Carbon nanostructures formation during γ-irradiation of the graphene layers on Ni

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Carbon nanostructures are widely studied in last twenty years owing to their unique electronic, magnetic and mechanical properties [1]. Special attention is drawn to the graphite single layers (graphene) because of their extremely high electron mobility and transparency in wide range of wavelengths [2, 3]. Stability and transformation of the graphene layers under different radiation exposures are important directions of research. This work presents results of the investigation of formation of various morphological nanostructures from the graphene layers on Ni film under γ-irradiation.

The graphene layers were synthesized by thermal treatment of Si(wafer)/SiO_2(200 nm)/a-SiC(50 nm)/Ni(1000 nm) sandwich structure in vacuum at 700-900 °C for 2-20 minutes. The a-SiC/Ni bi-layer was deposited on oxidized Si wafer by RF magnetron sputtering of the polycrystalline SiC and Ni target in single process without withdrawing of the wafer from a chamber [4]. Fabricated structures were subjected to γ-irradiation with doses up to $5x10^6$ Rad in vacuum and air. The graphene surface morphology and distribution of electrical potential were studied by optical microscopy (Axioscop 2 MAT, Carl Zeiss) in standard and differential interference contrast (DIC) mode, AFM and scanning Kelvin probe force microscopy (SKPFM, NanoScope IIIa Dimension 3000). Structure of graphene layers was analysed by micro-Raman spectroscopy (mRS, triple Raman spectrometer T-64000 Horiba Jobin-Yvon, equipped with electrically cooled CCD detector, and excitation by the 514 nm line of an Ar-Kr ion laser). To identify the origin of the structures generated under irradiation the graphene surface was examined additionally by scanning electron microscopy (SEM) combined with local high resolution Auger electron spectroscopy (AES).

Vacuum annealing of a-SiC/Ni bi-layer results in a formation of the graphene flakes with lateral size of about 20x20 μm (Fig.1a, b) which cover about 80% of the Ni surface [5]. Raman spectroscopy shows that the flakes possess different thickness (Fig. 1 c) and different defectiveness (not shown here) in central and edge regions.

The γ-irradiation in vacuum up to dose of $5x10^6$ Rad does not lead to any changes in structure of the graphene flakes. However the radiation in air with dose of $5x10^5$ Rad results in formation of new structures such as “domes” with height about 100 nm and “stars” with “rays” about 10-15 μm long (Fig. 2 a, b). SKPFM and AES testify that these structures are located on the top of multilayer graphene (see Fig. 3 a). The mRS and AES show that the structures are composed of carbon with graphitic structure. The “rays” are probably carbon tubes with diameters about 100-120 nm (see Fig. 2 c). The “domes” have a surface potential considerably higher than carbon layer (Fig. 3).

These nanostructures (“nanotubes” and “nanostars”) are obviously grown from graphenes. Possible mechanisms of graphenes delaminations and rolling under radiation exposure will be discussed.

Acknowledgements
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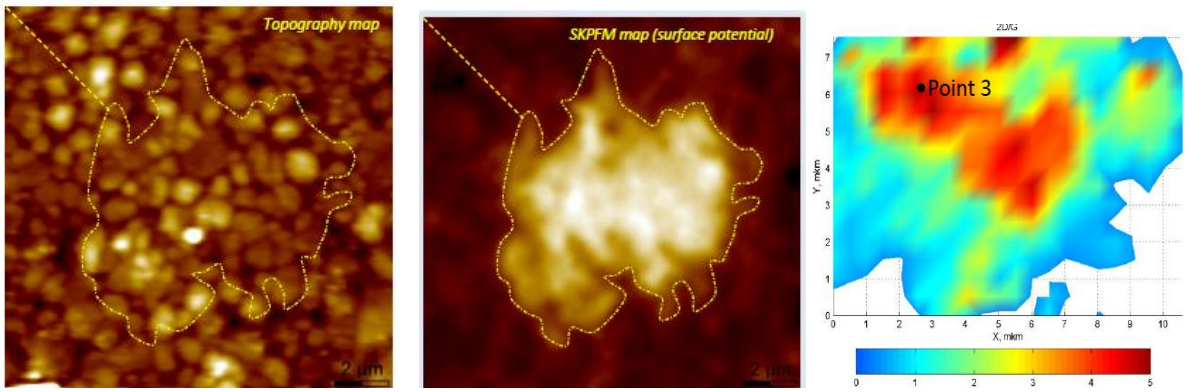
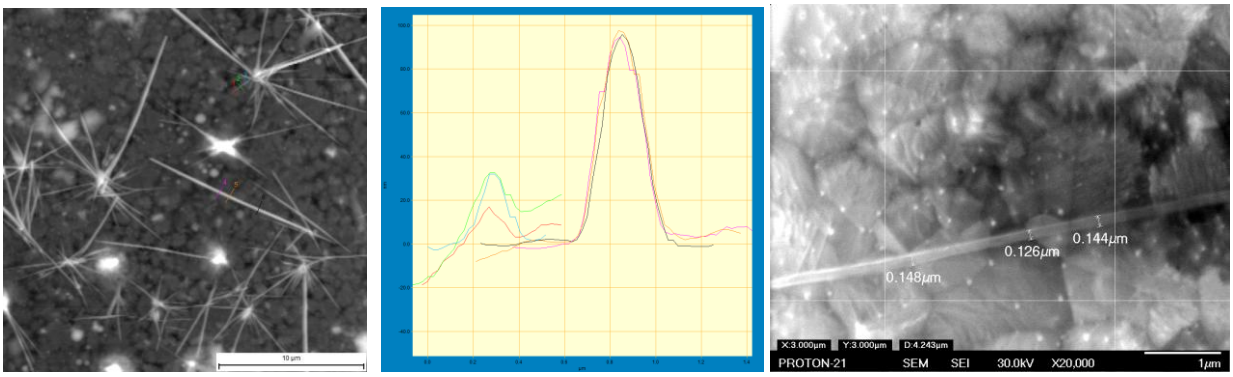


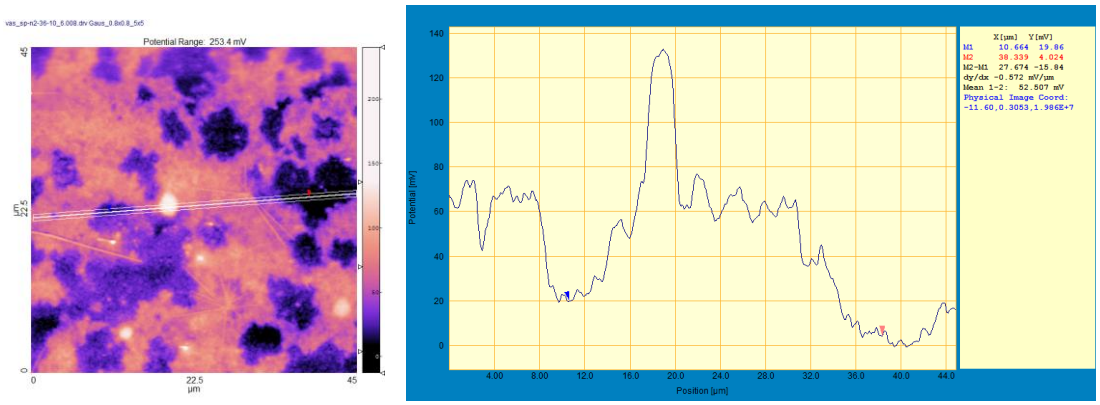
(a) **(b)** **(c)**

Figure 1. AFM surface map (a) and corresponding map of surface potential (b) and map of micro-Raman 2D/G bands intensity ratio (c) of the surface fragment of the graphene/Ni structure



(a) **(b)** **(c)**

Figure 2. . AFM surface map (a), AFM topography (b) along the lines shown in Fig. 2 (a) and SEM (c) of the surface fragment of the graphene/Ni structure subjected by γ-irradiation in air with dose $5x10^5$ Rad.



(a) **(b)**

Figure 3. The map of surface potential (a) of the surface fragment of the graphene/Ni structure after γ-irradiation in air with dose $5x10^5$ Rad and surface potential (b) along the line in Fig. 3 (a).