Novel Pressure-induced Phenomena in Condensed Matter Systems
J. Phys. Soc. Jpn. **76** (2007) Suppl. A, pp. 196-197

Charge Transport in Quasi-One-Dimensional Electron System on Liquid Helium

R. Kobayashi[1], I. B. Berkutov[1], S. Yamanaka[1,2], T. Arai[2] and H. Yayama[1]

[1]*Department of Physics, Kyushu University, Fukuoka 810-8560, Japan*
[2]*LTM Center, Kyoto University, Kyoto 606-8502, Japan*

(Received August 1, 2006)

We measured the electrical conductivities of quasi-one-dimensional (Q1D) electron systems on liquid helium surface as a function of temperature between 0.04 and 1.7 K. We prepared two kinds of the Q1D system with different materials. In the first system, the electrons were confined in a one-dimensional geometry on a suspended surface of liquid helium within multi channel made over plastic optical fibers. In the second system, the electrons were similarly confined in a single narrow channel made over metallic electrodes. In both systems, the electrical conductivity increased first with decreasing temperature, and passing through a maximum started to decrease. The magnitude of the maximum for the second system was much smaller than that of the first one. The peak temperature was 0.8 K for the first system and 1.2 K for the second system. From these results, we could deduce that the electrons localize near the edge of the channel at low temperature. This localization was possibly connected to the surface roughness of the substrate suspending the helium surface.

KEYWORDS: quasi-one-dimensional electron system, surface state electron, helium

1. Introduction

A unique idea to create a Q1D electron system on liquid helium was proposed, reducing a dimension of 2D surface state electron system.[1)] The idea is based on the formation of an electron chain in a 1D helium channel. The 1D helium channels are made by using a 1D optical grating on which grooves are formed by mechanical scratching or chemical etching. When the lower part of the grating is immersed in superfluid helium, it comes up and covers the surface of the grating. The grooves on the surface of the grating are filled with superfluid helium by a capillary force. Electrons supplied from the tungsten filament sit on these helium channels, and the Q1D electron chains are created.

Since the surface of the superfluid helium is automatically smooth and there is no impurity in low temperature, the Q1D system thus made is more ideal compared with that in semiconductor quantum wire.

After this idea, some variants have been reported: micro fabrication technique,[2)] other type of optical grating,[3,4)] nylon fishing lines,[5,6)] metallic plates,[7)] *etc*. are used to suspend the helium surface. In those systems, the decrease in electrical conductivity with decreasing temperature has been observed below ~1 K. This behavior has not been expected theoretically. To explain this anomalous behavior, concepts of "electron ordering"[2,8)] or "polaronic effect"[5,6)] are proposed. Alternative explanation is a localization of electrons near the edge of the channel.[3,4)] However, since there is no direct evidence so far, the origin of this anomaly is still in question.

In the present research, we prepared two types of Q1D system and compared the conductivity results, in order to clarify the origin of the anomalous behavior.

2. Experimental

The basic concept how to create Q1D electrons is the same as that developed in refs. 1,5-7. As a substrate material which suspends the helium surface, we adopted plastic optical fibers (we call this "the plastic system"), and copper material ("the metal system").

2.1 The plastic system

The experimental arrangement in the plastic system is schematically shown in the inset of Fig. 1. Fifty optical fibers in diameter 0.24 mm are placed above identical driving and measuring electrodes, with a size of 8 x 15 mm^2. The superfluid helium flows over the fibers and fills the spaces between the fibers. The surface of the helium sags in the center of the gap with a mechanical balance between the gravity and the surface tension of the helium. This sag leads to the formation of 1D channels between the fibers.

The lower electrodes were held at zero potential and a negative potential was applied to the upper electrode to create a vertical electric field. The electrons supplied from a tungsten filament located near the upper electrode are pressed onto the helium surface by the vertical electric field. Under the action of the electric field and due to the curvature of helium surface, the electrons are collected in the center of the grooves to form Q1D chain. The method for measuring the conductivity of electrons is the same as that in ref. 6.

2.2 The metal system

The inset of Fig. 2 schematically shows the arrangement of electrodes in the metal system. The electrodes are made of copper metal without any dielectric supports to prevent the electrons from sticking to them. When the top of the electrodes is located at a height 1.0 mm above the level of bulk liquid helium, the 0.2 mm gap is filled with superfluid helium by a capillary force. Similarly as in the plastic system, a single helium channel is formed in the gap.

Electrons are supplied briefly turning on a tungsten filament located above the electrodes. The electrons supplied onto the electrodes readily flows into the electrodes. The gate electrode produces an electric field to press the electrons downward onto the surface of liquid helium. Since the surface of the helium has a curvature as shown in the inset of Fig. 2, the electrons are forced to move to the center of the channel to form Q1D chain. The electrons are driven by an AC electric field along the channel. The conductance is calculated in the same way as shown in ref. 9 which is based on an equivalent circuit.

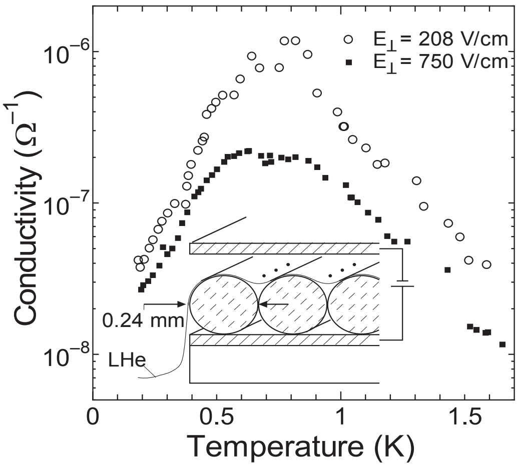

Fig. 1. The conductivity of electrons as a function of temperature for the different pressing fields in the plastic system. Inset is a cross section view of the plastic system.

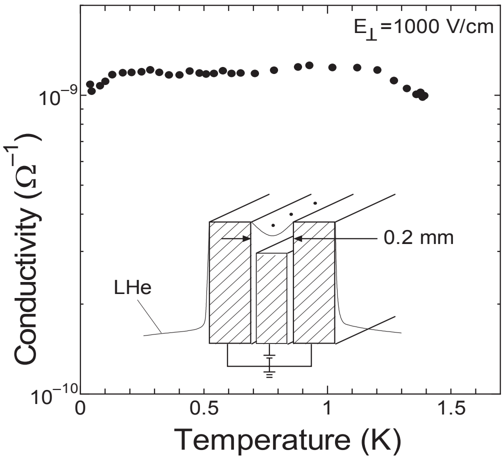

Fig. 2. The conductivity of electrons as a function of temperature in the metal system. Inset is a cross section view of the metal system.

3. Results and Discussion

Figure 1 shows the conductivity of electrons in the channel made of curved helium surface suspended by the plastic optical fibers (the plastic system). The two curves show a similar behavior. Neglecting small noise, it is seen that, with decreasing temperature from 1.7 K, the conductivity increases first but starts to decrease passing through a large maximum around 0.8 K. Near the maximum, the conductivity is lower in higher pressing field. These data show similar behavior as those of other experiments[2-6] made so far.

The thickness of the helium is thin near the edge of the channel in the plastic system. When the electrons exist near the edge of the channel, the distance between the electron and the dielectric (optical fibers) is small, and so the electron feels the image force from the dielectric strongly. The surface of the optical fibers is not smooth in microscopic size. Therefore, the electrons feel random potentials which are caused by the surface roughness of the optical fibers.

In low temperature region ~0.2 K, the electrons near the edge of the channels are captured by these random potentials. However, as the temperature increases, the captured electrons are released by thermal excitation and contribute to the carrier transport. As a result, the conductivity increases as the temperature increases up to 0.8 K. However, above 0.8 K, the conductivity decreases because the electrons are scattered by helium gas atoms[9,10] whose density increases exponentially with temperature. The behavior in Fig. 1 is thus explained.

Figure 2 shows the conductivity of electrons in the groove made of curved helium surface suspended by the metallic electrodes (the metal system). The absolute value is much smaller than that in the plastic system because the number of channels is 1/50 times less than the plastic system. The temperature dependence is not very strong, but it shows small two peaks at 1.2 K and 0.2 K. Theoretical[10] and experimental[4,7] investigations have revealed that the peak at 0.2 K is a transition from the ground state to the excited states for the electrons in a parabolic potential well which is formed by the vertical electric field and the surface curvature of the helium.

It is obviously seen that there is no large peak in Fig. 2 as that in Fig. 1. If we assume that the peak at 1.2 K in Fig. 2 is originated in the same physical mechanism as for the plastic system, the magnitude is much smaller. The reason why the magnitude of the peak is much smaller is attributed to that little amount of the electrons are captured by the roughness of the substrate surface. Although there is no dielectric in the metal system, the copper electrodes are exposed in the atmospheric air before cooling and the surface is a little oxidized. The electrons can be captured by the oxide layer but the number is much less than that on dielectric. This oxide layer might be connected to the small peak at 1.2 K.

4. Conclusion

We measured the conductivity of Q1D electrons on liquid helium in two different systems. The temperature dependence of the conductivity showed different behavior in the two systems. This difference is attributed to the localization of electrons near the edge of the channel in the system with dielectric substrate. The localization originates in the electron capture by the random potential formed by the surface roughness of the substrate material.

1) Yu.Z. Kovdrya V.A. Nikolaenko: Sov. J. Low Temp. Phys. 18 (1992) 894.
2) P. Glasson, V. Dotsenko, P. Fozooni, M.J. Lea, W. Bailey and G. Papageorgiou: Phys. Rev. Lett. 87 (2001) 176802.
3) H. Yayama, A. Tomokiyo, O.I. Kirichek, I.B. Berkutov, Yu.Z. Kovdrya: Low Temp. Phys. 23 (1997) 878.
4) Hideki Yayama and Igor B. Berkutov: Physica E 18 (2003) 171.
5) S.P. Gladchenko, Yu.Z. Kovdrya and V.A. Nikolaenko: J. Mol. Liq. 120 (2005) 175.
6) S.P. Gladchenko, V.A. Nikolaenko, Yu.Z. Kovdrya and S.S. Sokolov: Low Temp. Phys. 27 (2001) 1.
7) S. Yamanaka, T. Arai and H. Yayama: Proc. Int. Conf. Low Temp. Phys. LT24, Orlando Florida, 2005, AIP Conf. Proc. Vol. 850 (2006), pp. 1460.
8) G. Piacente, I.V. Schweigert, J.J. Betouras and F.M. Peeters: Phys. Rev. B 69 (2004) 045324.
9) Y. Iye: J. Low Temp. Phys. 40 (1980) 441.
10) S.S. Sokolov, G.-Q. Hai and N. Studart: Phys. Rev. B 51 (1995) 5977.