Numerical Investigation on Asymmetric Bilayer Systems at Integer Filling Factors

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A large number of studies have been made on $\nu = 1$ bilayer system which correspond to itinerant XY ferromagnet in terms of the pseudospin language. Here pseudospin $\uparrow$ and $\downarrow$ assign electron in the top and bottom layer, respectively. Recent experimental and theoretical investigations in single-layer[1,2] and bilayer[3,4] at $\nu = N$ $(N > 1)$ have further enlarged this field. When two layers belong to different Landau levels, another kind of quantum Hall ferromagnet phase can be seen that is the easy-axis or Ising ferromagnet, in which the many body state with either of two aligned Landau levels completely filled and the other empty are energetically favored than the coherent superposition state mentioned above. In a double-quantum well structure the thickness and height of the middle barrier can be adjusted, then independent control of tunneling and interlayer Coulomb interaction is possible. For large interlayer separation, we can expect other phases.

Performing a finite size numerical calculation on sphere and toroidal geometry and the Hartree-Fock analysis, we investigate the evolution of the ground state involving further large layer spacing region at several integer filling factors. The results are following.

At $\nu = 1/2 + 5/2$, the easy-axis to easy-plane transition occurs. To see the properties of the pseudospin order, we consider the responce of the pseudospin on the 'tunneling rate' Δ_{SAS} which is fictitious source field for the asymmetric bilayer system with different Landau levels. Figure 1 indicates an easy-axis to easy-plane transition first proposed in Ref[4] and the transition to weak interacting phase.

At still larger filling factor, situation is dramatically changed. We found two kinds of stripe state that are staggered stripe and parallel stripe state. To see it we calculate the two-particle correlation function on torus geometry. We set the origin at the center of the rectangular. As Fig.2 shows, we found that around the origin the electrons with up pseudospin cluster on a stripe region and the electrons with down pseudospin keep away from the stripe regions at $d/l = 0.9$. At large enough layer spacing, at $d/l = 1.2$ the stripes are aligned in phase.

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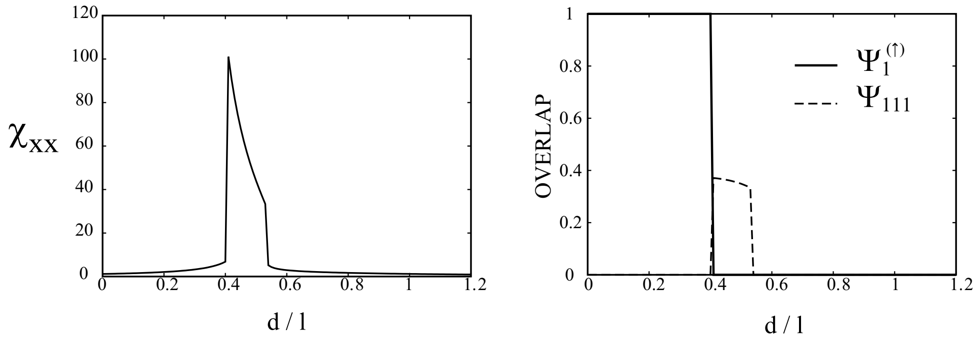

Figure 1: Pseudospin susceptibility and overlap with the Ising and XY ferromagnetic state.

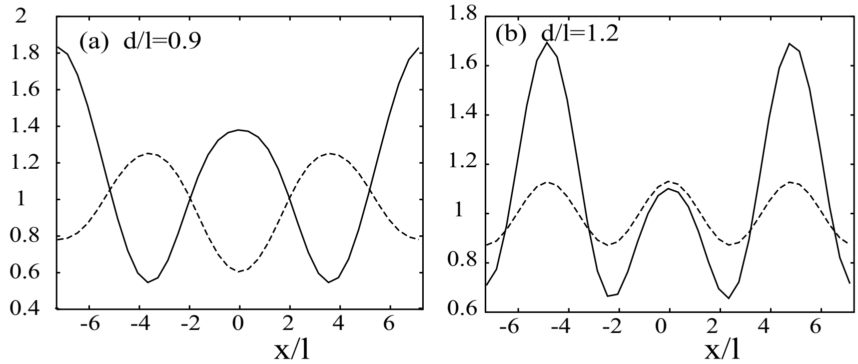

Figure 2: Two-particle correlation functions in the system with some ranges of the layer separation at $\nu = 5$ or 6. The solid line indicates $g_{\uparrow\uparrow}(x, y = L_y/2)$ and the dashed line indicates $g_{\uparrow\downarrow}(x, y = L_y/2)$ The data indicates not only the staggered stripe state but the parallel stripe state.