Preparation of Ga-terminated NEA-GaAs (100) surface by HCl-isopropanol treatment for nano-analysis by STM

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The negative electron affinity (NEA) surface receives low energy nearly equal to the band gap energy of a semiconductor to emit an electron because this lowers the vacuum level than the conduction band minimum. In particular, NEA-GaAs surfaces show distinct characteristics, such as high spin polarization, low emittance, short pulse availability, and high intensity.

NEA surfaces are made by adding Cs and oxygen alternatingly onto the clean surface of GaAs. It is considered that Ga plays an important role in the functioning of the NEA surface, and we have studied actual adsorption structures of Cs on an Ga-terminated (100) GaAs surface by using scanning tunneling microscopy (STM). However, it is extremely difficult to obtain a flat Ga-terminated surface without an epitaxial growth system in vacuum conditions, because NEA-activated surfaces usually require the GaAs substrate temperature to be increased to as high as 600℃ to remove the native Ga oxide from the surface while the As oxide evaporates at 450℃. As a result, after thermal treatment at 600℃, the GaAs surface will be highly rough and it is difficult to obtain a smooth Ga-terminated (100) GaAs surface capable of displaying the adsorption structures of Cs using STM.

In this work, we prepared the GaAs (100) surfaces with the HCl-isopropanol (HCl-iPA) treatment and annealing in ultrahigh vacuum (UHV) 1.0×10^{-8} Pa to study the adsorption structures of Cs on the Ga-terminated GaAs (100) during the NEA activation process using STM. The HCl-iPA treatment of the substrates was performed in a nitrogen-filled glove bag connected to a load lock chamber, following a procedure utilized by Tereshchenko et al.[1] The wet etching method removes the oxidized film, and the Ga atoms were eliminated, leaving the As-capped layer. Through thermal treatment at 300 ℃ for 12 h under UHV, a thick As-capped layer desorbed from the GaAs (100)[2], resulting in the formation of a flat Ga-terminated surface with additional annealing at 500℃ for 3min.

Figures 1(a) and (b) show typical filled-state STM images of the HCl-iPA GaAs (100) surface after degassing at 300℃ and subsequent annealing at 500℃, respectively. Random terraces, separated by single steps or multi-steps of GaAs, can be observed in the STM images. It was found that the obtained GaAs (100) surfaces made STM observation possible and had no rough surface state according to the processing. The relation of surface adsorbate structures and the actual electron emission nature of NEA-GaAs will be discussed.

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[1] O.E. Tereshchenko, S.I. Chikichev, A.S. Terekhov, Appl. Surf. Sci. 142 (1999) 75.

[2] P. Laukkanen, M. Kuzmin, R.E. Perala, R.-L. Vaara, I.J. Vayrynen, Appl. Surf. 206 (2003) 2-7.

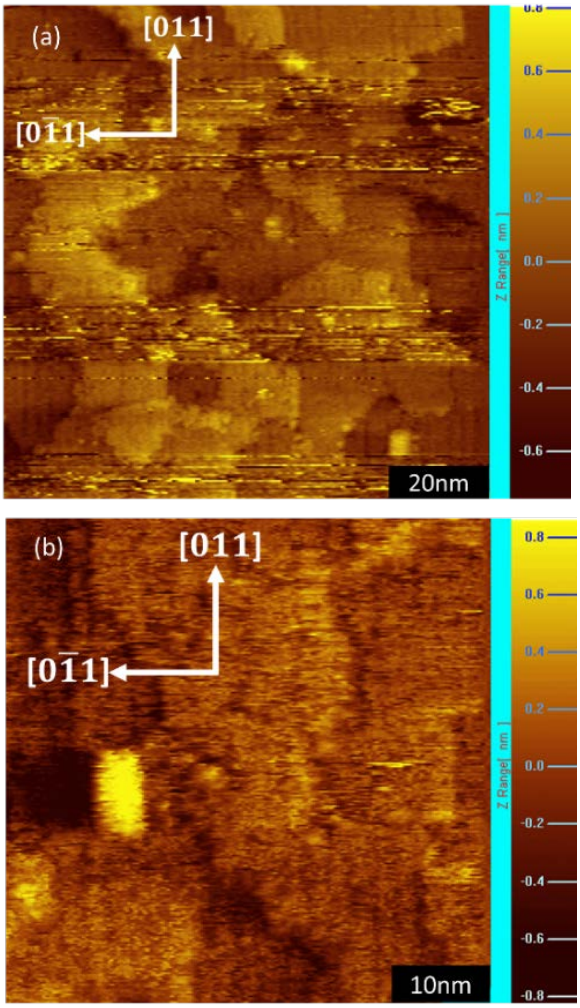

Figure 1: GaAs (100) surface after the HCl-iPA treatment: STM images of the HCl-iPA GaAs (100) surface after annealing at 100nm×100nm (a) and 50nm×50nm (b). The crystallographic directions are marked by white arrows, and both images exhibit the presence of bright and dark rows running along the (011) direction. Image (a) was taken at -2.3 V sample bias voltage with a tunneling current of 0.60 nA, and image (b) was taken at -2.0 V with 0.60 nA. The etching of the GaAs samples was carried out in 3 M solution of HCl in isopropanol for 120 s. Then, they were rinsed in isopropanol for 50 min for transporting preparation and blown with nitrogen. After introduction into the vacuum chamber without atmospheric exposure, the samples were degassed in UHV at 300 °C for 12 h. After that, the samples annealed to encourage surface reconstruction. The annealing temperature was increased to 500°C.