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Thermoelectric power of catalyst-free GaAs nanowires grown by MBE-VLS method

J. H. Paek, M. Yamaguchi, and H. Amano

Department of Electrical Engineering and Computer Science, Nagoya University,
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
Phone: +81-(0)52-789-3638 E-mail : j_paek@nuee.nagoya-u.ac.jp

1. Introduction

Compound semiconductor nanowires (NWs) have been investigated because of their potential as the new application in electrical and optical devices of the next generation. NWs have been extensively studied by thermoelectric power measurement owing to their higher thermoelectric figure of merit, *ZT*, than the bulk [1]. The carrier density of NWs could be estimated from their Seebeck coefficient. Moreover, the *ZT*'s and carrier densities of InSb, ZnO and GaN NWs measured from thermoelectric power have already been reported [2, 3], however, the thermoelectric power of catalyst-free GaAs NWs has not been reported yet. In this study, we determined the thermoelectric power of catalyst-free Si-doped GaAs NWs grown on a Si substrate by MBE-VLS method which is combined molecular beam epitaxy (MBE) with a vapor-liquid-solid (VLS) method.

2. Experiment and results

The catalyst-free GaAs NWs were grown on Si using the MBE-VLS mechanism [4]. After organic chemical cleaning, the (111)Si substrate was transferred into the MBE chamber. The substrate was heat-treated at 580^{o}C for 5 min in arsenic atmosphere. Then Si-doped GaAs NWs were grown at 580^{o}C for 90 min. The growth rate of planar GaAs was 0.7 ML/sec. The As flux was ~10^{-5} torr. The average length and diameter of the NWs from scanning electron microscopy (SEM) images were about 35 µm and 60-200 nm, respectively (fig.1). The carrier density of the Si-doped (001) GaAs layer was $n=7.9\times10^{18}$ cm^{-3}, determined by Hall measurement. Photolithography and electron beam lithography (EBL) were used to fabricate the contact pads and electrodes, respectively. The Ti/Au (30 nm/120 nm) was used as contact pads and global marks which were formed by photolithography and deposition on a SiO_2/Si substrate. The sample was dipped in isopropyl alcohol where the GaAs NWs were dispersed by ultrasonic cleaning. After EBL for the electrode pattern, a Ni/Pd/Au (80nm/120nm/180nm) metal layer was deposited. The sample was also annealed at 300˚C for 1 min. The electrical characteristics of the GaAs NWs were measured by semiconductor parameter analyzer (Agilent Technologies 4155C). The inset of Fig.2 shows a SEM image of the device. A joule heater is used for making the gradient of substrate temperature. Two electrodes showed ohmic contact. The voltage between these electrodes was measured while the joule heater was being warmed. Figure 2 shows the result. As the electric current of the joule heater increased, the voltage changed nonlinearly, which means that quadratic current is dependent on temperature. Therefore, the thermo electromotive force ΔV_t was observed. From the sign of ΔV_t, the Si-doped GaAs NWs showed n-type conductivity. NWs have two growth modes : <111> axial growth and (110) side wall growth. Si atoms might be incorporated mainly in the (110) side wall [5]. Therefore, it is considered that this result is different from that obtained by another group owing to the lower growth temperature or higher As flux, which is the growth condition for n-type (110) GaAs [5-7]. Heat spreads hemi-cylindrically inside

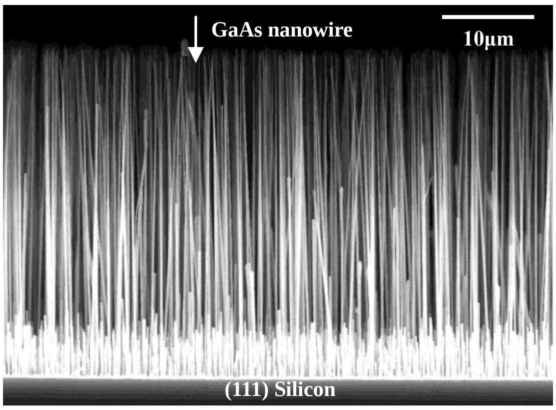

Fig.1 Catalyst-free Si doped GaAs nanowires grown on (111)Si substrate

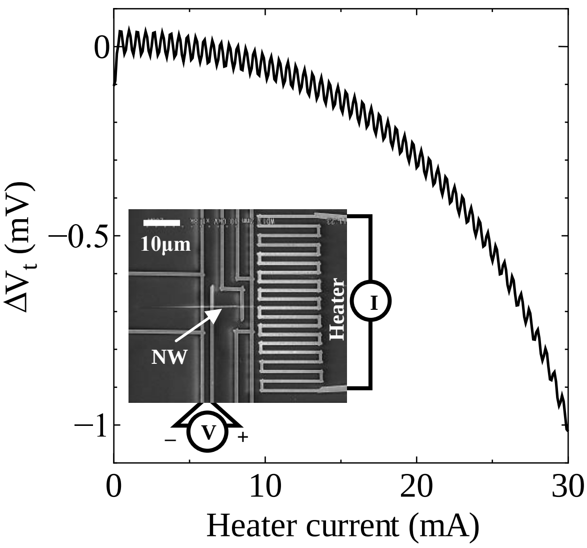

Fig.2 Thermoelectromotive force ΔV_t of catalyst-free n-type GaAs nanowire. Inset is the SEM image of the device

the Si substrate. Thus, the temperature difference ΔT between positions r_1 and r_2 of the two electrodes should be

$$\Delta T = \frac{2\pi\kappa Q}{l}\ln\left(\frac{r_2}{r_1}\right)$$

where κ is the thermal conductivity of Si, l is the width of the heater, and Q is the electric power of the joule heater. When ΔV_t is about -1 mV, the Seebeck coefficient could be calculated to be about -200 $\mu V \cdot K^{-1}$. The carrier density of Si-doped GaAs NWs is $n \sim 10^{18}$ cm^{-3} from bulk data [8].

3. Summary

The electrical characteristics of the Si doped GaAs nanowire grown by MBE-VLS method was estimated by the thermoelectric measurement.

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