephasing times T_2 for continuum excitation is of the order of a few tens of fs for excitation densities N in the range 10^{10} -10^{12} cm^{-2} [2]. In such conditions, no interesting information is obtained from the time integrated FWM signal $S_{FWM}(\Delta T)$, when the pulsewidth exceeds T_2. In contrast, the spectrogram, $S_{FWM}(\omega,\Delta T)$, is a direct visualization of the phase dynamics of the emission frequency, as shown with quasi-instantaneous Kerr-media [4].

Figure 1 presents a series of PS obtained with $N=3x10^{12}cm^{-2}$. Each spectrum has been normalized to unity in order to display the dynamical behavior. The laser spectrum is shown as a dotted curve. A clear dynamical shift of the FWM power spectrum is observed. The maximum of $S_{FWM}(\omega,\Delta T)$ is shifted to high energies relative to the laser spectrum at early delays ($\Delta T<0$). It shifts to the lower energies as ΔT increases. Figure 2 presents the position of the maximum of $S_{FWM}(\omega,\Delta T)$ vs ΔT, showing that the shift can be as large as $\Delta E \approx 5meV$. This temporal behavior is density dependent as observed in different sets of measurements.

We attribute the above observations to many-body effects that renormalize the optical response of the non-equilibrium e-h Fermi-sea created by the intense pulse [5]. This renormalization originates mostly from the Fermi-sea excitations with very small energy and is therefore concentrated at its two edges. It produces an enhanced emission at the high energy edge and a reduced emission at the low energy one, resulting in the observed dynamical shift. This "*blue shifted*" emission is the counterpart of the "*red shifted*" spectral hole burning observed in pump-probe experiments [6,7]. For non-equilibrium distributions this effect corresponds to the well known Fermi-edge singularity of equilibrium distributions.

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Figure Caption

Figure 1: Four-Wave-Mixing spectra as function of delay Δt. The spectra have been normalized to unity to show the high energy shift for Δt<0.

Figure 2: Position of the maximum of the Four-Wave-Mixing spectra (with respect to the laser energy) vs Δt for an excitation density $3x10^{12}$ cm^{-2}.

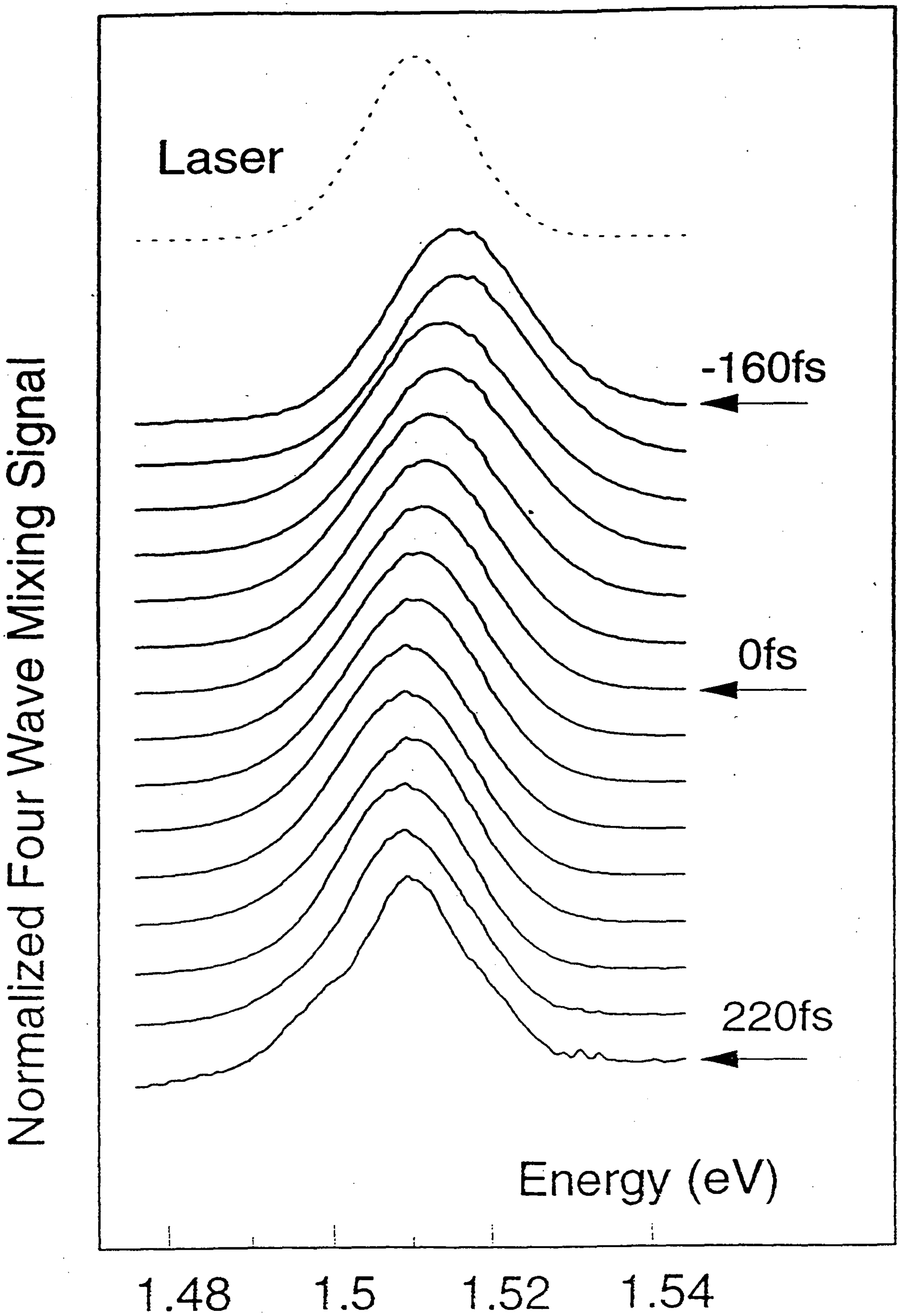
Laser
-160fs
0fs
220fs
Normalized Four Wave Mixing Signal
Energy (eV)
1.48
1.5
1.52
1.54

FIG. 1

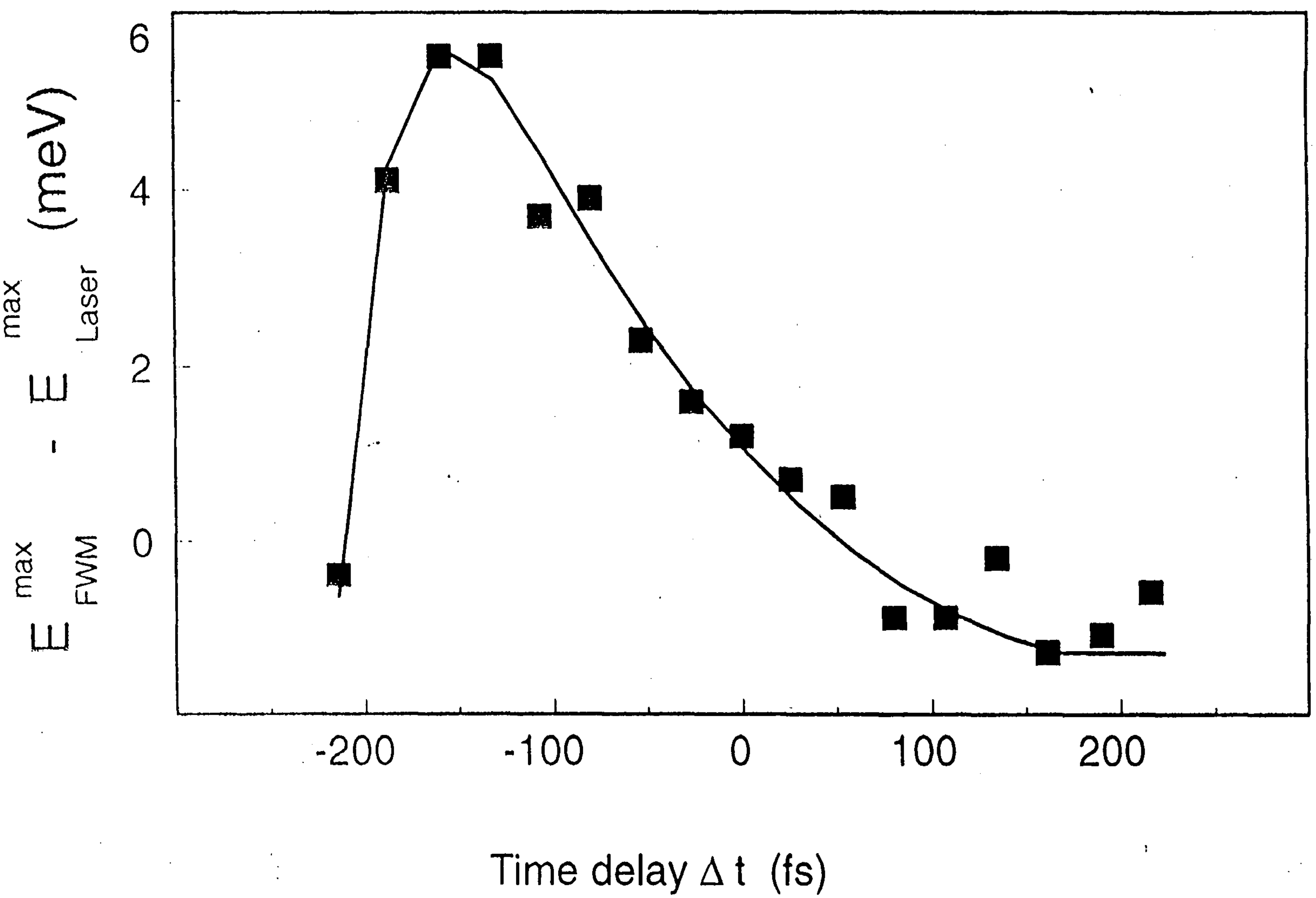

FIG. 2

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720