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著者(和文)	SIMANULLANG MAROLOP
Author(English)	Marolop Simanullang
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Student name: Marolop Dapot Krisman Simanullang

Student ID: 11D14060

Title of the thesis: Low-temperature growth of Ge nanowires for electron device application

Abstract

This thesis describes the growth of germanium nanowires (Ge NWs) at low temperatures for electron device application. Ge NW, as one of the one-dimensional semiconductor materials, has been extensively studied during the last few years because it promises to play a key role in emerging applications of nanoscale electronic devices, photonic devices, and sensors. We have successfully grown Ge NWs at temperatures even far below the eutectic temperature of the AuGe alloy (by 100 C). This thesis can be divided into eight chapters.

Chapter 1 (Introduction)

Chapter 1 describes the motivation and objectives of this study. Germanium nanowires have unique advantages over other semiconductor nanowires: high hole mobility and relatively low growth temperature. Ge NW growth requires less thermal energy and therefore cheaper processing cost. Its lower growth temperature makes Ge NW attractive for device fabrication on low melting point, flexible substrates. This work aims at preparing straight and narrow Ge NWs with high quality at relatively low temperatures, developing the method for Ge NW surface passivation, and investigating the basic electrical properties of Ge NWs.

Chapter 2 (Experimental method)

Chapter 2 presents the experimental equipments used in this study to prepare and characterise Ge NWs and devices fabricated using the nanowires. Ultra-pure gold nanoparticles as the catalyst for Ge NW growth in this study were deposited using an electron beam evaporator. The Ge NWs were grown in a low-pressure chemical vapour deposition (LPCVD) reactor equipped with several gas precursors which are important in the semiconductor technology, such as Si_2H_6, GeH_4, and PH_3 that allows the in situ process to be carried out and therefore offers a possibility of semiconductor nanowires integration and synthesis of doped nanowires. Atomic layer deposition (ALD) as a reliable technique for depositing ultra-thin, conformal films with atomic

level controllability is used to deposit Al_2O_3 and HfO_2 for Ge NW surface passivation. The Ge NW devices were fabricated using ultra-high resolution electron beam lithography technique.

Chapter 3 (Germanium nanowire growth)

Chapter 3 discusses about the gold nanoparticles as the catalyst for Ge NW growth. This chapter includes the discussion about the nanoscale size effect on melting point of gold and eutectic temperature of the AuGe alloy. Ge NWs can be grown below the eutectic temperature of the AuGe alloy due to the nanoscale size effect. The effect of the surface condition is also discussed in this chapter by growing the Ge NWs on bare Si and Ge substrates and SiO_2 substrates.

Chapter 4 (Effect of temperature and precursor partial pressure)

Chapter 4 describes about the effect of the growth temperature on Ge NW density and geometry. To complement the observation, the effect of the partial pressure of GeH_4 on Ge NW geometry is also discussed. The Ge NWs in this chapter were grown via a single- and two-step growth technique. The Ge NWs with a straight structure can be grown at relatively low temperature and relatively high GeH_4 partial pressure or at relatively high temperature and relatively low GeH_4 partial pressure.

Chapter 5 (Mechanism of Ge nanowire growth)

Chapter 5 discusses the relationship between the size of the AuGe droplets and the dimension of the nanowire (length and diameter). How the diameter of the nanowire can be decreased by decreasing the growth temperature is also discussed in this chapter. The phenomena observed in this study can be explained using the Gibbs-Thomson effect. By controlling the growth temperature and tuning the size of the gold nanoparticles, we have successfully grown ultra-thin Ge NWs with diameter as small as 3 nm, the smallest diameter of the Ge NWs ever reported.

Chapter 6 (Microscopic study of Ge nanowires)

Chapter 6 presents the investigation of the microscopic structure of the Ge NWs using the transmission electron microscopy (TEM) technique. The Ge NWs were grown at low temperatures via a single-step and two-step growth techniques. The investigation includes the

gold diffusion, defects, and crystallinity difference between straight and tapered structure on the nanowires.

Chapter 7 (Fabrication and characteristics of Ge nanowires devices)

Chapter 7 presents the method for the passivation of Ge NW surface using aluminum oxide and hafnium oxide deposited via the atomic layer deposition technique. The basic electrical properties of the devices fabricated using uncoated nanowires and nanowires coated with aluminum oxide are also presented.

Chapter 8 (Conclusion and future work)

Chapter 8 gives the conclusion and possible works that may be implemented using Ge NWs. We have successfully grown straight and narrow Ge NWs with highly crystalline structure. We have found that aluminum oxide deposited via the ALD technique is promising for a long-term passivation of Ge NW surface.