Researching the electrical properties of single A3B5 nanowires

A A Vasiliev¹, A M Mozharov¹,², F E Komissarenko², G E Cirlin³, D A Buravlev³ and I S Muckin¹,²

¹Renewable Energy Lab, St. Petersburg Academic University, St. Petersburg 194021, Russia
²The metamaterial Lab, University ITMO, Saint-Petersburg 197101, Russia
³Epitaxial nanotechnology Lab, St. Petersburg Academic University, St. Petersburg 194021, Russia

E-mail: ftf.vasiliev@yandex.ru

Abstract. We investigate electrical characteristics of GaN, GaAs and GaP NWs which are grown with MOCVD and MBE. We developed measurement technique and it allows to determine the required properties of the structures.

1. Introduction

The A3B5 material systems can be applied to create LEDs, detectors, transistors, solar cells and others. However, there are several technologic difficulties such as obtaining high-quality and effective planar structures (in the case of GaN, etc.) and the high cost of production (GaAs, etc.). Therefore, it’s required to find new approaches to create the semiconductor structures. Nowadays, researchers carry out many experimental and theoretical work to understand the process of formation NWs and how they can be doped. NWs are rods, which diameter is much smaller than their length. Since the geometrical parameters, composition and doping level can be controlled, NWs can be successfully used to develop a lot of semiconductor devices [1,2].

1.1. Synthesis NWs

There are two most widely use growth technology: metal-organic chemical vapour deposition (MOCVD) and molecular beam epitaxy (MBE). Both technologies have some advantages and limitations. For example, MBE gives us atomic layered control of growth. In the case of using MOCVD the average growth speed is higher than in MBE. Using these technologies and different methods of growth NWs can be synthesized. The most common method is based on the vapour-liquisolid mechanism with metal catalysts [4,5]. In this work we investigate GaN, GaAs NWs which were produced by means of MOCVD and MBE [6,7,8].

1.2. Measurements

There are different measurement techniques which are used to determine electrical properties of planar semiconductor heterostructures. However, not some of them are suitable for measuring properties of NWs. Therefore, we developed a methodology for measuring the properties of single NWs.

In order to determine the electrical properties we need to create the ohmic contacts to single NW. Measuring the VAC we can calculate conductivity \( \sigma = 1/R = 1/V \). In order to independently determine the
carrier concentration and their mobility in the NW, it is necessary to use a transistor structure. It’s known, that conductivity is proportional to carrier concentration and mobility. However, field effects mainly depends on the concentration, therefore we can calculate carrier concentration using a transistor structure n=1/ερμ.

2. Experiment
In order to form ohmic contact to a single nanowire the following procedure was applied. The synthesized NWs were separated from the growth substrate with ultrasonic method and transferred to the quartz or Si/SiO2. Contacts were created using methods of the laser photolithography or electron lithography and thermal evaporation in a vacuum. For some samples annealing is required (annealing temperature depends on the sample). For producing the transistor structure, it’s necessary to form the third contact. It can be placed on the back side of the substrate, or on top of the structures.

2.1. Investigation of GaN NWs
We studied GaN NW’s conductivity, carrier concentration and mobility. We used MESFET structure to independently determine the carrier concentration and mobility. The drain/source ohmic contacts Ti/Al/Ti/Ag (30/150/30/100 nm, they were annealed at 710 °C) were formed on a quartz substrate as shown in Figure 1 (a). We measured VAC and determined that conductivity was 16 S/cm. The gate contact was evaporated with Pd (50 nm). Then we measured VAC of the gate and I_dvs from V_g as shown on Figure 1 (b, c).
Figure 1(a,b,c). Scheme of the transistor (a), VAC of the transistor (b), VAC through the gate for the source and drain contacts (c).

The contact of gate is made of aluminium (it is 300 nm thick and it was annealed at 690 °C). Contacts drain/source were formed from Ni/Pd/Zn/Pd (5/15/10/30 nm, without annealing). As a result of measurements, the following VAC characteristics of the NWs were obtained when different voltages were applied to the source/gate as shown in Figure 2 (b, c).

When the gate voltage increases, the NWs’s conductivity increases too. This is due to growth of the carriers density in the NW-electrons. Therefore, it can be concluded that the NWs is n-type.

2.2. Investigation of the type of doping of GaAs NWs

We investigated a type of GaAs NWs and needed to produce a transistor structure on a NW (figure 2a). For this we used a Si/SiO2 substrate (substrate is p-type, thickness of Si02 layer is 224 nm).

Figure 2(a,b,c). Scheme of the transistor (a), VAC of the transistor (b), VAC through the gate for the source and drain contacts (c).

The contact of gate is made of aluminium (it is 300 nm thick and it was annealed at 690 °C). Contacts drain/source were formed from Ni/Pd/Zn/Pd (5/15/10/30 nm, without annealing). As a result of measurements, the following VAC characteristics of the NWs were obtained when different voltages were applied to the source/gate as shown in Figure 2 (b, c).
When the gate voltage increases, the NWs’s conductivity increases too. This is due to growth of the carriers density in the NW-electrons. Therefore, it can be concluded that the NWs is n-type.

2.3. Investigation of the mobility and carriers concentration in GaAs-p type NWs

To estimate mobility and carrier concentration contacts were formed to a single NW on a quartz substrate. Contacts were created from Ni/Pd/Zn/Pd (5/15/10/70 nm). Because NWs were doped we got an ohmic contacts to some NWs without annealing as shown in Figure 3, annealing temperature is 405 °C).

From the obtained data, we estimated the value of \( n\mu = (0.5/5)10^{21} \text{ (V·s·cm)}^{-1} \). Using the dependence of \( n \) on \( \mu \) in the GaAs-p type, we could established that \( \mu \approx 50 \text{ cm}^2/(\text{V·s}), n\approx 10^{19} \div 10^{20} \text{ cm}^{-3} \).

3. Summary

In this work we developed the technique of measurements the electrical characteristics of single NWs. In according to this technique the properties of the single GaN and GaAs NWs were carried out. We can conclude that method allows to investigate different structures.

4. Acknowledgments

This work was carried out with the support of President grant (14.Z56.17.3632-MK), the Russian Foundation for Basic Research (150206839 A, 16-32-60094 mol_a_dk and 163200560 mol_a), the leading universities of the Russian Federation (grant 074U01), grant of government of the Russian Federation (16.2593.2017/PCh).

References

[1] Li Y, Xiang J, Quang F, Gradecak S, Wu Y, Yan H, Blom D A and Lieber C M. 2006 *Nanoletters* **6** 1468
[2] Bjork M T, Ohlsson B J, Sass T, Persson A I, Thelander C, Magnusson M H, Deppert K, Wallenberg L R and Samuelson L 2002 *Appl. Phys. Lett.* **80** 1058
[3] Li S, Waag A 2012 *J. Appl. Phys.* **111** 071101
[4] Kihyun C, Munetaka A and Yasuhiko A 2012 *J. of Crystal Growth* **357** 58-61
[5] Rozhavskaya M M, Lundin V V, Lundina E, Davydov S, Troshkov S I, Vasilyev A A, Brunkov P,
Baklanov A, Tsatsulnikov A F, Dubrovska V G 2014 J. Appl. Phys. 14 11399
[6] Stephen D H, Xinyu S and Xin W 2006 Nanoletters 6(8) 1808-11
[7] Bouravlev A D, Sibirev N V, Gilstein E P, Brunkov P N, Mukhin I S, Tchernysheva M, Khrebtov A I, Samsonenko Yu B and Cirlin G E 2014 Semiconductors 48(3) 344-49
[8] Bolshakov A D, Sapunov G A, Mozharov A M, Cirlin G E, Shtrom I V and Mukhin I S 2016 J. Phys. 741 012044