Comment on "Interaction of Magnetoexcitons and Two-Dimensional Electron Gas in the Quantum Hall Regime"

In a recent Letter Chen *et al.* reported very striking magneto-oscillations in the photoluminescence (PL) intensity of transitions arising from recombination of nonequilibrium electrons in the $n_c=2$ electron subband in $Al_yGa_{1-y}As$-$In_xGa_{1-x}As$-GaAs modulation doped quantum wells (QWs).[1] Maxima in PL intensity correlated with odd filling factors in Shubnikov–de Haas (SdH) measurements. The optical-SdH (OSdH) observations were attributed to oscillations in the strength of many-body Coulomb interactions of the $n_c=2$ "magnetoexciton" state with the high density of electrons ($n_s=1.1\times10^{12}$ cm^{-2}) in the $n_c=1$ subband. The purpose of this Comment is to point out that such magneto-oscillations in the $n_c=2$ intensity can be at least partially explained in terms of oscillations in the population of the $n_c=2$ subband with magnetic field.

In relatively wide, asymmetrically doped QWs, such as that discussed in Ref. 1 (width 150 Å), with high $n_c=1$ subband density, the electrostatic band-bending potential gives rise to a strong enhancement of the wave-function overlap of $n_c=2$ electrons with $n_v=1$ valence subband holes, relative to that for $n_c=1$ electrons. The result is a strongly enhanced oscillator strength (a factor of ~2 to 3) for E_{21} ($n_c=2\rightarrow n_v=1$) relative to E_{11} ($n_c=1\rightarrow n_v=1$) recombination, even without the inclusion of many-body excitonic enhancements for transitions occurring in E_2 close to the Fermi energy (Fermi energy edge singularity). We find excitonic enhancements of a factor of 2 to 3 (at 3-meV linewidth) for E_{21} transitions at zero magnetic field (B) in a series of asymmetrically doped QWs (Ref. 2) close to enhancements found for excitonic transitions of similar linewidth in undoped QWs.

In the magnetic field, oscillations of the $n_c=2$ population are expected each time E_2 is crossed by the Landau levels (LLs, number $N=0$, 1, 2, etc.) from the $n_c=1$ subband. These oscillations will be nearly periodic in $1/B$ since the variation in energy of E_2 is small, at least up to $B\approx7$ T. The spectra of Chen *et al.* (Fig. 3) indicate that as the $N=3$ LL approaches E_2 from 7.6 to 8.5 T ($v=5$ at 9.1 T),[3] the intensity of E_{21} shows a rapid increase with B field, with maximum E_{21} intensity at 8.5–8.6 T, $\sim$0.3–0.4 T after the peaks are no longer resolvable (at $\sim$0.5 T *below* $v=5$, as noted in Ref. 1). Even though the $N=3$ LL is apparently above E_F ($v=6$ at 7.6 T from the electrical SdH) the PL spectra indicate that it has a significant population up to at least 8.2 T when it is no longer resolved. When the partially occupied $N=3$ LL and E_2 reach their closest approach (an anticrossing is shown in Ref. 1), E_2 will have its maximum population. A maximum in E_{21} intensity will then be expected, enhanced relative to E_{11} transitions by the greater wave-function overlap. The crossing of $N=3$ with E_{21} occurs within 0.4 T (Fig. 3 of Ref. 1), at most, of the maximum in E_{21} intensity.

Account must also be taken of the fact that spectroscopic E_{21} and $N=3$ LL energies are observed in PL and not the true E_2 and E_1 energies which determine the subband populations. Excitonic effects are relatively strong for the $k=0$ $n_c=2$ subband electrons compared to those for electrons in $n_c=1$,[1] as shown by the small shift rate for E_{21} in B field in Fig. 5 of Ref. 1. The result is that the spectroscopic E_{21} energy will be lowered by $\sim$2–3 meV relative to that for $n_c=1$ transitions.[4] This will lower the *apparent* field of the $N=3$ LL crossing with E_2 by $\sim$0.4 T, bringing the field of maximum E_2 population in even closer agreement with the maximum in E_{21} intensity.

We believe that the above arguments provide a plausible basis for oscillations in $n_c=2$ PL intensity with B field. The fields at which E_{21} maxima occur are strongly influenced by the crossing of $n_c=1$ LLs with $n_c=2$, as determined by the $n_c=1,2$ subband separations. Indeed, we have observed maxima in E_{21} intensity close to either odd or even filling factors in samples with differing E_2-E_1 separations.[5] Turberfield *et al.*[4] have reported peaks in $n_c=2$ subband intensity (at integer v from 10 to 1) in GaAs-GaAlAs heterojunctions at 120 mK, but with large variation in $n_c=2$ intensity only at $v=1$.

In summary, the effects of population oscillations must be accounted for before the OSdH observations in Ref. 1 can be ascribed to oscillations in many-body interactions. The magnitude of the extremely well-resolved oscillations (1000:1 maxima to minima) is also very much greater (by a factor of 10 to 100) than the magnitude of previously studied many-body effects in quantum wells.

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[1]W. Chen, M. Fritze, A. V. Nurmikko, D. Ackley, C. Colvard, and H. Lee, Phys. Rev. Lett. **64**, 2434 (1990).

[2]M. S. Skolnick *et al.*, in Proceedings of the Twentieth International Conference on the Physics of Semiconductors, Thessaloniki, August 1990 (to be published).

[3]Determined from the field (7.6 T) for $v=6$ (Fig. 4 of Ref. 1).

[4]A similar point is made by A. J. Turberfield *et al.*, Phys. Rev. Lett. **65**, 637 (1990).

[5]P. E. Simmonds *et al.* (to be published).

