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Wigner Crystal Phase Investigations in 2D Electrons on Helium Films

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Abstract: Wigner crystal is one of three important phases of the two-Dimensional Electrons System (2DES) on helium films. It represents the transition from the classical regime to the quantum regime and has many benefits in understanding the transport of the electrons in such a system. In this work, the Wigner crystal regime was observed and discussed in more detail and under well-defined conditions. The result shows a clear confirmation for the Wigner crystal at a density between 1010 and 1011 e/cm2 and suggests a new mechanism for the electrons transport. It also confirms that the melting of the Wigner crystal into a classical electron gas regime happened at a density of less than 1010 e/cm2.

Keywords: state electrons; Wigner crystal; Helium film; He-FET, Electrons mobility Surface.

1. Introduction

In general, low dimensional electron systems become a significant topic of modern electronics, and they are applicable to many system applications [1-2]. The advantage of surface state electrons (SSE) is that the density can easily be varied continuously from low value, where the system in the classical gas regime, through a Wigner crystal up to the degenerate Fermi gas. This is because the surface could be charged intentionally from a distinct electron source, actually, a tiny heated filament, in a very devoted way [3-5]. Prof. P. Leiderer's group has extensive experience with such systems [6-8], and I was a member of this group [9]. The first experimental observation for the Wigner crystal regime for 2D electrons on liquid helium was conducted by Gann, RC et al. in 1979 [10]. Their study has confirmed that the electrons move on the liquid helium surface can be in a state of locative disturbance. Or it can form a uniform structure known as a Wigner crystal. Since that time, many research works have been carried out to understand the 2-DES Wigner crystal regime in more detail [11-13]. In their last research, P. Brussarski et al. were found evidence for 2D electron Wigner crystal transport in solids by sliding [14]. Their conclusion guides us to compare it with the 2-DES Wigner crystal on helium films by using our rather simple experimental setup in more detail and under well-defined conditions.

2. Materials and Methods

Three separate volumes cryostat of 4He bath has been used in this work. The helium level and thus the helium film was determined through a helium level capacitor and controlled by using a step motor attached to the insert which holding the sample inside the cryostat. The samples used in these measurements resembled field-effect transistors, and we call it He-FET in our previous works [09,15,16]. The technique used in such measurements was done using the electrodes of the He-FET and electrometers to apply the voltage and measure the current simultaneously with high sensitivity (pA). A negative voltage (≈ -1.0 V) is connected to the guard of the He-FET to preventing electrons from going out of the sample. And so that the experiments were done under a condition better than before for such a system.

3. Results and Discussion

The more important issue in our measurements is the stability of the pick-up current which indicates that the electrons have relatively constant mobility through the gate constriction. The first study of the stability of the SSE in liquid helium was carried out by SA Jackson and PM Platzman [17]. They proved that the SSE is more stable in a film rather than bulk helium. The first pump run of the experiment shows clearly the transition from bulk helium to helium film and its effect of the dc-measurements, see Figure 1.

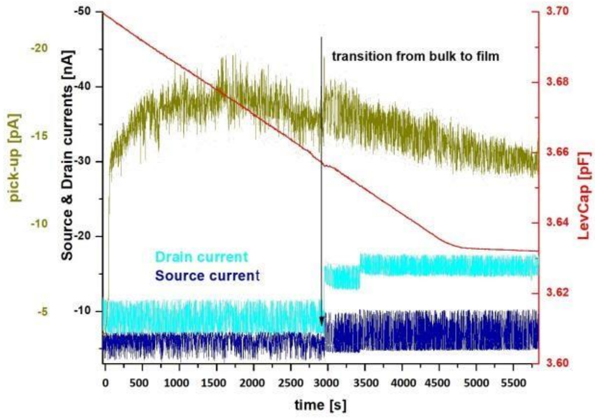
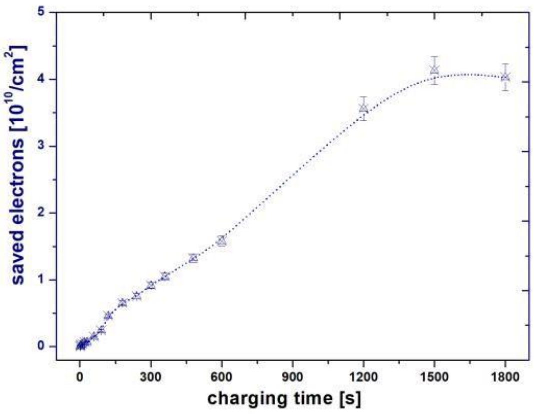


Figure 1: Transition from bulk to film during the experiment run

The model of the number of saved electrons and the potential distribution [12], has been used to explain the transport of the electrons in the Wigner crystal regime. According to the phase diagram of surface state electrons on liquid helium, the Wigner crystal phase can be observed at electron density greater than 1010 e/cm2. In our result, this value has been achieved with high accuracy and simple method. Figure 2 shows the electron density which achieved experimentally as a function of charging time. The graph looks more or less linear and tends to saturation at a long charging time. This saturation is due to the gate potential barrier and the potential distribution across the sample [12]. This result gives the first indication of the Wigner crystal phase and it should be supported by another physical confirmation. It is well known that the electrons have the lowest mobility at the Wigner crystal regime. Let us assume that the electrons transporting in a sliding way of motion, then due to Coulomb interaction we should expect a long time for the electrons to cross the gate channel. Also, we should expect a breakdown of the Wigner crystal after a 20. while and this is actually what we observed in our experiment.



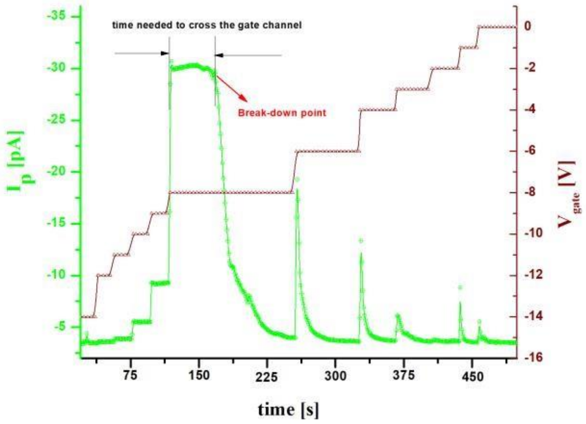


Figure 2: The Electron density that experimentally achieved as a function of charging time

Figure 3: The Picked-up electrons (Ip) as a function time after saving them at the source for a period of time

As we can see from figure 3, when the gate is opened partially (from -9V to -8V), the Wigner crystal electrons take about 60 seconds to cross the gate channel. After that, since most of the electrons were passed through the channels, the electron density in the source area was decreased to a value below 1010 e/cm2. Thus, the Wigner crystal breaks down into a classical gas regime and the sharp beaks in the pick-up current (Ip) confirm this hypothesis. The sharp beaks mean that the mobility of the electrons is increased suddenly due to the phase transition from Wigner crystal to classical gas. These results and its discussion give a good explanation for the electron transport in the Wigner crystal regime and interpret the motion mechanism of the electron in such a regime in a sliding way.

4. Conclusions

Wigner crystal regime was observed and discussed in more detail and under well-defined conditions. Furthermore, a new explanation for the electron transport in the Wigner crystal phase has been discussed and the motion mechanism of the electron in such a regime has been interpreted in a sliding way.

Author Contributions: Authors contributed equally in this paper.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix B

All appendix sections must be cited in the main text. In the appendixes, Figures, Tables, etc. should be labeled starting with 'A', e.g., Figure A1, Figure A2, etc.

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