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# Exploring Two-dimensional Electron systems at Extreme Magnetic Fields with Optical and Terahertz 2DFT Spectroscopy

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## Introduction

The main objective of this proposal is the investigation of the fundamental many-body interactions of two-dimensional electron and hole gases at high magnetic fields. The main experimental goal in the proposed work is to perform coherent four-wave mixing (FWM) and two-dimensional Fourier transform (2DFT) experiments systematically on the GaAs/AlGaAs and transition-metal dichalcogenides (TMD) materials.

## Experimental

We have measured 2DFT spectra from one undoped and one modulation doped GaAs/AlGaAs quantum well at different magnetic fields from zero to 25 Tesla. We have performed preliminary absorption and FWM measurements. We also collected preliminary data on $MoSe_2$ and $WSe_2$ up to 25 Tesla. The measurements were taken in cell 1 and 5.

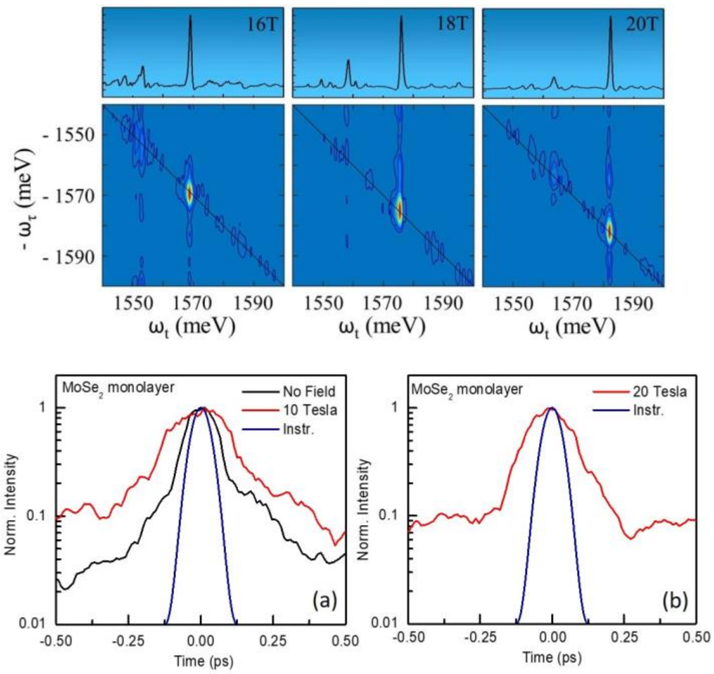


**Fig1**. (Top) 2DFT spectra of quantum wells collected in cell 5 using the split helix magnet. (Bottom) Time-integrated FWM spectra of monolayer $MoSe_2$ collected at the split helix in cell 5.

## Results and Discussion

We have performed two-dimensional Fourier transform spectroscopy on undoped and modulation doped quantum wells in external magnetic fields as high as 25 Tesla. We have demonstrated the combined effect of Coulomb interactions and extreme quantum confinement on the electronic properties of two-dimensional electron gases, such as the validity of the jellium model and Kohn's theorem. In the regime of twofold quantum confinement, namely, in the out-of-plane direction provided by the quantum well barrier and in plane by the strong magnetic fields, the charge distributions of electrons and holes become strongly localized. The charge separation leads to an overlap region that is increasingly smaller with increasing magnetic fields and eventually becomes comparable to the in-plane unit cell. At this regime the microscopic details of the charge density distribution, namely the spatial fluctuations, become significant. This leads to a breakdown of the smooth charge assumption in the jellium model and brings the system outside the protective limit of Kohn's theorem. This breakdown is facilitated by the strong unscreened Coulomb interactions in the intrinsic sample. When the Coulomb interactions are weakened, the system returns to the usual assumption of smooth charge distribution and translation invariance along the plane. Physical Review B **95**, 245314 (2017)
Furthermore, we have also observed an interesting change in the excitonic dephasing of TMDs under magnetic fields up to 25 Tesla. This is an interplay between screening and bi-excitonic effects.

## Conclusions

We observe distinct differences in the Landau levels in the two samples. In the undoped sample we observe the formation of a novel state of matter that is generated by the Coulomb induced effects.

## Acknowledgements

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