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（博士課程）
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論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	材料 Materials Science and Engineering	系 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of	（Engineering）
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

In this thesis, I have developed and established the fabrication processes of robust and ultra-fine Pt-based nanogap electrodes with sub-3nm in gap separation and sub-20nm in linewidth for the realization of single-electron transistors (SETs) or single-molecular transistors by electron beam lithography (EBL) and electroless gold plating (ELGP) as mass-production possible method.

In order to fabricate the robust and ultra-fine nanogap electrodes, I have changed the base electrodes material from Au to Pt for the narrow source/drain (S/D) linewidth on 10nm scale and for the robust thermal stability against Rayleigh instability. By the optimization of nanogap design, dose exposure, and several EBL processes, ultra-fine Pt-based nanogap electrodes with 10 nm in S/D linewidth were fabricated and robust thermal stability was obtained up to 773 K in Chapter 2.

For obtaining sub-3nm-scale gap separation in these ultra-fine Pt-based nanogap electrodes, which is suitable for the size of single nanoparticle (NP) or single molecule toward the room temperature (RT) operable SET and single-molecular transistor, ELGP processes over ultra-fine Pt-based nanogap electrodes were developed. By the introduction of pre-treatment process and the optimization of several plating conditions, the controllability of sub-3nm in gap separation and sub-20nm in S/D linewidth over Pt-based nanogap electrodes was achieved by uniform-ELGP (U-ELGP) and hemispheric-ELGP (H-ELGP) in Chapter 3. Moreover, these ultra-fine ELGP Pt-based nanogap electrodes with sub-3nm in gap separation and sub-20nm in S/D linewidth have shown the strong durability against Rayleigh instability.

Finally, in order to check the effect of the ultra-fine Pt-based nanogap electrodes on SET operation, the chemically assembled SETs by chemisorbing Au NP and the colliodal InP@ZnS quantum dot (QD) as Coulomb island were fabricated and evaluated in their electrical properties as a function of operation temperature in Chapter 4. Consequently, the stable SET operation was achieved by large gate capacitance originated from sub-20nm-scale ultra-fine S/D linewidth. Moreover, InP@ZnS QD SET have shown the stable switching characteristics and unique hysteresis behavior in I – V characteristics.

I summarized this thesis by every chapters as follows:

• Chapter 1: Introduction

I explained the requirement and necessity of nanogap electrodes for the realization of nanoscale transistor such as SETs and single molecular transistors and then, introduced several fabrication methods for nanogap electrodes. I introduced the basic operation principle and reports of SET and molecular device. Finally, I suggested the objective of this thesis

• Chapter 2: Development of Fabrication Processes for Ultra-Fine Patterned Pt-based Nanogap Electrodes

For the fabrication of the robust and ultra-fine nanogap electrodes with very small gap separation and very narrow S/D linewidth for large gate capacitance, Pt as base electrodes material

and EBL were introduced because Pt has the higher melting point and smaller surface diffusion coefficient compared with Au, and EBL is mass-production available process. By optimizing nanogap design, dose exposure and EBL processes, robust Pt-based nanogap electrodes with 10 nm-scale in ultra-fine linewidth have been fabricated on SiO_2/Si substrates. In order to check the robustness of these ultra-fine Pt-based nanogap electrodes, several stability tests were carried out. As results, ultra-fine Pt-based nanogap electrodes maintained their structure unchanged up to temperatures of 773 K. In contrast, ultra-fine Au-based nanogap structure could not be fabricated using EBL process; they deformed into droplets owing to Rayleigh instability. This robust thermal stability of ultra-fine Pt-based nanogap electrodes was attributed to the low surface diffusion coefficient of Pt. Finally, the structural robustness of the developed ultra-fine Pt-based nanogap electrodes has been demonstrated in thermal, chemical and mechanical aspect.

• Chapter 3: Development of Electroless Au Plating (ELGP) Processes over Pt-based Nanogap Electrodes

To obtain sub-3nm in gap separation of ultra-fine Pt-based nanogap electrodes, ELGP processes was developed. For obtaining the clean Pt surface before ELGP process, several pre-treatments were investigated. As results, U-ELGP and H-ELGP over ultra-fine Pt-based nanogap electrodes could be selected and controllable by pre-treatment condition. By optimization of plating solution concentration and time, sub-3nm in gap separation and sub-20nm in S/D linewidth were fabricated by self-termination mechanism. Moreover, from the cross-sectional structure analysis of ultra-fine H-ELGP Pt-based nanogap electrodes by SEM, STEM and TEM, ultra-small gap separation as less than 1nm was verified and Au growth over the Pt polycrystalline was confirmed. In addition, these unique hemispheric nanogap ends structure at the gaps could improve the SET operation characteristics owing to the larger gate capacitance originated from additional reduction of S/D linewidth at the gaps. Finally, robust thermal stability of ultra-fine ELGP Pt-based nanogap electrodes was demonstrated by comparing with the previous ELGP Au-based nanogap electrodes.

• Chapter 4: Application of Ultra-Fine Pt-based Nanogap Electrodes for Single-Electron Transistors (SETs)

In order to confirm the effect on SET operation and to explore SET with new functionality by using the developed ultra-fine Pt-based nanogap electrodes, the chemically assembled SETs by chemisorbing Au NPs and InP@ZnS QDs between gap were fabricated and evaluated in their electrical properties as a function of operation temperature.

By comparing with the previous SET results by ELGP Au-based nanogap electrodes with 40~90 nm in linewidth, the stable SET operation by ultra-fine Pt-based nanogap electrodes was confirmed owing to large gate capacitance originated from 10nm-scale ultra-fine S/D linewidth. Moreover, by introducing InP@ZnS QD as Coulomb island, the stable SET operation by ultra-fine S/D linewidth was verified again and the unique hysteresis behavior in $I - V$ characteristics was obtained.

• Chapter 5: Conclusions

I summarized this thesis of study on fabrication processes of ultra-fine Pt-based nanogap electrodes. And then, I suggested future work to improve fabrication yield and mentioned the future perspective of ultra-fine Pt-based nanogap electrodes