《H28　様式　甲２の１／Style Kou 2-1》

学位論文の要旨

Abstract of Thesis

研究科 School	自然科学
専　攻 Division	地球生命物質科学
学生番号 Student No.	５１４２６２０１
氏　名 Name	上杉　英里

学位論文題目 Title of Thesis（学位論文題目が英語の場合は和訳を付記）

Study on novel physical properties induced by electrostatic carrier doping of two-dimensional layered materials
（二次元層状物質への静電的キャリアドーピングによる新規物性の開拓に関する研究）

学位論文の要旨 Abstract of Thesis

Electrostatic carrier doping has attracted much attention during a past decade because of a successful achievement to induce the novel physical properties such as metal-insulator transition,[1] spin polarisation,[2] circularly polarised luminescence,[3] ferromagnetism[4] and superconductivity.[5–7] Furthermore, an electronic device based on electrostatic carrier-doping, *i.e.*, field-effect transistor (FET) is a core element of modern electronics, and the progress of performance of FET device is a very significant task from technological point of view. Therefore, the study on electrostatic carrier doping is one of the most fascinating and significant research themes from viewpoint of both science and technology. For these reasons, the author has been studying electrostatic carrier doping of some low-dimensional chained (one-dimensional (1D)) and layered (two-dimensional (2D)) materials which have a high profile from view of materials science, electronics application, and solid state physics. Some materials are the most attractive quantum materials which may be understood within a framework of relativistic quantum mechanics. The final goal of this study is to clarify and detect the interesting physical and electronic properties of various low-dimensional materials using the technique of filed-effect carrier-doping. Furthermore, the author aims to tune the physical and electronic properties of the materials using filed-effect carrier-doping, and to induce novel physical properties, in particular superconductivity. The concreate purpose of this study is described below, in

connection with each chapter.

In chapter 1, a scientific background of this Doctor thesis is fully described, and the author clarifies the reason why this research is considered appropriate for her Doctor thesis *via* a historical overview of ‘field-effect carrier-doping’. The concreate purpose and motivation of the study is described in chapter 2. Her main studies are written in chapters 3 - 7 and summarised in chapter 8. She gives a comment for significance of the Doctor thesis in chapter 9. Through chapters 3 - 7, the author reports transport properties of various interesting materials, transition-metal dichalcogenides (TMDs) (chapter 3), low-dimensional Bi-based compounds (chapters 4 and 5), topological insulators (chapter 6) and graphene (chapter 7), which are electrostatically carrier-accumulated.

In chapter 3, the author explains FET properties of one of ideal 2D layered materials, $Mo(Se_{1-x}Te_x)_2$. The transistor properties of 2*H*-$Mo(Se_{1-x}Te_x)_2$ single-crystal FET is fully investigated with x-range of 0 to 1. The change of polarity in FET characteristics (n-channel to p-channel or ambipolar) with increasing x and the parabolic variation of μ value (the minimum μ at x = 0.41) against x were observed in the thin single-crystal FET. These results could be explained based on the variation of the electronic structure depending on x, and the static disorder due to mixing of Se and Te.

In chapter 4, FET properties of a new class of low-dimensional materials are mentioned. The target materials are the 1D and 2D Bi compounds, Bi_2CuO_4 and $LaOBiS_2$. For single-crystal Bi_2CuO_4, the p-channel operations in FETs with EDL capacitors are reported for the *aa* and *ac* planes. The FET characteristics in the *aa* plane of $LaOBiS_2$ were observed in devices with both SiO_2 gate dielectric and EDL capacitor using ionic liquid, and it showed n-channel operation, *i.e.*, electron accumulation. This study became the preliminary step for the filed-effect induced control of physical properties realized in chapter 5.

The author reports a field-effect induced superconductivity in $LaOBiS_2$, achieved by electrostatic electron-doping using EDL capacitor in chapter 5. In the temperature (*T*) dependence of resistance (*R*), the *R* decreased at 3.6 K and the *R*-drop disappeared with an application of high magnetic field, implying a superconducting state. This study reveals that electron-doping is necessary for inducing superconductivity in $LaOBiS_2$, as in $LaO_{1-x}F_xBiS_2$. The EDL FET was demonstrated to be a powerful tool for a high-density carrier-accumulation in BiS_2-layered materials.

In chapter 6, the author applies the EDL FET technique for topological insulator which is one of the most attractive objects in current solid state physics. Metallic behaviour in Bi_2Se_3 changed to insulating one through Ag-doping, *i.e.*, the Ag-doping of Bi_2Se_3 can move the Fermi level downward so that the Fermi level crosses the surface states. $Ag_xBi_2Se_3$ showed an insulating behaviour in the T-dependence of resistivity (ρ) above 35 K, but below 35 K, ρ suddenly decreased with decreasing T. Furthermore, an application of positive gate voltage in $Ag_xBi_2Se_3$ EDL FET produced a metallic behaviour. These results show that hole-doping through the replacement of Bi^{3+} by Ag^{+} and electrostatic electron doping can tune the Fermi level of Bi_2Se_3 precisely.

In chapter 7, the author proposed a new type of EDL FET device utilizing graphene edge. The transport properties of graphene edge EDL FET were different between zigzag and armchair forms. Actually, a conductance peak (flat band) ascribable to the singular electronic state was detected around the charge neutrality point of transfer curve in zigzag-edge EDL FET, while such a peak was not detected for armchair-edge. It has been found from the T-dependence of transfer curve that the observation of a flat band in zigzag-edge EDL FET device originated from the hopping transport between zigzag edges, implying that zigzag and armchair edges are intermixed in the graphene edge used for the EDL FET.

Thus, the author evidenced an importance and an effectiveness of electrostatic carrier doping for the clarification of physical / electronic properties, the control / tuning of electronic properties and the induction of novel physical properties such as superconductivity throughout a whole of this thesis.

References

[1] H. T. Yuan *et al.*, *Adv. Funct. Mater.* **19,** 1046 (2009).
[2] H. T. Yuan *et al.*, *Nature Phys.* **9,** 563 (2013).
[3] Y. J. Zhang *et al.*, *Science* **344,** 725 (2014).
[4] Y. Yamada *et al.*, *Science.* **332,** 1065 (2011).
[5] A. T. Bollinger *et al.*, *Nature* **472,** 458 (2011).
[6] J. T. Ye *et al.*, *Nature Mater.* **9,** 125 (2010).
[7] K. Ueno *et al.*, *Nature Mater.* **7,** 855 (2008).