Reconstruction of volume structure of carbon based conductive polymer composites

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Conductive composites based on polymers with different fillers such as graphene, carbon nanotubes, carbon black are promising functional materials for different areas of modern science and technology [1]. One of promising methods of sample preparation of such composites is latex technology [2-5]. In this work several different composites of polystyrene (PS), epoxy resin and graphene (Gr), carbon nanotubes (CNT) and carbon black (CB) were investigated by combination of Atomic Force Microscopy (AFM) and ultramicrotomy [6]. Previously, the volume structure in form of clusters with similar level of conductivity was observed by conductive-AFM (C-AFM) in PS-CNT composite [3]. The 3D reconstruction of single cluster of Gr was carried out in [4]. Here, we report on similar results for PS-Gr and epoxy-CB composites (Fig. 1a). Graphene clusters with different current level were observed on relatively large scale of few micrometers. Similar to PS-CNT results [3], formation of domains with different current level might be explained by connection of neighboring graphene clusters by places with high resistivity. As a result conductivity of whole cluster is determined by such places with high resistance ("bottle neck"). The results of 3D reconstruction of PS-Gr are shown in Figure 1b (9 slices with 180 nm z-step were used). Clusters with different current level are clearly seen in current distribution images. Similar result was observed for epoxy-CB composite. However, highly resistive places between clusters in volume of graphene composite were not detected due to large size of clusters. We found such places in epoxy-CB composite (Fig. 2), where particles and domains are smaller. In Figure 2 transition from one cluster to another one is seen. The obtained results clearly confirm domain organization of conductivity in volume of all measured composites: PS-Gr, PS-CNT, epoxy-CB. All abovementioned volume reconstructions were performed by using C-AFM. However, other AFM techniques can be used for 3D reconstruction of local electrical properties as well. The use of Electrostatic Force Microscopy (EFM) for 3D reconstruction of PS-Gr structure is shown in Figure 3. The EFM contrast is the result of Coulomb interaction between charged Gr flakes and AFM probe. The local I-V curves measured on single particles on surface of all samples show linear and nonlinear behavior, which is the result of coexistence of ohmic and tunneling currents in sample volume.

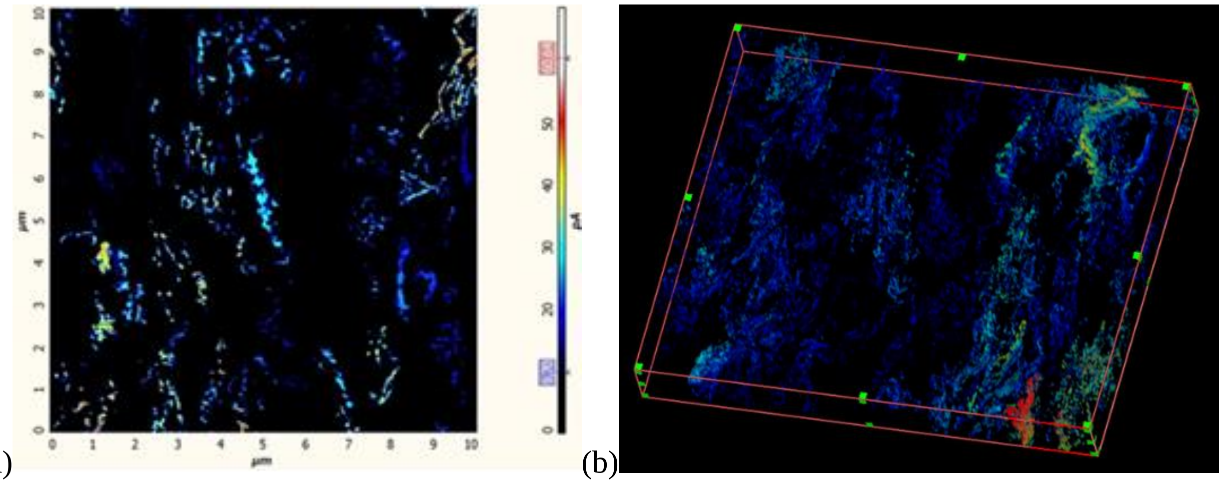
(a)  (b)

Figure 1. Current distribution images of PS-Gr composite: (a) conductive-AFM image; (b) volume 15.7x13.6x1.4 micrometers, z-step 180 nm, 9 slices.

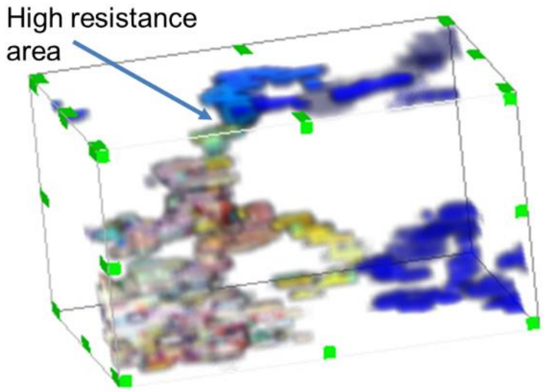


Figure 2. Epoxy-CB composite. The arrow indicates area with high resistance, which determines conductivity of neighboring domain. 28 scans, z-step is 20 nm.

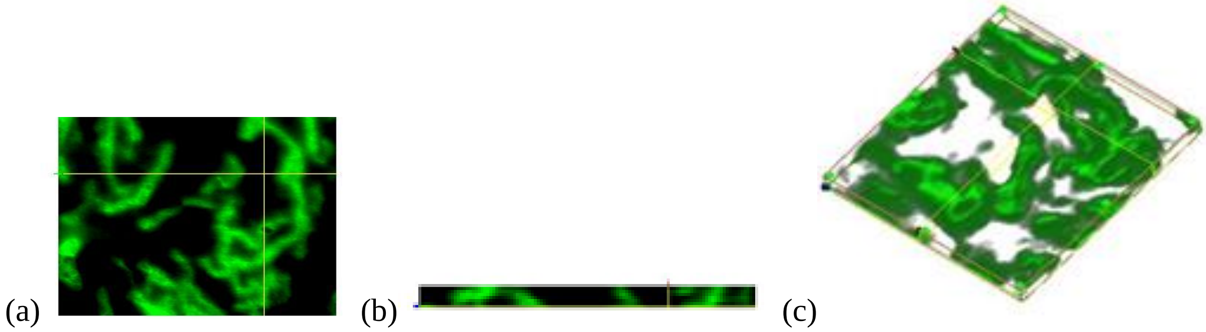


Figure 3. 3D reconstruction of PS-Gr composite by using EFM: (a) EFM image, (b), (c) cross-section and 3D reconstruction of volume structure based on 8 slices.

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