Observation of a Possible New Non-Abelian Quantum Hall State

by Wei Pan

Motivation—When two identical particles are exchanged, if they are bosons (for example, photons) the wavefunction is unchanged; if they are Fermions (for example, electrons) the wavefunction changes sign. If the two particles are the so-called non-Abelian particles, not only is the wavefunction changed but also the order of exchange of multiple particles becomes relevant, as shown in Fig.1. This topological degree of freedom is insensitive to local perturbations and can be utilized for achieving fault-tolerant quantum computation, which promises an exponential increase in computing power over a classical computer.

It is now generally believed that the quasiparticle excitations of the even-denominator fractional quantum Hall effect (FQHE) state at Landau level filling factor ν=5/2 may obey exotic non-Abelian statistics. Observations of other non-abelian even-denominator FQHE states have been rare beyond the ν=5/2 state more than twenty years since its discovery. On the other hand, an observation of a new non-Abelian FQHE state would not only be of interest by itself, but may also further elucidate the still enigmatic ν = 5/2 state.

Accomplishment—Recently, a new even-denominator FQHE state at ν=1/4 was observed in magnetic fields up to 45T in a high quality $Al_{0.24}Ga_{0.76}As/GaAs/Al_{0.24}Ga_{0.76}As$ modulation doped quantum well. The two-dimensional electron density of the sample was $n = 2.55 \times 10^{11}$ cm^{-2} and the mobility $\mu \sim 10^7$ cm^2/Vs. In Fig. 2 we display R_{xx} and R_{xy} as a function of perpendicular magnetic field ($B_\perp$) for $\theta = 0$ and $\theta = 20.3°$. A FQHE state is present at ν=1/2 with both a minimum in R_{xx} and a weak plateau in R_{xy}. This FQHE state becomes fully developed at $\theta = 20.3°$ with R_{xx} vanishingly small and R_{xy} precisely quantized at $2h/e^2$. Moving to higher magnetic fields, in the absence of tilt, a kink is noticeable in R_{xx} at ν=1/4 along with a very subtle deviation from the classical Hall slope in R_{xy}. With the sample tilted to $\theta = 20.3°$ degrees the kink at ν=1/4 in R_{xx} has developed into a well defined minimum on top of the rising background and a plateau has emerged in R_{xy}, indicating a FQHE state at ν=1/4. Furthermore, the comparison between the derivative of the Hall resistance $dR_{xy}/dB_\perp$ and R_{xx} also corroborates the formation of a ν=1/4 FQH state.

The nature of this FQHE state is not known at the present time and many theoretical models have also been proposed. More work is needed to address the question whether it is a non-abelian state, or an abelian two component state, or a non-abelian generalization of the two component state.

Significance—The non-Abelian FQHE states are at the center of current interests due to their potential applications in performing topological quantum computation. There has been an ongoing effort to discover more FQHE phases whose elementary excitations exhibit non-Abelian statistics. It can be expected that the observation of the new FQHE state at ν=1/4 will impact and stimulate a great deal of developments in theoretical physics and in quantum computing.

Sponsors for various phases of this work include: DOE Office of Basic Energy Sciences

Contact: Wei Pan, Semiconductor Material and Device Science
Phone: (505) 284-9545, Fax: (505) 844-3211, E-mail: wpan@sandia.gov

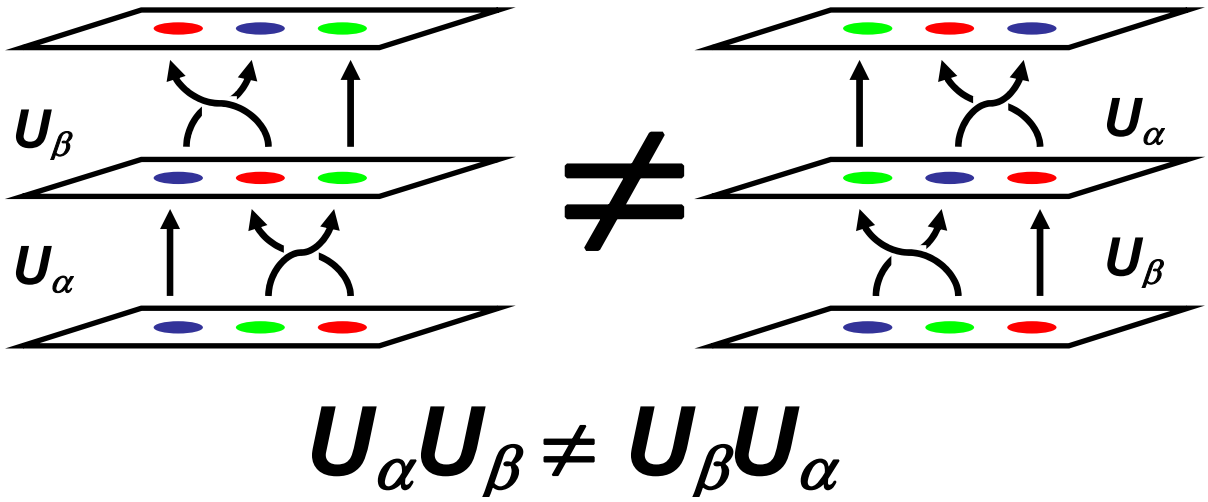

Figure 1. Shows schematically that the order of interchange of two particles is relevant for non-Abelian particles.

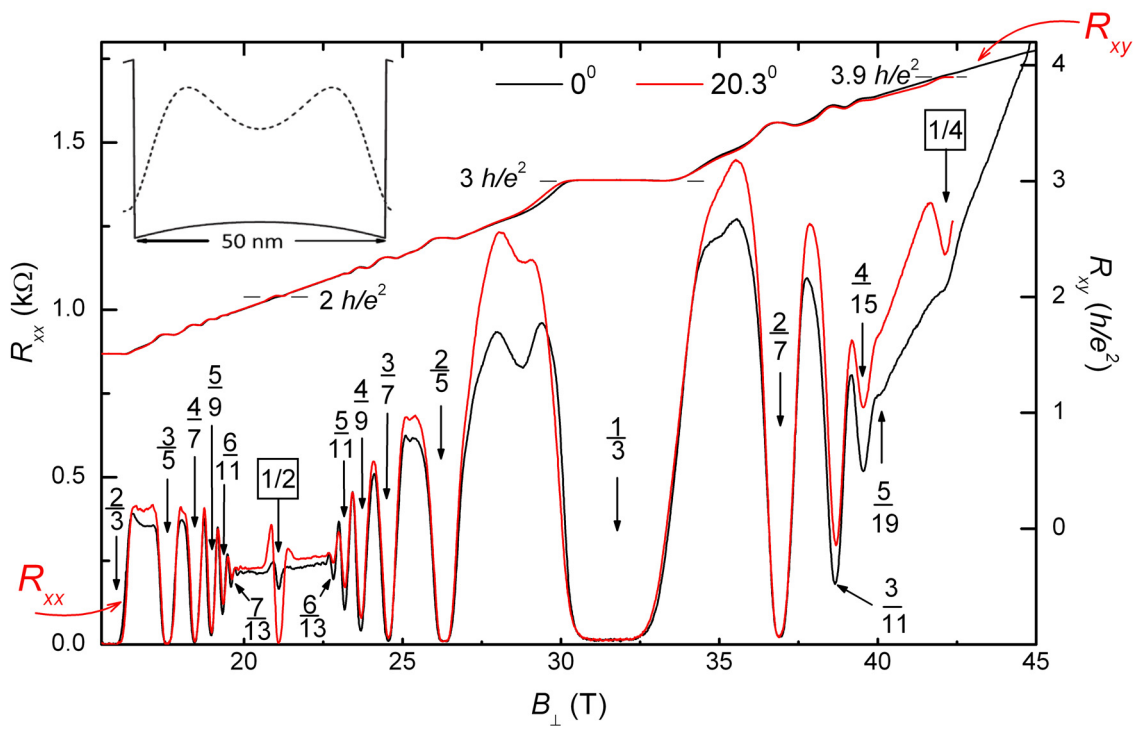

Figure 2. R_{xx} and R_{xy} as function of perpendicular magnetic field, $B_\perp$, for θ=0° and 20.3° at T ~ 35 mK. Some of the odd-denominator FQH states are labeled. The filling factors ν=1/2 and ν=1/4 are also marked. The horizontal lines at $R_{xy}=2h/e^2$, $3h/e^2$ and $3.9h/e^2$ highlight the plateaus at those values.