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# MBE growth and optical properties of GaAs nanowires grown on Si(111) substrate using two-temperature steps regime

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**Abstract**. We report on the growth and optical properties of pencil-like GaAs nanowires (NWs) grown using an original two-temperature growth mode on Si substrate. Optically, the NWs array is active up to the room temperature. The low-temperature PL spectra is composed by the narrow bands corresponding to the direct, bound to surface states and bound to impurity excitons. After toluene treatment, the fine structure is disappeared in the spectra.

## 1. Introduction

Si is a key material of today's semiconductor electronics. However, the realization of light-emitting devices based on Si, which are necessary for optoelectronic device integration, is still an open problem due to the indirect nature of the Si band structure. Freestanding III-V NWs have recently attracted a rapidly increasing interest due to their unique growth, structural, transport and optical properties as well as a variety of promising applications as building blocks for future nanoelectronic [1] and nanophotonic [2] devices. Due to the ability to accumulate for strain in two dimensions [3], NW geometry is ideal for monolithic integration of semiconductor materials with different lattice constants. In particular, coherent, low temperature epitaxial growth of III-V compounds on silicon is of paramount importance for applications. It has been recently shown experimentally that coherent III-V NWs can be grown epitaxially on lattice-mismatched substrates by the vapor-liquid-solid mechanism. In this paper we present MBE growth and optical examination of GaAs nanowires grown on Si(111) substrate using two-temperature steps regime allows one to obtain pencil-like NWs.

## 2. Experimental.

Growth experiments are carried out using Riber Compact21 MBE setup equipped with the effusion Au cell, on Si(111) substrates. Detailed procedure of NW growth is described in Ref. [4]. In brief, the desorption of an oxide layer from the substrate in a separate, vacuum-combined with the growth reactor, chamber is done. Then, to promote the NW formation by the growth catalyst, the deposition of ~ 0.5-1 nm thick Au layer is performed. The samples are then annealed in order to form liquid drops of alloy of Au with the semiconductor material of the substrate and transferred to the growth chamber. The MBE growth of GaAs NWs is carried out by the two-step temperature MBE technique. Firstly, the substrate temperature is set at 550°C and the growth of NWs is initiated. At the second stage, after 20 min. of the growth the substrate temperature is lowered to 530°C and next 40 min. of growth is performed. As a result, non-trivial, a pencil-like shape of the NWs is obtained. The process of NW nucleation and growth is monitored *in situ* by the reflection high energy electron diffraction (RHEED) technique. After several minutes of the growth, initially linear RHEED patterns are converted into the spots corresponding to the formation of wurzite-like crystallographic phase in the NWs. At the end of the process, the RHEED spots are partially converted into mixed cubic/hexagonal patterns. After the growth, the samples are studied by applying the scanning electron microscopy (SEM) and low-temperature photoluminescence (PL) techniques. Low temperature measurements is performed using neodymium laser (532 nm, exciting power density is 1.5 W/cm$^2$) in a He cryostat.

## 3. Results.

In Figs. 1 we present typical SEM image of GaAs NWs grown on the Si(111) substrate. The nanowires exhibit pencil-like shape having ~ 150 nm diameter at the base whereas ~ 25 nm at the top. This unconventional geometry is attributed to the two-step growth regime. At the first step, the NW diameter is dictated by the Au droplet size. At the second stage, at lower substrate temperature, the diffusion of the adatoms along the NWs sidewalls is suppressed. As a result, the formation of the nuclei at the sidewalls become sufficient and a lateral growth of the NWs is clearly observed.

Surprisingly, this NWs array is optically active up to the room temperature despite of the high density of the surface states typical for the Au-associated growth of GaAs NWs. The low temperature PL spectrum for as grown samples consists of a number of the narrow bands corresponding, to our opinion, to the direct (and indirect cubic/wurzite), bound to surface states and bound to impurity excitons. Indeed, PL spectra taken at 15 K consist of 1.52 eV PL band which is assisted to the direct exciton transition in GaAs NWs having cubic crystallographic phase shifted by 3 meV due to the quantization in a thinnest part of the NWs (25 nm in diameter) [5]. We note that we did not observe this shift for the NW arrays grown using conventional, one temperature step regime where cylindrical shape of the NWs were formed with a diameter ranging within 50 – 80 nm. Other bands (at 1.5 eV and 1.507 eV) are typically attributed to the cubic/wurzite transitions and unintentional doping [6]. In addition, sharp PL lines are observed which, most probably, correspond to the excitons bounded to surface states or excitons bounded to the impurity (Fig. 2). The authors[7] explain attributed them to the *bound* exciton emission from hexagonal/cubic boundaries. . In our case, we believe that these PL features correspond to surface-related exitons. In [5] it was established that the *bound* exciton related emission is quenched at ~ 40K This is clearly demonstrated in Fig.2 case where PL temperature dependence is presented. At 30K most of the fine lines are disappeared whereas PL bands corresponding to 1.5 eV, 1.507 eV and 1.52 eV remain. To prove our assumption about presence of sharp lines in PL spectra, the NWs are subjected to the toluene treatment with consequent drying during 15 min at $150^0$C (which has to eliminate the surface-related exitons). After this procedure, the fine structure is disappeared in the spectrum (Fig.3, except of the lines corresponding to the cubic and cubic/wurzite interface excitons or the lines corresponding to the impurity states [6]) which supports the proposed origin of the narrow lines in the low-energy part of the PL spectra.

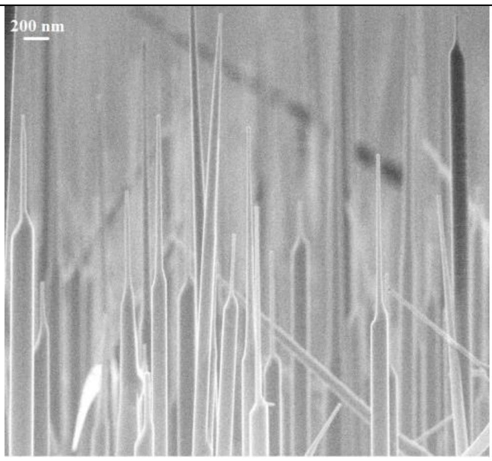


**Figure 1.** SEM image GaAs NWs grown on Si(111) substrate using two-step temperature mode.

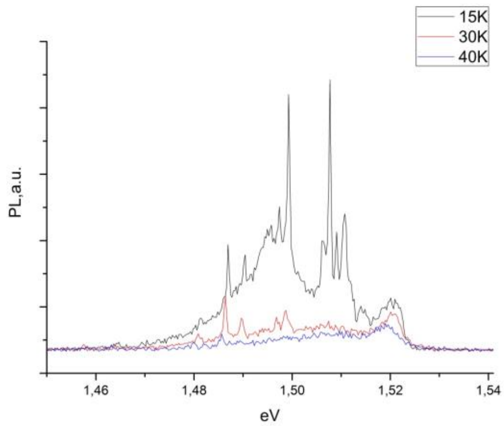


**Figure 2.** PL temperature dependence of GaAs NWs array grown on Si(111) substrate using two-step temperature mode.

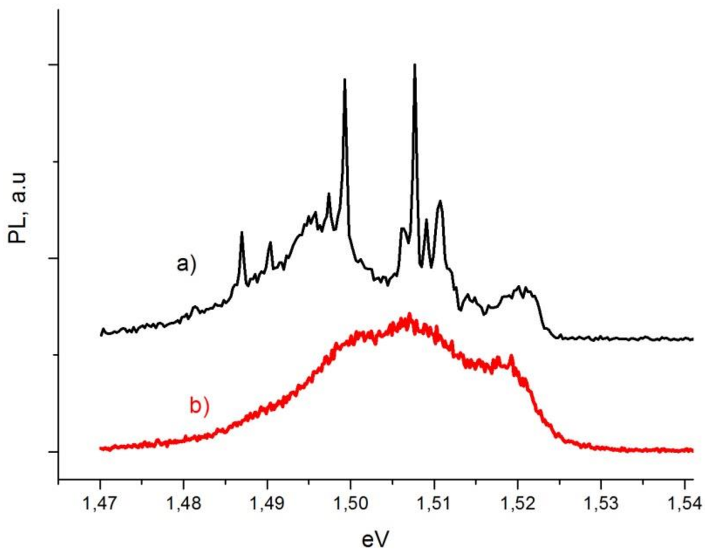


Figure 3. Low temperature PL spectra of GaAs NWs array taken at 10 K before (a) and after (b)

toluene treatment.

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