Spin-Droplet State of an Interacting 2D Electron System

N. Teneh[1], A. Yu. Kuntsevich, V. M. Pudalov, and M. Reznikov

[1] tnimrod@tx.technion.ac.il

Technion, Israel Institute of Technology

Introduction

Magnetic ordering of a two dimensional electron system (2DES) is determined by the interplay of electronic Coulomb interaction and Pauli principle. As density decreases the ratio between interaction and Fermi energies increases, pushing the system towards a ferromagnetic instability.

Experimental Technique

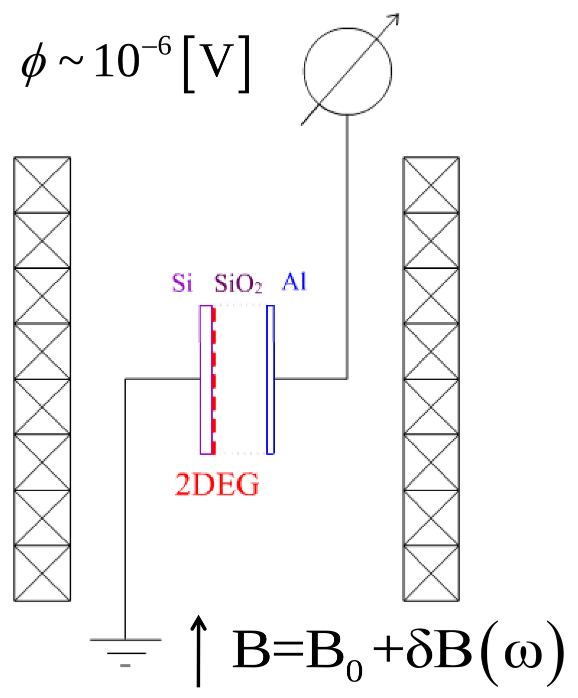
We measure recharging current between the gate and the 2DES generated in response of the in-plane magnetic field modulation at a constant gate voltage[1,2]. This current can be expressed through the modulation of the chemical potential μ:

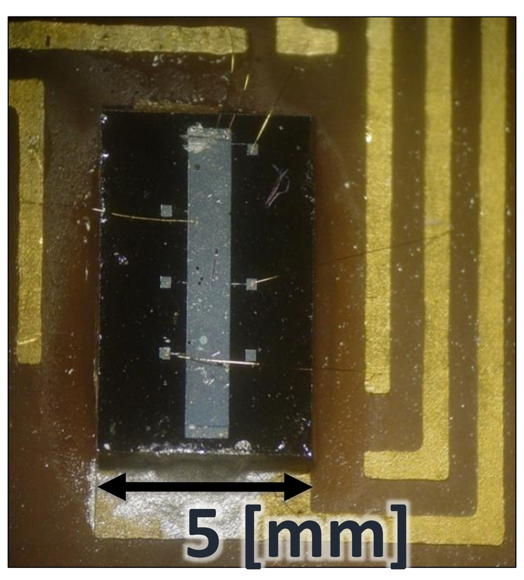
$$\frac{e^2}{\tilde{c}}\frac{dn}{dB} = -\frac{\partial \mu}{\partial B}$$

Where n is the 2DES electron density and $\tilde{c}$ is capacitance.
We infer about 2DES magnetization using a Maxwell relation:

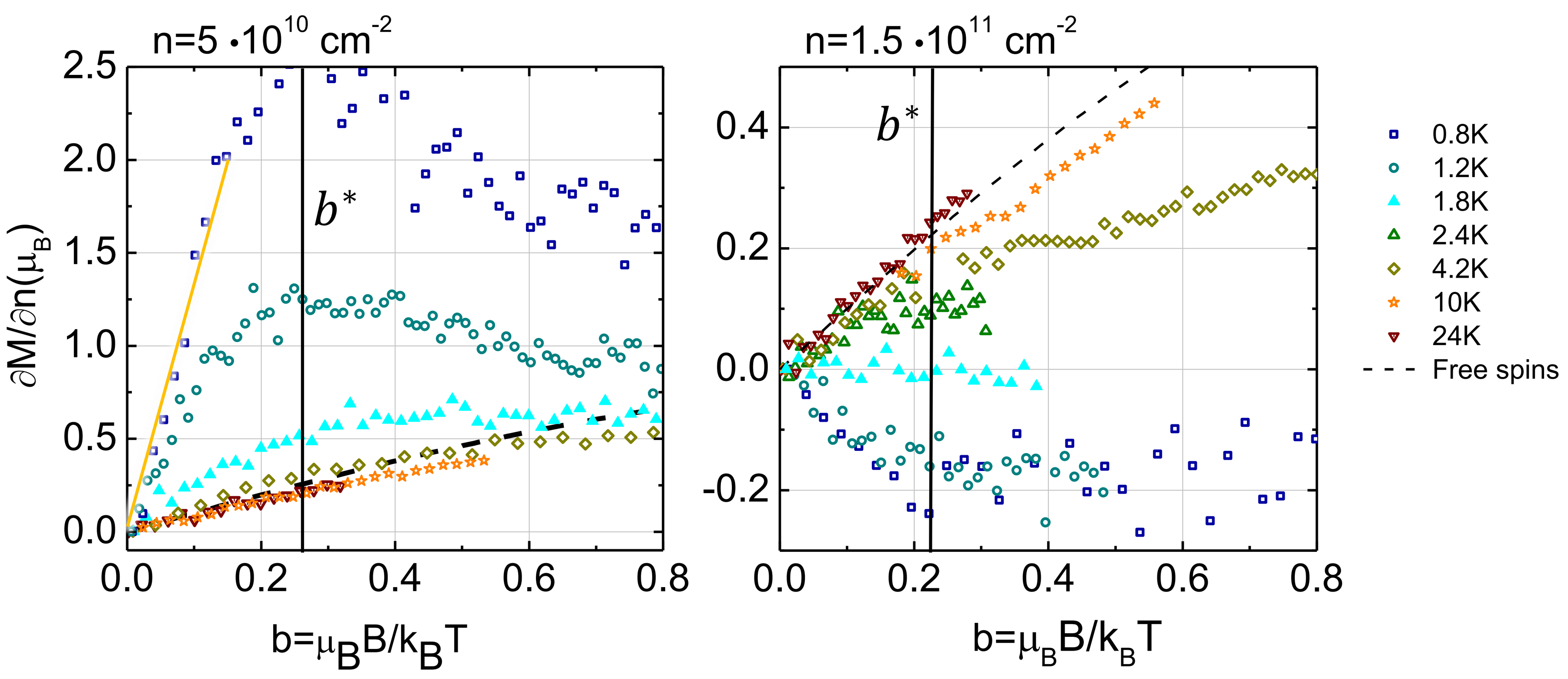
$$\left.\frac{\partial \mu}{\partial B}\right|_n = -\left.\frac{\partial M}{\partial n}\right|_B$$

We studied a high-mobility 2DES in (100) - Si MOSFET structures. In-plane magnetic field was modulated at a frequency ranging from 4 to 12 Hz and amplitude $< 40\text{mT}$. Measurements were performed over a wide range of temperatures (0.4-20K) in magnetic fields up to 9 T.





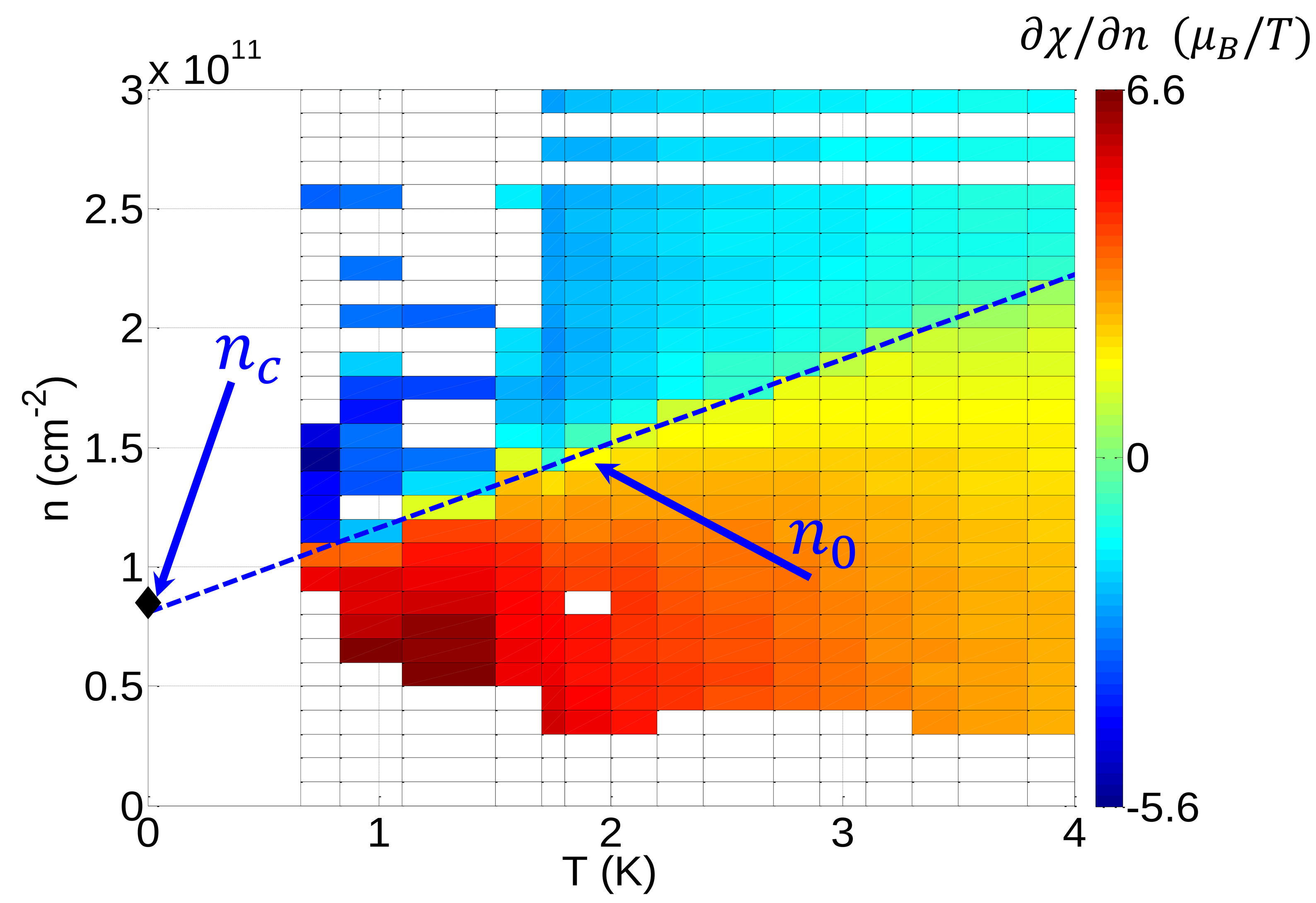
Results[3]



- Low-field slope of $\partial M/\partial n$ vs. normalized magnetic field b is much steeper than expected for an independent spin ½.
- $\partial M/\partial n$ vs. b is nonlinear.
- Low temperatures $\partial M/\partial n$ reaches a maximum at b^*, with $\partial M/\partial n > \mu_B$ (evidence for ferromagnetic interaction).
- $b^* \approx 0.25$ for a wide range of densities.

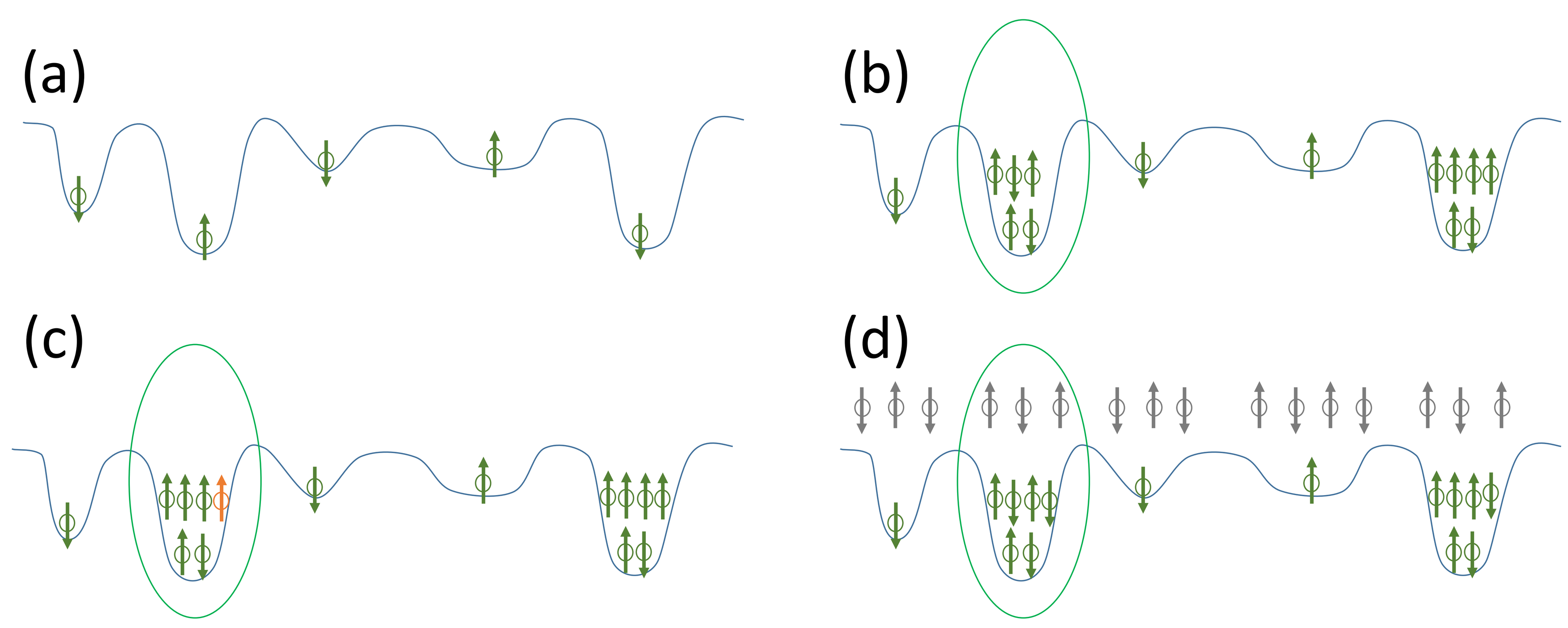
Relation to Metal Insulator Transition (MIT)

Color map shows $\partial\chi/\partial n$ vs. density n and temperature T.
We define $n_0(T)$ =n$(\partial\chi/\partial n = 0)$; it extrapolates to n_c, the Metal Insulator critical density, at $T = 0$.



Physical Picture

Our system is imperfect, therefore potential across the 2DES is inhomogeneous.



a) At low densities each of the disorder-induced potential wells is populated by up to one electron, due to Coulomb repulsion.
b) As the density is increased Coulomb interaction favors droplets with large spin in order to gain exchange energy.
c) Adding an electron can flip the spin of another electron. Hence, $\partial M/\partial n$ can exceed μ_B.
d) For even higher densities screening becomes dominant, itinerant electrons interact with electrons in a droplet, reducing the total spin: adding an electron to the system reduces the total magnetization, leading to $\partial M/\partial n < 0$. At very high densities adding an electron to the system doesn't change the magnetization, hence $\partial M/\partial n$=0 .

Summary

We present experimental evidence for the existence of spin droplets on both side of the MIT, with typical total spin $J = 1/2b^* \approx 2$.

References

[1] O. Prus et al. PRB **67**, 205407 (2003)
[2] M. Reznikov et al. JETP Letters **92**, 7 pp.470-474 (2010)
[3] N. Teneh et al. PRL **109,** 226403 (2012)