

Fundamental Study on Designed Synthesis of Single Crystalline Metal Oxide Nanowires by A Vapor-Liquid-Solid Process

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Name

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A Vapor-Liquid-Solid Process

(気液固成長プロセスを介した単結晶金属酸化物ナノワイヤの構造・機能設計に関する
基礎的研究)

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Category

論 文 内 容 の 要 旨 Thesis Summary

This thesis has been devoted to fundamental study on designed synthesis of single crystalline metal oxide nanowires by a vapor-liquid-solid (VLS) process. This kind of nanowires attract much attention due to their unique physical properties and various applications. However, the species of functional metal oxide nanowires formed by VLS method are limited without understanding the underlying growth mechanism although the oxide system must be more complex due to its multi-element system. Furthermore, the VLS process of metal oxides in general requires relatively high growth temperatures. In addition, as semiconductors, wide range control of carrier density has played an essential role on developments of devices. Such wide range control of carrier density of oxide nanowires has been impossible due to the occurrence of unintentional carrier doping. These problems of oxide nanowires would essentially limit the wide range of its applications. This study aims to solve the problems mentioned above. The details are shown as follows;

Firstly, I show a strategy to firstly fabricate single crystalline NiO nanowires via VLS route, which essentially expands the material species of novel oxide nanowires via VLS process. My strategy is based on the suppression of the nucleation at vapor-solid (VS) interface, which promotes the nucleation only at liquid-solid (LS) interface. Furthermore, this strategy allows us to reduce the growth temperature of single crystalline NiO nanowires, which is the lowest growth temperature so far reported.

Secondly, I propose a rational concept to reduce the growth temperature in VLS growth process of various metal oxide nanowires. Molecular dynamics (MD) simulation theoretically predicts that it is possible to reduce the growth temperature in VLS process of metal oxide nanowires by precisely controlling the vapor flux. Experimentally, I found the applicability of this concept for reducing the growth temperature of VLS processes for various metal oxides including MgO, SnO₂ and ZnO. In addition, I show the successful applications of this concept to VLS nanowire growths of metal oxides onto tin-doped indium oxide (ITO) glass and polyimide (PI) substrates, which require relatively low growth temperatures.

Finally, I demonstrate 6 orders of magnitude control of electrical conductivity of single crystalline Sb-doped SnO₂ nanowires grown via VLS process with the spatial homogeneity of dopants. This electrical conductivity range via an intentional impurity doping is the widest of the ones in metal oxide semiconducting nanowires reported so far. Strictly tailoring two crystal growth interfaces (LS and VS) via a flux control is required to suppress an unintentional carrier doping during a crystal growth in the presence of impurity dopants. This is because an unintentional carrier doping occurs at VS interface, controlling a crystal growth only at LS interface is essential to promote an intentional impurity doping at LS interface. In addition, the presence of Sb dopants strongly enhances a SnO₂ crystal growth at VS interface, which requires further strict flux controls to suppress a detrimental unintentional carrier doping, as theoretically revealed by molecular dynamics simulations. This wide range electrical controllability of single crystalline metal oxide nanowires will be a foundation to design various electronic and energy device applications utilizing their semiconducting properties.