Scanning tunneling microscopy of a graphene layer placed on a micro structured substrate

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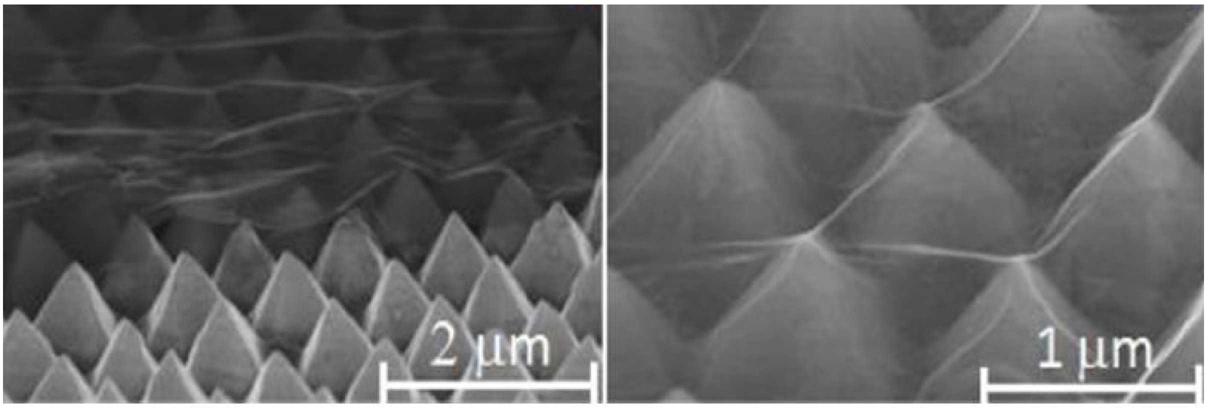
Abstract. The features of the surface topography and the local energy spectrum of the graphene layer placed on a two-dimensional array of GaN pyramids are studied using scanning tunneling microscopy and local tunneling spectroscopy. This structure can be used as a test structure for the application of graphene as a flexible conductive transparent electrode in optoelectronics. Sagging of a graphene layer in the space between pyramids is found and the sagging value is estimated to be about 20% of the pyramid height of 1.1 μm. Local energy spectra show the change of the graphene electron energy spectrum due to the mechanical stress at sagging.

1. Introduction

Graphene can be used as an alternative inexpensive transparent contact in optoelectronic devices due to its high transparency, flexibility, low cost and availability of large area production by Chemical Vapor Deposition (CVD) [1–3]. The information about the morphology of a graphene layer used as an electrical contact is very important for the optimization of technology. Unfortunately, scanning electron microscopy (SEM) cannot be used due to high transparency of graphene for the electron beam. Scanning tunneling microscopy (STM) can help in this situation and provide the detailed information about the features of the graphene layer topography. At the same time, local tunneling spectroscopy (STS) can be used to study spatial distribution of the electron density in the graphene.

2. Experimental setup

We have studied the graphene layer placed on a two-dimensional array of GaN pyramids (figure 1) having the same morphology as the nanostructured LEDs [4]. The few-layered graphene has been grown by the CVD technique on a nickel layer as described in [5]. CH_4 was used as a carbon source for growth. The average thickness has been characterized by Raman spectroscopy and found to be equal to 4 monolayers. A GaN micro-pyramids array with hexagonal symmetry was fabricated by the metal organic vapor phase epitaxy technique using selective area growth [6]. The height of pyramids was 1.1 μm and the distance between pyramids was 1 μm. The pyramids were covered with a 300 nm thick SiO_2 layer to avoid the influence of the substrate on the electronic properties of graphene. To transfer the graphene on the SiO_2 covered micro-pyramid array, a wet transfer process has been used [2]. We have used a home built scanning tunneling microscope with an electromagnetic coarse approach system. All STM measurements were conducted at ambient conditions and at room temperature in the constant current mode with the bias voltage applied to the sample. Tungsten tips prepared by electrochemical etching have been used. Local tunneling spectra have been acquired in different points of the graphene surface.

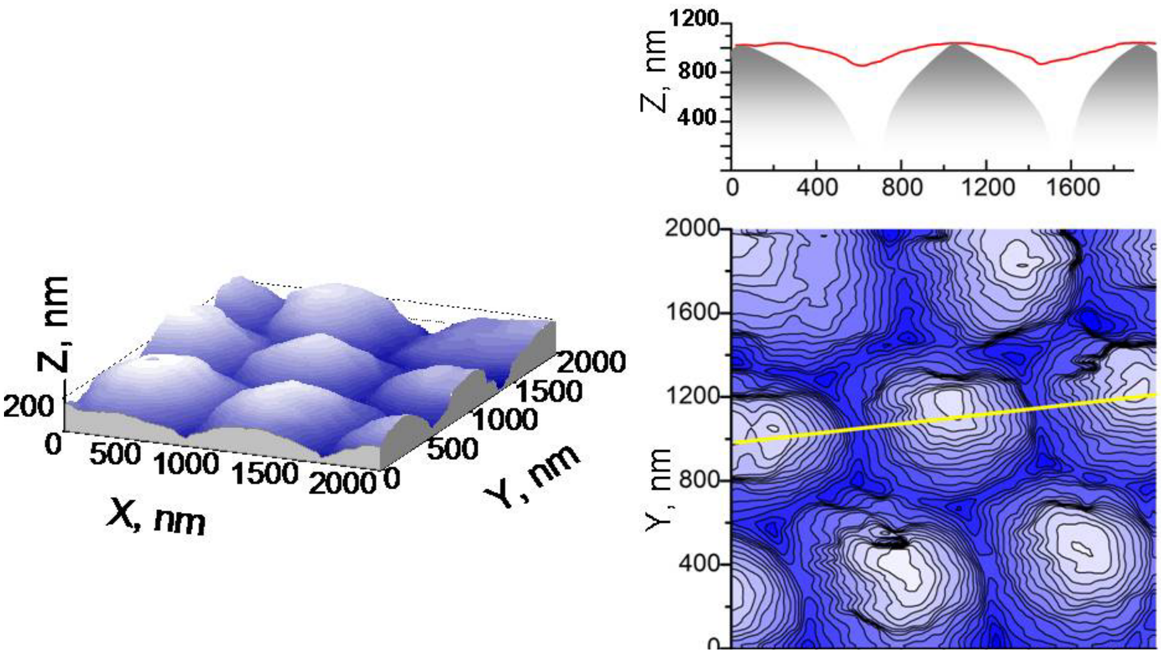


(a) (b)

Figure 1. SEM images of the graphene layer placed on the array of GaN micro-pyramids at 2 µm scale (a) and at 1 µm scale (b).

3. Results and discussion

The typical STM image of the graphene surface is presented in figure 2(a). The topography of graphene has the periodic structure replying the hexagonal symmetry of the GaN pyramids array. The graphene layer is suspended between tops of adjacent pyramids and has small sagging in the middle of this distance. The size of sagging is about 200 nm (about 20% of height of a pyramid). The profile of the cross-section of the graphene layer is presented in figure 2(b) (red line). The surface of graphene is almost flat around the top of a pyramid and then bends slowly with increasing of the distance from a pyramid. The graphene layer demonstrates thus rather high elastic stiffness in spite of its polycrystalline structure. We can see a sharper bending of this layer in the middle of the space between pyramids but even in this case the layer retains the surface integrity. We could not see any damages of the graphene layer in all STM images of our sample. This information can be useful for wider application of graphene as an electrode in optoelectronics.



(a) (b)

Figure 2. STM image of the graphene layer placed on the array of GaN micro-pyramids (a), cross-section of the layer and profile of this section with sketchy images of GaN pyramids. The image was acquired at a bias voltage of 0.2 V and a tunneling current of 0.1 nA.

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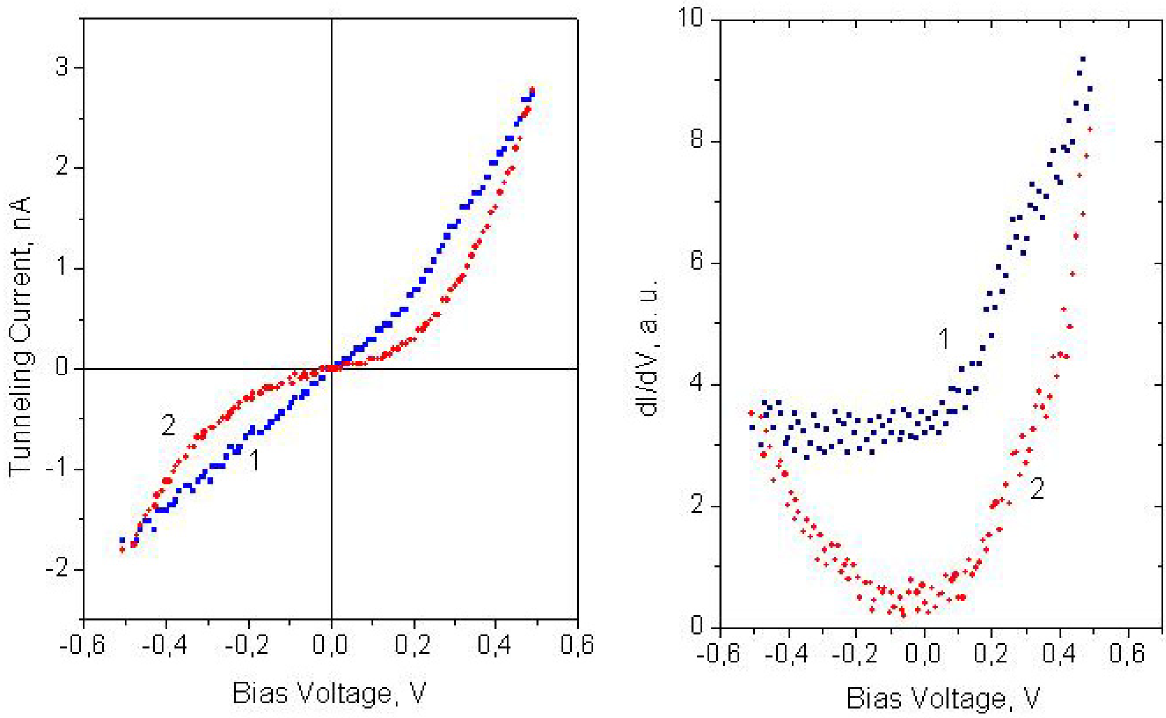
Local tunneling spectra of the electron density were acquired for different areas of the graphene surface. The experimental data for the graphene layer on the top of a GaN pyramid and in the area between pyramids are presented in figure 3. The dependence of the tunneling current on the bias voltage for the flat surface of graphene on the top of a pyramid (curve 1 in figure 3(a)) is almost linear. The same dependence for the area between pyramids (curve 2 in figure 3(a)) is significantly nonlinear. A linear curve indicates the metallic conductance in this area of the graphene layer. The well-known tunneling differential conductance reflects the energy dependence of the electron density of states (DOS), and the zero bias voltage corresponds in this case to the Fermi energy in the sample. Curve 1 in figure 3(b) indicates the constant DOS in graphene above the Fermi energy and the increase of DOS below it. A nonlinear current-voltage dependence indicates the presence of some features in DOS. Curve 2 in figure 3b shows the appearance of a wide minimum of DOS at the Fermi energy. It is unlikely to be an energy gap since the differential conductance is not zero at all bias voltages. This minimum is not symmetric relative to the zero bias voltage: DOS is higher at positive bias voltages. The similar minimum in local tunneling spectra was presented in [7]. This transformation of the electron density of states can be connected with the local mechanical stress in the graphene layer due to its sagging between pyramids [8].



(a) (b)

Figure 3. Local tunneling current-voltage characteristics (a) and tunneling differential conductance dependencies on bias voltage (b). 1 – for the graphene layer on the top of a pyramid, 2 – for the graphene layer in the area between pyramids.

4. Conclusion

This work proves that the scanning tunneling microscope can be a powerful tool to study the features of the surface topography and the local energy spectrum of graphene placed on any micro structured substrates. In the case of GaN pyramids as a substrate, we did not find any damages of the graphene layer. The layer remains conductive in spite of its sagging between pyramids. It confirms good prospects of using graphene as a flexible conducting transparent electrode in optoelectronics.

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